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# INTERNATIONAL Turbomachinery

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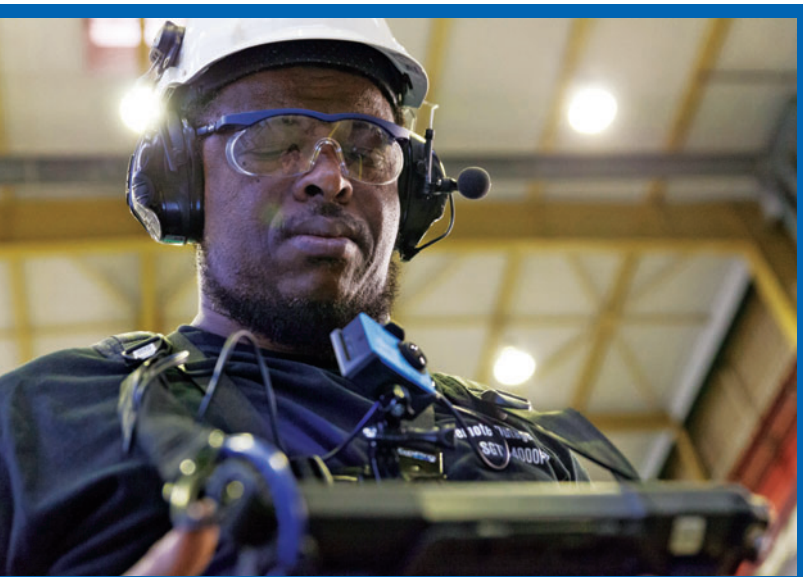

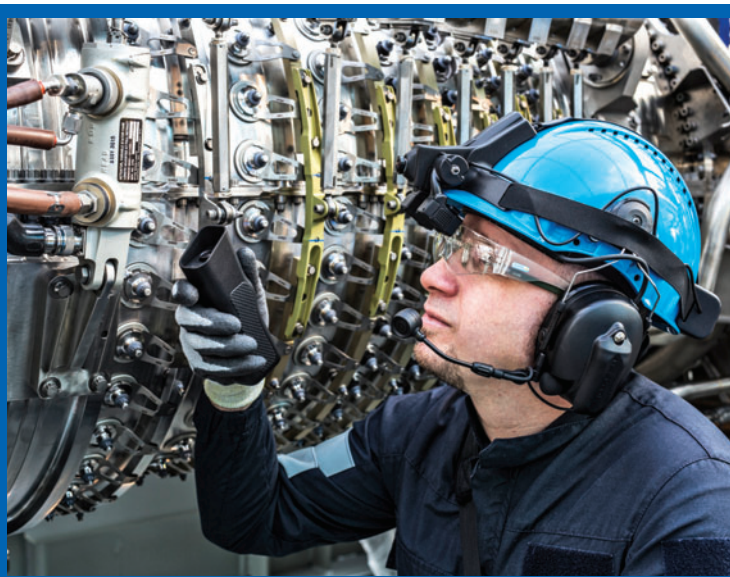

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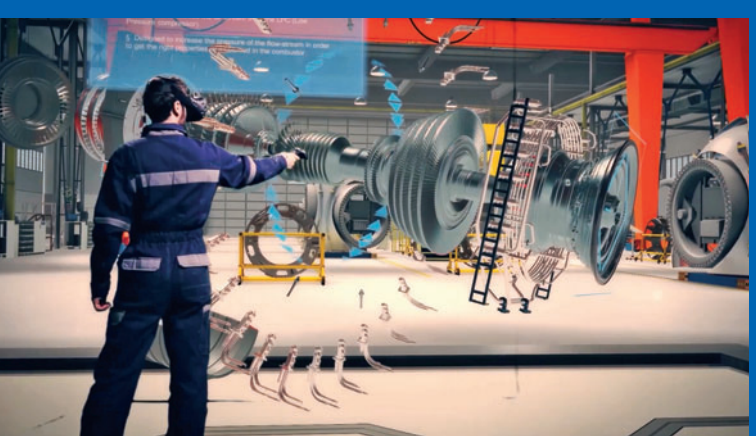

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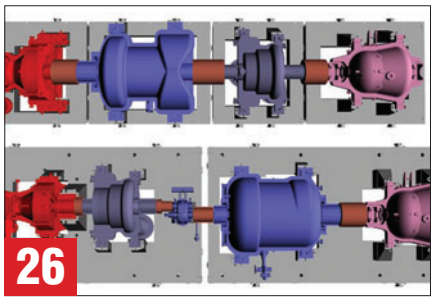




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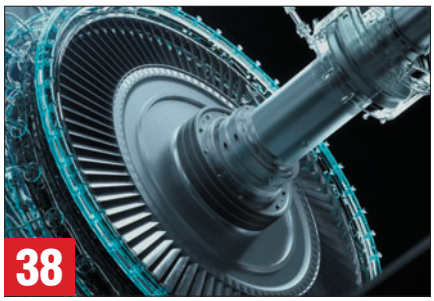
## 8 INDUSTRY NEWS




## 38 NEW PRODUCTS



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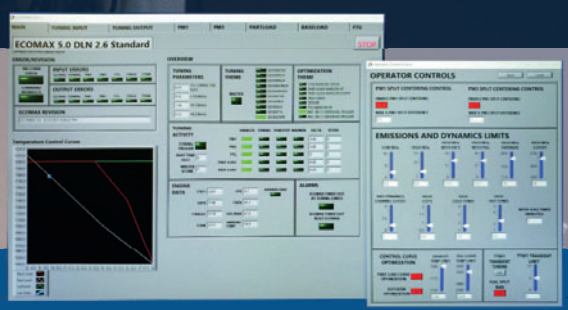


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# HOW REAL IS VIRTUAL REALITY?

A great many virtual reality (VR) and augmented reality (AR) tools have entered the market. Their aim is to aid in inspection, maintenance, training, apprenticeship and knowledge transfer.

But how valuable are they on the shop floor? Have we virtually reached a point of technological maturity, or does the equipment still need to be augmented with additional breakthroughs in terms of network connectivity, design and user-friendliness? That is the topic of our cover story.

> **Worldwide spending on AR and VR is already in excess of $18 billion and rising rapidly.**

Many VR and AR devices are now available from Microsoft, Google, Daqri, Ubimax, PTC, Upskill, RealWare, HTC, Glass and Worklink. These companies are working with Baker Hughes GE, Elliott, Siemens, Howden, MAN Energy, MTU Maintenance, GE Aviation and other turbomachinery vendors to provide workable tools that either immerse the user in a virtual environment or augment the real world with additional digital data — schematics, maintenance schedules and work instructions.

From a training perspective, a trainee can roam through a virtual world to create realistic-seeming motions, scenes and experiences. Digital twins are another outgrowth of VR. They provide a digitized copy of a plant or turbine that mirrors the actual operating conditions of the real world.

AR overlays virtual objects, such as diagrams, lists of instructions and other aids, on top of the actual environment. These images and directions are typically superimposed on eyeglasses that relate directly to the view of the operator.

If a technician needs to change a bolt on a casing, the AR device highlights the bolt and supplies the proper torque and any other data required to carry out the task. The operator then marks the task as done, automatically updating the database.

For from being a distant dream, worldwide spending on AR and VR is already in excess of $18 billion and rising rapidly. The bulk of spending is in the industrial sector. This technology is coming soon to a shop floor near you!

The Compressor Choke story addresses how choke conditions in an axial compressor could lead to a catastrophic failure. The author explains how choke conditions often go unnoticed, and how root cause analysis may mistakenly assign responsibility for the failure to compressor surge.

The Combustion Turbine Operations Technical Forum from March is featured in our show report. There is plenty of material in there about parts supply issues for Rolls-Royce Trent (now Siemens) aeroderivatives, operations & maintenance tips and fleet status updates from the big OEMs.

Additional stories include noise abatement in turbomachinery, rebuilding cooling towers, bearings & seals, condition monitoring tips and blade reliability.

Our Myth Busters point out the surprisingly extreme conditions in which modern blades operate. There have been a few GT failures over the years. But the reliability and availability of these machines have significantly increased, as failure mechanisms are better understood, prediction and test methods have improved, and condition monitoring tools have identified problems before they led to failures.

By the time you read this, we will have returned from the Turbo Expo and perhaps even the HRSG Forum. We hope you enjoy the rest of the summer. ■

Drew Robb

DREW ROBB
*Editor-in-Chief*


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## Siemens digest

Siemens was awarded a contract to provide three residue compression trains for two 250-million-ft³/day (MMSCFD) cryogenic gas plants in the Delaware Basin. Each train consists of a 22,000-hp motor, gearbox and multi-stage Dresser-Rand Datum centrifugal compressor mounted onto a single skid. The compressors, motors, and drives will all be built by Siemens in the U.S. and are scheduled for commissioning in the latter part of 2020.

Siemens has expanded its relationship with Veros Systems. The combination of Veros ForeSight technology with Siemens Large Drives provides performance and health monitoring of motors and assets without installing sensors on rotating equipment.

The system uses Siemens MindSphere, the cloud-based Internet of Things (IoT) operating system that connects products, plants, systems and machines, and harnesses that data with analytics. SiDrive IQ in MindSphere, a digital platform for optimizing drive systems, allows for a higher availability, serviceability, productivity and efficiency.

Siemens has received an order from BASF to modernize a power plant in Schwarzheide, Germany. The Brownfield Exchange project involves replacing a gas turbine (GT) from another OEM with a 57 MW SGT-800 GT as well as servicing this machine for 15 years. In addition, Siemens will install Siestart battery storage for startup independent of the grid. The plant also provides process steam.

Presenso and Siemens are partnering in artificial intelligence (AI) and machine learning for predictive asset maintenance. Presenso will support Siemens' Operations & Maintenance (O&M) services with its real-time industrial analytics integrated into the Siemens Remote Diagnostic Services (RDS) portfolio and smart field sensors. Presenso helps to detect abnormal behavior patterns, indicative of evolving asset failure.

Siemens and Chronicle have begun a partnership to protect against industrial cyberthreats. Chronicle's Backstory platform provides increased visibility across information technology (IT) and operational technology (OT) to provide operational insights and help organizations to confidently act on threats. The partnership will help energy companies securely leverage the cloud to store and categorize data, while applying analytics, AI and machine learning to OT systems that can identify patterns, anomalies and cyber threats.

Chronicle's Backstory, a global security telemetry platform for investigation and threat hunting, will be the backbone of Siemens managed service for industrial cyber monitoring, including in both hybrid and cloud environments.

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


**Dresser-Rand Datum centrifugal compressor like the one to be used at the gas processing plant in the Delaware Basin**

The OSD will be accessible 24/7, equipped with machine learning tools and manned by technical experts to provide faster troubleshooting and guidance. Siemens' RDS is part of the Omnivise Digital Services portfolio, which combines asset data with OEM industry expertise.

Siemens and TÜV SÜD are working together to lower the volume of cyberattacks on critical infrastructure by collaborating on digital safety and security assessments, as well as industrial vulnerability assessments. TÜV SÜD will offer digital assessments that incorporate Siemens as a provider of cybersecurity vulnerability assessments across the entire cyber asset management lifecycle.

Siemens has signed an agreement in Iraq for the EPC construction of a 500 MW gas-fired power plant in Zubaidiya, the upgrade of 40 GTs with upstream cooling systems, and the installation of 13 of 132 kilovolt substations along with 34 transformers across Iraq.

Siemens has secured an order for the turnkey construction of a new combined cycle power plant (CCPP) for the integrated liquefied natural gas (LNG)-to-Power project GNA 1 of Gás Natural Açu in the Port of Açu in the state of Rio de Janeiro, Brazil. Siemens also signed a long-term service agreement (LTSA) and will both operate and maintain the plant. With a capacity of approximately 1.3 GW, construction started in 2018 and is slated for operation in 2021.

## Doosan contract

South Korea's Doosan Heavy Industries & Construction strengthened ties with U.S. private energy firm, Midland Cogen Venture (MCV), for the maintenance and improvement of MCV's GTs, wind power, energy storage and CCPPs. Doosan GTs will also be applied to repowering existing plants.

As part of this agreement, Doosan Turbomachinery Services agreed to provide repair and part replacement service for core components of seven GTs of MCV's combined cycle cogeneration plant in Michigan for six years.

## Voith USA

Voith has opened a 32,000-square-foot in Houston, TX to serve the gearbox needs of the North American power, oil and gas industries. Repair, overhaul and retrofit services are available for all brands of gearboxes, including Voith's Vorecon variable speed planetary gearbox, S-couplings and torque converters.

## Baker Hughes order

Baker Hughes GE has been awarded a contract to supply turbomachinery equipment for the first phase of BP's Greater Tortue Ahmeyim floating liquefied natural gas (FLNG) project located offshore Mauritania and Senegal. BHGE will provide four compressor trains for offshore gas liquefaction onboard Golar LNG's FLNG project that is expected to deliver 2.5 million m.t. of LNG per annum. Each of the trains will consist of a PGT25+G4 aeroderivative GTs driving a centrifugal compressor.

## PWPS mobile power

PW Power Systems (PWPS) has been chosen to supply three 30 MW FT8 MobilePac GTs to ARG Precision in Puerto Rico. It will provide power in case of an outage due to a natural disaster or restoration works on the powerlines or existing generating units.

*Continues on page 10*

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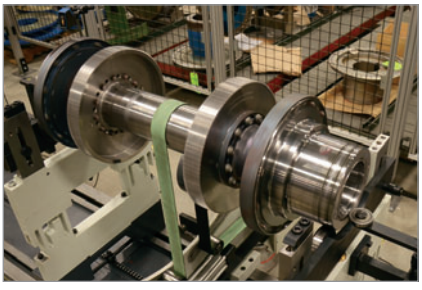

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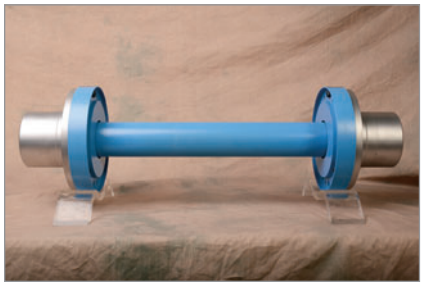

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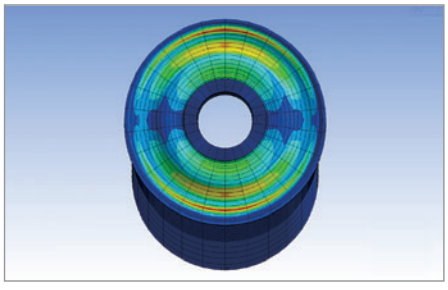

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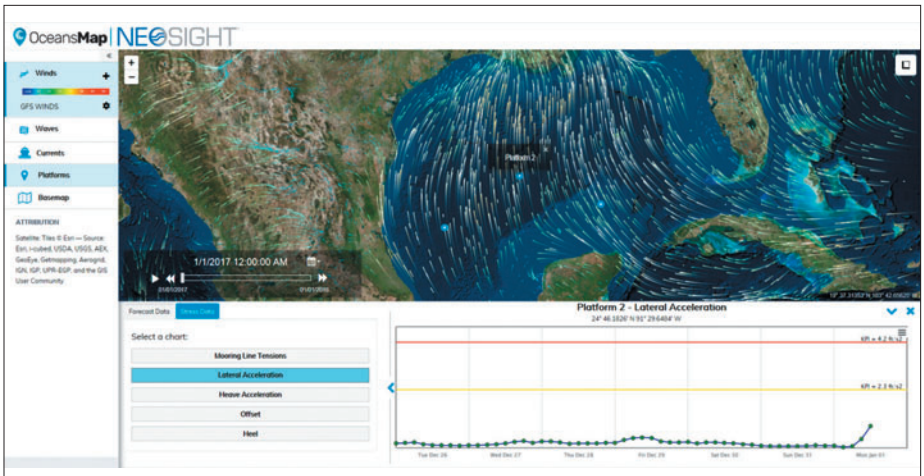
**CEO of Ansaldo Energia Giuseppe Zampini and President of REP Holding Tagir Nigmatulin signed a joint venture**

## Ansaldo deal

REP Holding and Ansaldo Energia have established a joint venture (JV) to produce, modernize, repair and provide a full-cycle service offering for high-power industrial GTs and steam turbines (STs) in Russia. The products offered by the JV include three Ansaldo Energia GT models in the power range from 70 to 340 MW as well as two STs ranging from 40 to 350 MW.

Ansaldo Energia will transfer to the JV exclusive rights to use its technology to manufacture, sell and service GTs and STs in Russia, and in CIS and other countries agreed by the parties.




**OceanMap with NeoSight**

## Digital twin for Shell

Stress Engineering Services, Inc., (SES) together with RPS Group have implemented NeoSight FPS and OceansMap as a pilot program for Shell to improve management of floating production facilities. This provides Shell with automation, digitalization and data analysis techniques.

NeoSight FPS is a digital twin for floating production systems built on SES' NeoSight platform. NeoSight leverages physics-based models and data science algorithms to provide integrity management and operational support. OceansMap was originally developed by RPS to aggregate and manage ocean data and is used by oil companies and mission critical agencies, such as the U.S. Coast Guard to support global search and rescue activities.

*Continues on page 12*

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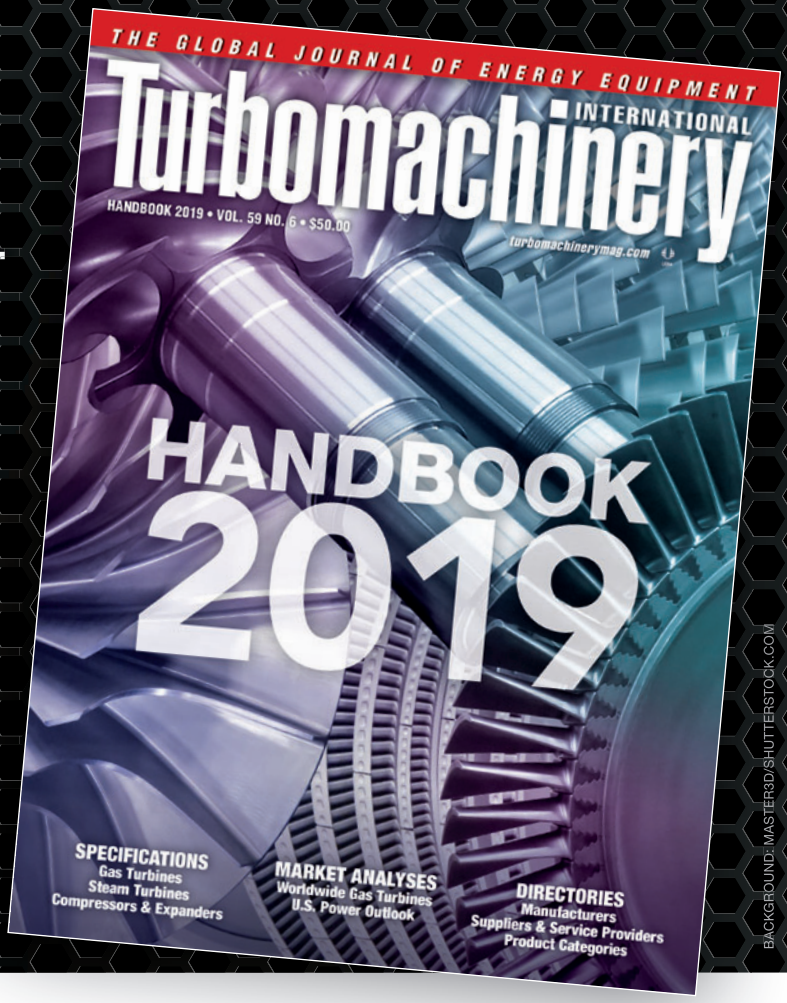


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## MHPS digest

Mitsubishi Hitachi Power Systems (MHPS) will upgrade its GTs and other components at two Egyptian power plants. MHPS will supply the new components for the M701F GTs and other generator parts at the 750 MW Siki Krir and El Atf power plants. Siki Krir is located west of Alexandria; El Atf is east of the city.

MHPS and Magnum Development launched the Advanced Clean Energy Storage (ACES) project in central Utah. It will develop 1,000 MW of energy storage. As part of the project, MHPS has developed GT technology that enables a mixture of renewable hydrogen and natural gas to produce power with low carbon emissions.

The roadmap aims to use 100% renewable hydrogen as a fuel. Magnum owns and controls a salt formation for Compressed Air Energy Storage and renewable hydrogen storage options.

MHPS has received an order for two H-25 GTs from Lee & Man Paper Manufacturing, a Chinese paper manufacturer, for a factory in Guangdong Province. The units will be used in a cogeneration system with an output of 62 MW as well as 150 tons per hour of steam during duct-firing. Operations are scheduled to start in 2020.

MHPS has received an order for its hybrid power generation system, named Megamie, integrating solid oxide fuel cell (SOFC) with a micro-gas turbine (MGT), from Hazama Ando. The system will be delivered in mid-2019 to help ease $CO_2$ emissions.

The system uses city gas as fuel, generating electricity with both ceramic SOFC stacks, that operates at around 900°C, and an MGT. The fuel is not burned; SOFCs generate electricity from the chemical reaction between oxygen in the air and hydrogen and carbon monoxide extracted from city gas. The MGT generates electricity from the post-process, resulting in efficient fuel use. When it functions as a cogeneration system, residual exhaust heat is recovered as steam or hot water, increasing overall efficiency.

## Emerson controls

Emerson has been selected to modernize PLC-based controls for power and water plants and remote sites operated by the City of Fremont Department of Utilities in California. The organization operates and manages water/wastewater collection, treatment and distribution, as well as coal and natural gas power generation, transmission and distribution systems that serve customers in a 60-square-mile area.

Problems included outdated programmable logic controllers (PLCs) with limited spare parts inventory, lack of support, inability to automate data collection and reporting, and lack of visibility into the operations of substations, lift stations and remote assets. Ovation's automation platform including a compact controller and SCADA technologies, will help eliminate these issues. It will be completed in 2020.

## Kawasaki and Toshiba

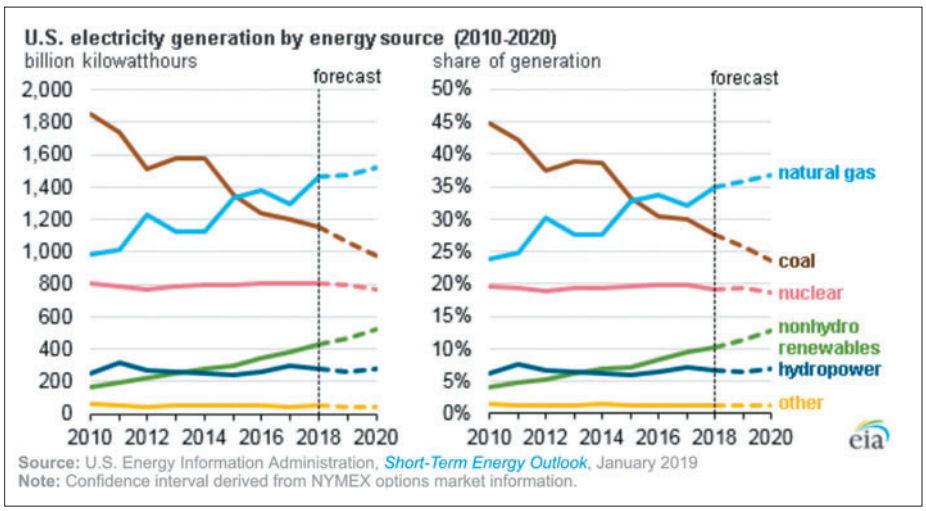
Kawasaki Heavy Industries and Toshiba Energy Systems have entered into an agreement to supply medium-capacity STs for utility and industrial power plants. This follows a shift in the market for STs from the large-capacity to small and medium (300 MW or less).

Toshiba and Kawasaki have been engaged in joint development of STs which combine the material and the reliability technologies of Toshiba with the compact, high-speed turbine technology and packaging technology of Kawasaki.

The two companies have agreed to effectively use each other's supply chains and to manufacture and sell 100–200MW class STs. Kawasaki will supply HP turbines and reduction gears, while Toshiba will supply IP and LP turbines.

## Renewable growth

In 2019, the renewable energy sector (hydro, biomass, wind, solar and geothermal) is projected to generate more electricity than coal-fired plants (240 GW of still-operating capacity), according to the U.S. Energy Information Administration (EIA) Short-Term Energy Outlook.




**Natural gas consistently provides more power than coal in the U.S. Now renewable output is beginning to exceed coal**

EIA sees renewable generation topping coal-fired output sporadically this year, and again in 2020. The estimates in the EIA outlook show renewable energy generating 2,322 and 2,271 thousand MWh/day in April and May, respectively. This topped coal's output of 1,997 and 2,239 thousand MWh/day during those months.

The first instance of natural gas-fired generation exceeding coal's output happened in 2015. The final monthly crossover point occurred in January 2018, and natural gas has held the uncontested top spot in electricity generation ever since.

On an annual basis, the two fuels each accounted for about 33% of the electricity market in 2015; since then, their trajectories have taken different paths. By 2018, natural gas's share had climbed to 35% while coal had dropped to 27%. The trends for both are expected to continue.

The tipping point for renewable energy may already have been reached in Texas, where natural gas, wind and, increasingly, solar, are steadily pushing coal out of the system. According to data from the Electric Reliability Council of Texas (ERCOT), wind and solar generation topped coal's output in the first quarter of 2019.

Overall, wind and solar capacity generated 19.41 million MWh during the first quarter, beating the 18.97 million MWh pumped out by the state's coal-fired plants.

## Fincantieri shipping

Pemamek has received an order from Fincantieri for PEMA automation technology for its shipyards. Pemamek will deliver a laser-hybrid, thin-plate, flat-panel line totaling 300 meters.

It includes one-sided welding, a milling station, and profile assembling and welding stations both with laser-hybrid welding process, profile processing line, panel trimming station and several robotized welding

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systems to weld T-beams onto the panels. The production line is customized according to Fincantieri's needs to build cruise ship panels and blocks.

## Sargent & Lundy acquisition

Sargent & Lundy has acquired ARES Corp.'s energy business, ARES Energy Services Division (ESD) to achieve growth in government services. ARES ESD primarily serves the U.S. Department of Energy (DOE).

It has core competencies in engineering and design; facility operations, management and maintenance; project management; and safety, security and risk management. DOE facilities that ARES ESD currently supports include Los Alamos National Laboratory, Idaho National Laboratory, Hanford, Sandia National Laboratory, Lawrence Livermore National Laboratory, and Oak Ridge National Laboratory.

The energy services business also provides management and operations services for the DOE National Training Center in Albuquerque, New Mexico, and has teamed with Parsons Corporation on a Defense Threat Reduction Agency contract to secure nuclear materials.

## Sulzer partnership

Sulzer has signed a partnership deal with Kato Engineering to provide repair and maintenance services for generators in North America and Australia. Adding the Kato generator range will provide greater product coverage. Similarly, the level of expertise offered to existing Sulzer customers will now be available to all those operating Kato generators. The Kato range of generators is in operation extensively in the oil and gas, mining and power generation sectors.

The Tornio Manga LNG receiving terminal is the largest such facility in the Nordic region.

## LNG terminal

The Tornio Manga LNG receiving terminal has been inaugurated in Tornio, northern Finland. The project was led by Manga LNG Oy, a joint venture between the Finnish companies Outokumpu Group, SSAB, Gasum Oy and EPV Energy.

Wärtsilä was brought in for LNG handling systems, the use of LNG as fuel and project execution. Wärtsilä's EPC (engineering, procurement and construction) solution includes unloading, storage, pipeline distribution, regasification, truck loading and ship bunkering.

The terminal will supply natural gas to Outokumpu's Tornio steel mill and LNG to local industries, mines, and others in the region. LNG from the terminal will also be supplied to the LNG storage facility provided by Wärtsilä at the SSAB Raahe steel mill.

The terminal supplies LNG as fuel to ships, such as the new icebreaker Polaris, operating in the Gulf of Bothnia. Truck access to the terminal facilitates fast and efficient deliveries of the LNG.

Wärtsilä will serve the Tornio Manga LNG terminal under a 10-year maintenance agreement. This Liquefied natural gas is a low emission fuel, which can be used by the land-based, shipping and energy industries. Compared to alternative fossil fuels, substantial reductions can be obtained in carbon dioxide, nitrogen oxide and particulate matters emissions.

## GE digest

GE Power has installed and commissioned a new 9E GT at the Iraqi Ministry of Electricity's Al Qudus Power Plant. The site was previously capable of generating up to 1,125 MW. The new turbine adds 125 MW. GE is also providing maintenance, parts and rehabilitation works.

GE has completed the first stage of an upgrade at a power plant in Ivory Coast. One of two GTs at the Azito III plant will be upgraded to boost production by 15 MW. A similar upgrade on the second unit will begin later this year.

The plant will have GE's Predix asset performance management software. GE's MXL2 upgrade was carried out on the first turbine, compressor and combustor and is designed to be compatible with all installed GT13E2 units.

GE has bagged an order to deliver its HA GTs for the Hill Top Energy Center, a 620 MW natural-gas fired power plant in Pennsylvania. GE will be working with Kiewit Power Constructors to integrate its 7HA.02 GTs into the power plant. GE's order also includes an ST and generator and a new heat recovery generator (HRSG) in addition to a multi-year services agreement.

GE Power has completed the Advanced Gas Path (AGP) upgrades on four 9E GTs at East Delta Electricity Production's 1.5 GW West Damietta Power Plant in Lower Egypt. The upgrade has enhanced fuel efficiency by up to 2.2% and increased the average output per turbine by over 4.5 MW. It also increased the average duration between maintenance works on the units from 12,000 to 32,000 hours.

Israel Electric awarded a contract for the Orot Rabin modernization project to GE, which will include an order for a 9HA.01 heavy duty GT. GE has also been selected for a second 9HA GT with a contract award expected by the end of 2019. This is part of the conversion of the existing power station from coal to gas. The order also includes the ST, generator, HRSG and BOP equipment, as well as a 15-year services agreement.

## Ethos contract

EthosEnergy has been awarded a multi-million-dollar upgrade contract at a facility in Illinois. The contract is for six LM6000PC turbine control upgrades as well as a Balance of Plant (BOP) control system upgrade for the LM6000 portion of the plant which also has four Frame 7FAs. The contract will be installed for summer peaking season 2019.

EthosEnergy has also been awarded a six-year ECare maintenance contract covering two SGT-200 GT packages including scheduled maintenance, breakdown support and technical assistance. Additionally, the scope of work includes converting the SGT-200 packages to a DLE Low Emission Combustion System.

## Reduced emissions

GTI has signed an agreement with Korea Electric Power Research Institute (KEPRI), a unit of KEPCO, to jointly

research and develop oxygen-fired pressurized fluidized bed combustor (Oxy-PFBC) technology that promises power generation with substantially reduced emissions.

The agreement focuses on combustor work which can lead to power generation with carbon dioxide ($CO_2$) capture that is more efficient and lower cost than current $CO_2$ capture technologies.

Oxy-PFBC uses oxy-fuel combustion, a process that burns solid fuel using a pressurized mixture of oxygen and $CO_2$, instead of air, to produce heat to generate electricity. This improves process efficiency and results in exhaust gas that is primarily $CO_2$ and water vapor, thereby reducing the cost of capturing the $CO_2$ for later use or permanent storage underground. It also eliminates particulate emissions, an attribute important for air quality in South Korea.

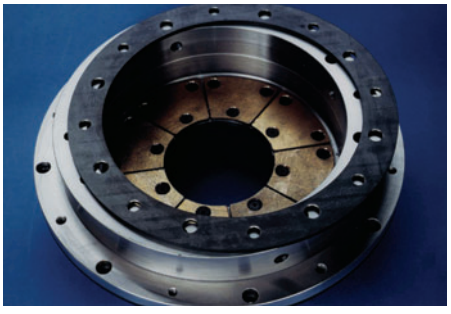
Oxy-combustion enables high-efficiency gas cleanup, while pressurization shrinks the equipment size and the cost. The combustor is expected to be one-third the size of a traditional combustor and less than half the cost.

PFBC can result in electricity production from coal with near-zero emissions, while biomass-coal blends can achieve negative $CO_2$ emissions. The partners are working to validate the process, mature the technology, and address technology gaps to progress the commercialization of more economical $CO_2$ capture technologies.

## Bearing performance

It is difficult for engineers to predict whether a hybrid bearing will outperform a steel one in a given application, or if performance benefits are worth the extra investment. The conventional equations engineers use to calculate the rating life of a bearing do not reflect the real-world performance of hybrid designs.

To rectify this, engineers at SKF helped to develop the Generalized Bearing Life Model (GBLM). Using GBLM, engineers can determine benefits from hybrid bearings. In the case of a poorly lubricated pump bearing, for instance, the rating life of a hybrid bearing can be up to eight times that of a steel equivalent. For a screw compressor bearing running with contaminated lubricant, the hybrid offers a rating lifetime a hundred times greater than a conventional steel bearing.



**A new test enables engineers to calculate the life of a traditional bearing with a hybrid bearing**

## GTC acquisition

Gas Turbine Controls (GTC) has agreed to acquire 100% of the shares of Industrial Control Care (ICC), a Dubai company. The acquisition is part of GTC's portfolio and growth plan to expand its offerings to cover the support of industrial controls.

The transaction is expected to close in the second or third quarter of 2019. GTC will continue its core offerings to support obsolete systems, but the acquisition of ICC widens its range of controls systems.

## GE Steam president

GE Steam Power has announced Michael Keroullé as President & CEO of the $5 billion business. Keroullé succeeds Andreas Lusch who will step down after a 32-year career.

*Continues on page 16*

## MAN Energy digest

MAN Energy opened its new U.S. headquarters and Gulf Coast service center in Brookshire, TX, about 30 miles west of Houston. The new workshop and office complex combines engine and turbomachinery repair operations, which were formerly located at two different sites.

It serves as the home base for over 140 employees. Over 100,000 square feet of the new campus are allotted to the service shop, an expansion of nearly 60%. One of the two new shop bays features a 50-ton crane with a 35-foot hook height. A new rotor balance stand with a capability up to 100,000 pounds and laser cladding cell are further features.

Modec, a Japanese firm which supplies floating production storage and offloading (FPSO) vessels, has awarded a contract to Man Energy Solutions for six centrifugal compressor trains. They will be used in gas production on a new FPSO to be deployed in offshore Mexico.

The scope includes three medium-pressure/high-pressure (MP/HP), two low-pressure (LP) and one fuel gas compressor train with one single stage centrifugal compressor driven by a fixed-speed electric motor. They are expected to be delivered for installation in February 2020. The FPSO will process 90,000 barrels of crude oil and 75 million ft³ of gas per day.


MAN's new U.S. headquarters

MAN Energy has received an order from Estonian TSO Elering to deliver two Mopico compressor systems for the Balticconnector project. Major gas projects in the Baltic region include the Gas Interconnector Poland–Lithuania (GIPL), the Balticconnector project, and the development of infrastructure between the Baltic states.

The GIPL aims to connect the Baltic and Finnish gas networks with the continental European gas network by the end of 2021. The Balticconnector will provide a gas link between Finland and Estonia. The order includes two Mopico RM40 compressors with a MAN M33 motor each and a corresponding active magnetic bearing system supplied by MAN-owned MECOS. In addition to the compressor systems, the scope includes the delivery in 2020 and commissioning.


Michael Keroullé

Keroullé was most recently Steam Power's Chief Commercial Officer and has been with the company for 19 years. He held roles ranging from Project Director to the Managing Director of the environmental control business in Europe and the boiler business in India. Sacha Parneix, Regional Sales Leader for GE Steam Power MENAT, will take over as Chief Commercial Officer.

## LNG fuel supply

MAN Energy Solutions' marine LNG fuel-gas-system manufacturing business, MAN Cryo, will supply an LNG fuel-gas supply system to a Norwegian live-fish carrier ordered by Nordlaks.

The system forms part of a hybrid gas-battery propulsion solution. MAN Cryo's scope of supply for each vessel covers: 2 × vertical vacuum insulated 146-m³ LNG tanks, each with 2 × redundant tank connecting spaces; 2 × BS100-GR bunker stations; and 2 × HEU 100 glycol-heat exchanger units. Delivery of the vessel is expected during 2021.

## Chiller growth

In the coming years, the global absorption chillers market is projected to display a positive outlook according to a new report by Persistent Market Research. The market value is expected to increase at a moderate pace with double-stage chillers accounting for substantial share throughout the forecast period.

The global absorption chillers market was valued at nearly $1.2 billion in 2018, with growth of 3.6% compared to 2017. The U.S. accounts for the biggest share in absorption chillers. South Asia is expected to witness the fastest growth during the forecast period, supported by the rising demand from chemicals and pulp & paper manufacturing.

Increasing installation of solar-powered absorption chillers across various end-use industries is a key factor spurring interest in absorption chillers. However, the high installation cost of absorption chillers as compared to mechanical and electrical chillers results in a long payback period.

## Clean Power Act replaced

The Affordable Clean Energy (ACE) rule by the U.S. Environmental Protection Agency (EPA) has been issued to replace the Clean Power Plan (CPP). The new rule will regulate greenhouse gases (GHGs) and focus on the 600 U.S. coal-fired units, deciding how to meet new emission guidelines.

Further sections stipulate best system of emissions reduction related to GHG, including how power generators can improve heat rate via operating and maintenance practices, and candidate technologies: intelligent soot blowers, boiler feed pumps, air heater and duct leakage control, variable frequency drives, steam turbine blade path upgrades and economizer replacements.


The Clean Power Act has been replaced with the Affordable Clean Energy Rule

## GE job cuts

GE Gas and Power is cutting 450 jobs at two of its manufacturing sites in in Birr and Baden, Switzerland. Both plants will remain open. This follows cuts of 1,200 jobs at its Swiss operations last year, and almost 500 jobs cut at GE units in France. These French and Swiss facilities formerly belonged to Alstom.

## Siemens spins and cuts

Siemens has decided to spin off its Gas and Power unit. This will end its interest its power generation, transmission, oil and gas and related businesses. Its majority stake in Siemens Gamesa Renewable Energy will also be spun off as part of the deal. The company has devised a Vision 2020+ strategy and aims to focus on digitalization technologies, software, automation, smart infrastructure (SI) and healthcare.

One of the goals of the move is to create an independent Gas and Power business, which currently has sales of more $314 billion and over 44,000 employees. A stock exchange listing for the new entity is expected by September 2020.

This announcement was followed by plans to cut 2,700 jobs from its Gas and Power division. This is in addition to 10,400 positions already being cut throughout the Siemens organizations as part of cost-cutting measures. ■

# MULTIPLE MONITORING METHODS

AMIN ALMASI

Many condition-monitoring methods are effective in detecting specific failures and problems. However, each has its limits, and false alarms can be an issue.

Methods of predicting the remaining life of components have also been developed. They are usually reliability-based or developed around mathematically complex models. In simple terms, condition-monitored measurements have been divided into two regions: a stable zone and failure zone.

In the stable zone, condition measurements are considered normal or quasi-normal and, hence, a reliability-based model is often employed. When condition measurements indicate a problem or an issue, both reliability and condition-monitoring information are usually combined to predict the remaining machinery life.

The life-prediction model is dependent on the quality and accuracy of the condition-monitored measurements. Therefore, the application of multiple condition monitoring methods can significantly enhance life prediction and consequently predicted life.

Multiple data sources, backed up by information from several independent monitoring methods, enables more accurate life prediction.

After all, it may be unwise to stop turbomachinery for repair or overhaul based on only one abnormal monitoring signal. Without multiple monitoring technologies coming to the same conclusion, the health of equipment cannot be properly assessed.

Vibration analysis, oil analysis, wear-debris analysis, acoustic emission monitoring and temperature measurements are among the possible technologies that can be employed.

Two or more should be used on every piece of machinery. If at least two monitoring methods indicate there is an issue, action can usually be taken with confidence.

Vibration analysis is commonly used as a permanent monitoring system with two or three others used as needed to confirm detected issues. For critical machinery, as many as five options might be used as permanent online (live) monitoring methods.

For example, online vibration monitoring, such as bearing double (X-Y) vibration sensors and vibration measurements of casings, is often provided, as well as online temperature measurements (in the form of resistance temperature detectors or others) for bearings.

**Without conclusions based on multiple monitoring technologies, the health of equipment cannot be properly assessed.**

In the case of abnormal vibration and temperature, oil or wear debris analysis could be used to further evaluate the bearings. A spike in bearing materials (such as lead, tin or aluminum) would indicate a bearing issue is developing.

In the case of gearboxes, online vibration monitoring might detect high vibrations. Oil analysis could then be arranged for further reliability assessment. A slight increase in iron could be considered as confirmation of a problem in the gear unit.

Without the benefit of two, three or even four technologies that confirm the likelihood of a problem, there is always a risk that an inspection after a shutdown might find nothing wrong.

Case in point: the measured vibration level for one compressor reached triple the baseline value during a period of two months. Lubrication oil analysis also showed a significant increase in bearing materials and other contaminants.

The equipment was stopped at the first opportunity. Detailed inspection and observation detected a damaged seal that allowed contaminants to invade the bearing. This was the cause of high vibration and abnormalities in the lubrication oil analysis.

## Failure modes

Any effective condition monitoring package requires a good understanding of the failure modes and degradation mechanisms involved. Most monitoring methods applied today focus on temperature measurements, vibration analysis, acoustic emission, oil monitoring and wear debris analysis.

Methods such as performance monitoring based on flow-rate, pressure, power, and so on, are well understood and should also be used. Creep and fatigue models, too, can be used for monitoring of different parts and components.

Overall, condition monitoring techniques can identify where turbomachinery problems are occurring and can often help to pinpoint the cause. However, it is far more difficult to predict the remaining life of machine parts once a problem has been identified. Too often, it is challenging to determine if a component needs to be replaced or repairs need to be performed. ■

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

# VIRTUAL AND AUGMENTED REALITY

Siemens is using AR and VR technology in training and in the field

## STATE-OF-THE-ART TOOLS FOR TURBOMACHINERY ADVANCE AND SIMPLIFY ENGINE DESIGN, FIELD SERVICE, TRAINING AND MAINTENANCE

**BY DREW ROBB**

Movies such as "Tron," "The Matrix" and "Strange Days" introduced the world to a new and sinister virtual reality. Fortunately, the latest virtual and augmented reality tools being introduced into the workplace have a more benign purpose.

These tools are training new hires much faster in complex engineering actions and shop-floor assembly tasks while helping engineers and designers devise new solutions. And they are being harnessed in the field to simplify inspection, add precision to routine inspections and to assist troubleshooters in isolating root causes.

Baker Hughes GE, Elliott, Siemens, Howden, MAN Energy, MTU Maintenance, GE Aviation and others are already using augmented reality tools in their offices, factories and energy plants. Daqri, Microsoft, Ubimax, PTC, Upskill, RealWare, HTC, Glass, Atlas Copco, Worklink are among the experts producing them.

### Virtual definitions

Virtual reality (VR) immerses the user in a digital environment on a computer screen or other digital device that is a version of real life. The latest versions of VR allow the user to roam through a virtual world and create realistic-seeming motions, scenes and experiences.

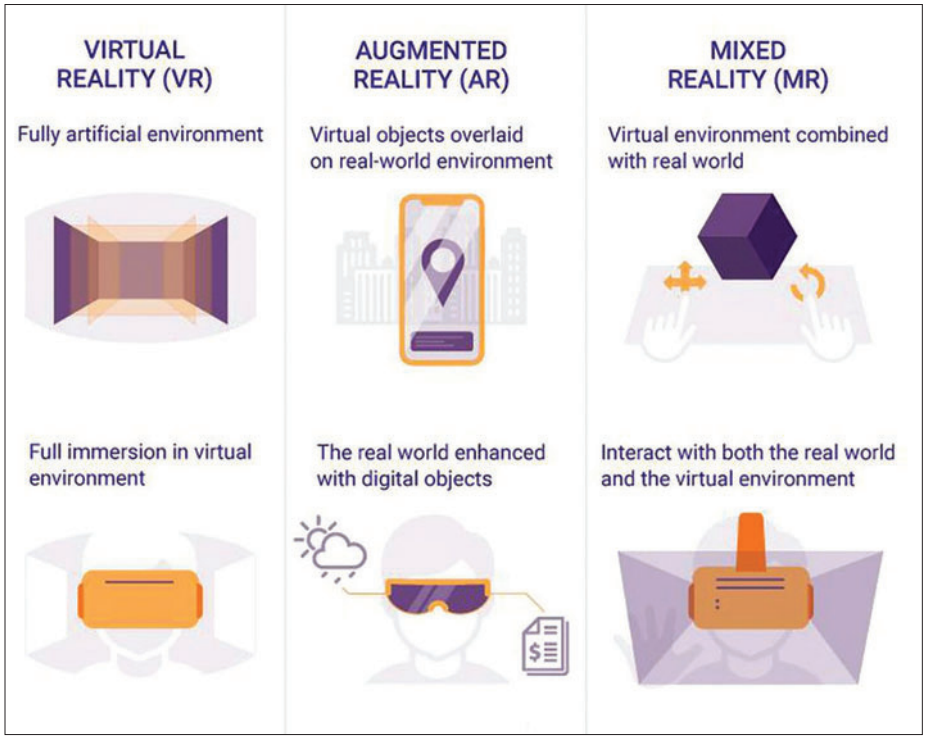
Augmented reality (AR) deals with overlaying virtual objects on top of a real-world environment. PDFs, diagrams, lists of instructions and other aids are superimposed on a device, such as eyeglasses, so the user is assisted in viewing, understanding or carrying out a physical action.

Mixed reality (MR) is an extension of AR that goes beyond mere overlays of data or documents to anchor virtual objects to the real world. In other words, virtual data is tied to the physical object in such a way that as the user moves, the virtual object adjusts to continue in alignment with the physical object. AR and MR are often used interchangeably.

Worldwide spending on AR/VR was around $18 billion in 2018, almost double the previous year, according to International Data Corp. (IDC). Commercial deployments represented more than 60% of the last year's total and will account for more than 85% of the market by 2021.

On-site assembly, safety, process manufacturing training and industrial maintenance are among the most widely used tools in the manufacturing sector. Field service, too, is a popular application of AR.

By next year, IDC predicts that 25% of field service personnel will use the technology, with the oil and gas sector leading the way in the number of deployments. About 14.4 million U.S. workers will wear smart glasses by 2025, up from around half a




**The difference between virtual, augmented and mixed reality.** *Courtesy of Quora*

million today according to analyst firm Forrester Research.

AR tools provide those in the field or on the shop floor the ability to access step-by-step instructions on repairs while performing work. They reduce the number of human errors, execution times and downtime and lessen the number of breakdowns, while improving worker productivity, fix rates and profitability. In addition, maintenance and assembly processes can be more easily documented and reviewed by supervisors.

AR can help new employees move through complex inspection, assembly and maintenance tasks, helping them attain competence faster than wading through manuals or tagging along with a veteran.

"As equipment becomes more complicated, problem isolation and diagnosis increase in difficulty," said Ralph Rio, an analyst at the ARC Advisory Group. "Obtaining a high, first-time fix rate requires good tools to determine the true source of equipment failures."

Rio explained that sensors inside equipment can provide technicians with process data, such as the temperature and pressure of materials in a pipe, or equipment data, such as vibration. By displaying these parameters, it is easy to see what is going on at a glance.

In the case of employee inexperience, the AR device can be hooked onto the screen of a remote expert who guides the user through the necessary actions. Having this take place via 3D headsets, such as Daqri Smart Glasses and Microsoft HoloLens, is less cumbersome than trying to set up a Skype video or conference call. The remote expert can annotate the display for the user and have that annotation remain aligned to the equipment even when technicians move around.

In all likelihood, OEMs will begin offering premium support services that enable access to remote experts via AR. This could speed field service and avoid delays while service providers deploy personnel to distant locations for inspections and repairs.

Meanwhile, OEMs in the turbomachinery sector are using AR or VR in a variety of ways.

## Elliott

Dan Butler, Application Engineer at Elliott, said his company has focused on VR via an HTC Vive headset along with software from Unreal Engine and an Alienware laptop.

"By using VR for internal design reviews, we can more easily and quickly detect potential manufacturing issues before the equipment hits the shop floor," said Butler. "We also have provided presentations to customers using VR, which gives them a much clearer understanding of the equipment layout and functionality."

Viewing things in VR gives a better representation than looking at a 2D drawing or even a 3D model on a computer screen, he said. The viewer is given a clearer sense of the scale of equipment.

As a result, designers can ensure such things as valve handles are easily accessed. Within the VR system, the designer reaches out a hand to determine accessibility. You can also judge if gauges are at the proper level by virtually standing at the right location.

So far, Elliott has not used any of this equipment in the field. But early experience indicates that it helps to identify potential issues faster. No training is required, only a quick explanation of the controls, said Butler.

## MTU

MTU has an AR pilot project known as "Inspection 4.0" running at its facility in Berlin-Brandenburg in collaboration with the Brandenburg University of Technology Cottbus-Senftenberg. It has two main goals:

- To centralize all data regarding a specific part into one system and improve knowledge management in the shop. This has the benefit of reducing the amount of time mechanics spend switching between documents and enabling them to focus on inspecting the part in question
- To converge the real and virtual world of maintenance.

"Data will be transferred to tablets or smart glasses so that the mechanic has a complete overview at all times," said Dr. Friedhelm Kappei, Head of Industrial Engineering, MTU Maintenance.

## Siemens

Siemens SGT-8000H combustor inspection virtual maintenance trainer (VMT) visualizes the hardware, tools, environmental health and safety requirements, and the sequence of steps to disassemble and assemble a burners on an SGT-8000H.

Trainees learn via tutorial mode and can repeat the training as often as necessary before starting and completing an assessment. A successful assessment is documented and is required before trainees can participate in practical training with the actual turbine. This has reduced training time on site and at Siemens Berlin training center.

"Trainees are better prepared, practical training is faster and the time saved is used for more exercises and additional scope," said Michael Stavenhagen, Siemens Gas & Power, Head of Digital Training Center. "VR/AR can also save in travel costs as collaboration can take place in a virtual environment."

As technicians often have to deal with situations onsite where additional support is required, live audio, video and AR software collaboration are available from remote experts. Siemens Omnivise Remote Service supplies field workers with the knowhow to monitor, maintain and repair assets using cloud-based

*Continues on page 22*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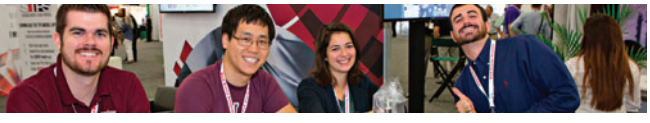


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Direct Head Measurements for Turbomachinery Design

Stability Considerations of Centrifugal Compressors Equipped With Active Magnetic Bearings

Experimental Evaluation of Performance and Mechanical Reliability for High Pressure Co2 Integrally Geared Compressor

Introduction to SCC Failures in Steam Turbines and Solutions

Numerical and Experimental Analysis of Flow-Induced Subsynchronous Vibrations in Integrally Geared Turboexpanders

Addressing a High Sub-Synchronous Vibration Problem in an Amb-Equipped Turboexpander

A Comparison of Type 1 versus Type 2 Testing – Recent Experiences Testing a High-Pressure, Re-Injection Compressor

A Refined Method to Check Tooth Contact Pattern of Gears Guarantees Factory Quality for Tooth Contact, But with Less Effort and Risk

A Resonance Condition Encountered in a Shop Overspeed Machine Due to Inertia Effects

Numerical Models and Experimental Validation of High Speed, High Load, Hydrodynamic Bearings

Dynamics of Modular Rotors in High Speed Centrifugal Compressors: Design, Operational Performance and Field Serviceability

## PUMP

Understanding the Effects of Selecting a Pump Performance Test Acceptance Grades

Study of Pulsation Dampener Designs for Reciprocating Pumps

Torsional Rotordynamic Excitation, Natural Frequency and Damping Characteristics in a Viscous Centrifugal Pump Application

Realistic Expectations From a Plan 66A Unique Bushing Design

A Fem Approach to Predict Acoustic Resonance in Multistage Centrifugal Pump

Investigation on the Influence of an Inducer on the Transport of Single and Two-Phase Air-Water Flows by Centrifugal Pumps

Cavitation Sensing and Optimization in Rotary Positive Displacement Pumps for Transfer Duties

Sand Management and Erosion Prediction in Subsea Multiphase Pumps

# TUTORIALS:

## TURBO

Methods to Effectively Evaluate Modern Journal Bearing Performance and Achieve High Reliability

Performance of Industrial Gas Turbines

Turbomachinery for Refinery Applications

Compressor Selection for LNG Liquefaction

Dry Gas Seal Failure Simulation Methodology

A Comparison of Operating Deflection Shape and Motion Amplification Video Techniques for Vibration Analysis

Revamp Design Considerations

Range Versus Efficiency — Striking the Proper Balance

Motor/Generator Set Non-Contacting Torsional Vibration

Computing the Safety Integrity Level (SIL) for Turbo Machinery Protection

Tutorial On Centrifugal Compressor Surge Control

Fundamentals of Fluid Film Thrust Bearing Operation and Modeling

## PUMP

Predicting Centrifugal Pump Type and NPSH in Early Facility Design

Methods to Determine and Specify Pump Dynamic Analysis

Improving the Use of Plant Operators

Precision Grouting of Turbomachinery

Tutorial: Transforming Condition Monitoring into effective Condition Based Maintenance

Submersible Pumps Condition Monitoring Using Motor Current Signature Analyses and Vibration Analyses Comparison

Application Considerations for Mechanical Seals in Variable Speed Pumps

Understanding Waterhammer in Pumping Systems – And Surge Suppression Options

Midstream Pipeline Applications

# CASE STUDIES:

## TURBO

Manifestations of Thermal Imbalance in IGC

Morton Effect With Pedestal Support Influence

Influence of Bearing Selection on MTBF (Mean Time Between Failure) of a Screw Expander in Geothermal Power Generation Service

High Vibration at Low Speed on a 25MW Turbogenerator System – Root Cause Investigation

Catastrophic Failure Diagnosis with Modal Analysis of Generator Endwindings

Piping Dynamics and Acoustics Simulation in Troubleshooting High Vibration and SBC's Failures of Reciprocating Compressor Piping System

Chandlersville and St. Paul: Unique Piping Vibration Issue in a New Centrifugal Compressor Installation

Valve Seat Failure on Steam Turbine

High Reliability Pistons for Reciprocating Compressors (Part 2) – 3 Years of Field Experience

Resolution of High Vibration on Generator

Gas Turbine Noise Abatement Case Study "Upgrading Initial Designed Noise Control System Reducing Excessive Noise Levels

Blade Failure Analysis for Compressor Driving Steam Turbine

Case Study of Harsh Environment Impact on Gas Turbines Pre-Mature Failures in Malaysia Offshore Waters and Novel Approach in Resolving the Prolong Issues

A Systematic Method of Determining the Source of Unbalance in a Rotor Assembly

Radial Subsynchronous Vibration Caused By Axial Vibration

Hydrogen Recycle Gas Compressor Fouling Mitigation Using Higher Suction Temperature

Fluid-Film Bearing Damage Detection Based on Vibration Data

Design and Implementation of Swirl Brakes for Enhanced Rotordynamic Stability in an Off-shore Centrifugal Compressor

Analysis and Troubleshooting of a Piston Rod Failure of RC

Analysis and Countermeasure for Sulfide Stress Cracking Of Centrifugal Compressor

## PUMP

Post-Event Analysis of Subsea Electrical Submersible Pumps Using Electrical Waveform Monitoring

Vertical Pump Resonance Problem

Identifying the Cause of a Plunger Pump Shutdown – Data Logging To the Rescue

Acoustic Resonance in a Progressive Cavity Pump

Poor Hydraulic Performance from a Pair of Large Barrel Pumps

Cavitation in VFD Driven Mainline Pumps in Series

Keyless Taper Fits with Non-Uniform Section Hubs

A Case Study: The Use of Motion Amplification to Measure and Visualize Relative Motion Between Components

Shop Run Test Failure of an API 610 Vertical Sump Pump: What It Exposed, and Why It Was Critical to Solve.

Extending MTBF of Seals in Boiler Feed Water Service

Testing and Troubleshooting of Pump Dry Gas Seals Operating with sCO2

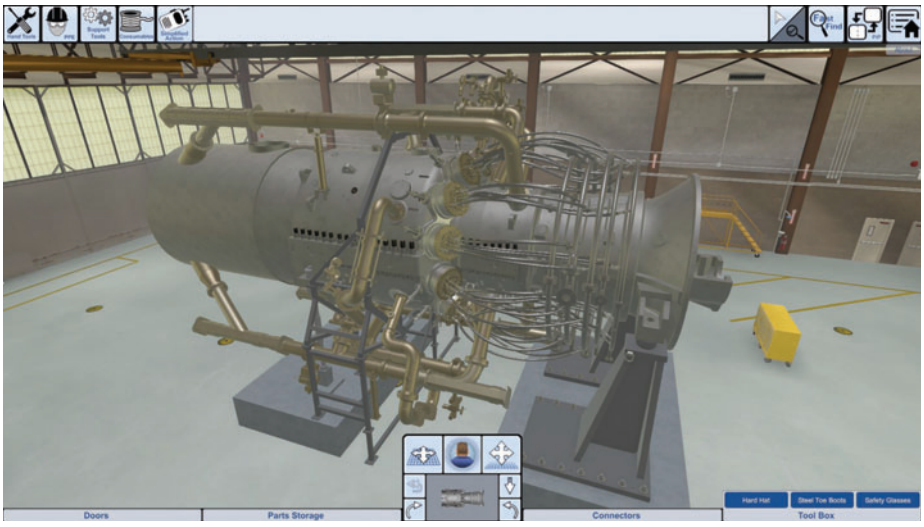
FOR A COMPLETE LOOK AT THE PROGRAM, INCLUDING SHORT COURSES (SEPT. 9) AND DISCUSSION GROUPS, VISIT **TPS.TAMU.EDU/PROGRAM**.

communication tools.

Benefits include:

- Increased productivity by helping to improve uptime to immediate expert support
- Enabling capabilities to support customers where travel restrictions apply
- Extending accessibility of experts by avoiding travel time
- Improved training effectiveness through availability of virtual information sharing
- Improved documentation through enhanced information sharing

"VR solutions focus on training, sales and digital twins," said Julian Zingel, Head of Marketing & Sales for Siemens Omnivise Remote Service. "AR solutions focus on enhancing field service and maintenance at site."




**Siemens SGT-8000H combustor inspection virtual maintenance trainer (VMT) visualizes the assembly of burners on an SGT-8000H**

## BHGE

Baker Hughes, a GE company, (BHGE) uses VR and 3D laser scanning and modelling in different phases of rotating equipment design, ergonomics validation, training and outage excellence optimization. VR and 3D support features, such as rotation of components to focus on details, zoom in, zoom out, and viewing the model from different directions, as well as highlighting interference between different simulated bodies. This offers more accuracy and clarity during the evaluation and design review phases.

By combining CAD and laser-scanning tools for machine design with a virtual plant scenario, BHGE has improved the effectiveness of the digital engineering process, risk has been reduced and productivity improved.

Unexpected installation hurdles have been avoided at an early stage, leading to safer and more effective project implementation. VR tools have also been used to design for maintainability, to train people on maintenance procedures and for outage excellence optimization.

"Virtual reality offers great opportunities to maximize production and enhance the safety of operations when maintaining or serving existing plant and installed turbomachinery equipment, as well as in outage optimization," said Alessandro Bresciani, Vice President, Global Services Turbomachinery & Process Solutions, BHGE. "In preparation for planned maintenance, the entire operation can be simulated virtually, identifying and addressing potential bottlenecks in advance, as well as training personnel. Effectively and accurately laying out an outage can help ensure that the work is undertaken efficiently and safely."

In preparation for a shutdown, technical surveys and outage simulations help to minimize issues in the execution of an outage. Layout is a crucial part of maintenance

**BHGE combines CAD and laser-scanning tools for machine design with a virtual plant scenario**

## Howden AR case study

The Vuforia software platform from PTC along with Microsoft HoloLens are being used by Howden to create step-by-step instructions that incorporate real-time and historic Internet of Things data from PTC's ThingWorx Industrial IoT platform and the Microsoft Azure cloud.

This AR solution helps Howden to enhance the customer in operating and maintaining equipment as part of its Data-Driven Advantage (DDA) program to leverage technology to meet customer needs.

Howden wanted to improve aftermarket Long Term Service Agreements (LTSAs) by transitioning from a reactive service approach to collaborative customer partnerships. PTC's Vuforia Studio AR helped the company to implement HoloLens with IoT and other data to create an enhanced view of equipment.

This includes being able to visualize what is going on inside machinery. Benefits include predictive maintenance alerts, more rapid parts identification repair sequences that are easier to follow and lowered downtime

One aspect of this is the digital twin, i.e., a 3D representation of the actual physical plant and equipment environment that is updated in real time. As changes are made to the equipment or processes, sensors relay that information, so it is viewable on the digital twin.

"We are overlaying digital twin data on the physical product to show our customers the operational condition and performance of the equipment," said Maria Wilson, Global Leader Data Driven Advantage at Howden. "Using Microsoft HoloLens, the experience is immersive, and you get to understand a lot more and look at the equipment in a way you never did before."

nance planning as sites involve the coordination and movement of large quantities of materials as well as lifting and logistic devices and people.

VR enables all items to be positioned on the virtual deck and a virtual simulation can be performed to ensure environmental health and safety requirements are met and the spaces are properly optimized for the job to be performed. 3D drawings and videos can then be passed to a manpower contractor for proper layout area preparation a few days prior to the outage.

In addition, high-definition 3D laser scanning technology is used to capture the existing plant configuration in the form of a high-accuracy point cloud. Combined with camera imaging, a point cloud can be rendered to provide a photo-realistic virtual view of the facility, bringing the plant to the project engineer's desktop as a 3D model. This is a step towards replacing traditional paper drawings.

BHGE has found that projects based on digital execution are more efficient than conventional design methods as they eliminate misalignments among drawings, optimize OEM and EPC contractor work processes and avoid redundancies during engineering development.

Once the 3D environment is ready to be explored, a feasibility study of the maintenance scope can be developed through analyses and simulations. VR adds the ability to check pros and cons of a project or tool, modeling it according to the needs and ensuring suitability for the actual configuration of the site.

VR transfers information in more realistic situations than traditional classroom and workshop training methods, engaging the trainee in a higher level of critical thinking, and providing the ability to see immediate results. It accurately simulates operational scenarios, so personnel are ready to face critical issues with the right preventive and corrective actions.

## MAN Energy

MAN Energy Solutions offers PrimeServ EyeTech, a remote support solution based on smart glasses. A head-mounted device enables live and mobile video conferences between experts in remote operating centres and customers on site working on equipment. EyeTech is one part of the Man PrimeServ Assist service which offers 24/7 expertise support.

"The service engineer can see whatever the technician onsite sees and guides him or her what to do next," said Caroline Horn, Digital Lab Leader Turbomachinery, MAN Energy Solutions Switzerland. "The customer has both hands free and gets all the information needed displayed on a head-mounted screen."

She added that issues can be resolved faster, travel costs saved, and the availability of machinery improved. For example, a specialist in Europe can solve an issue for a customer in the U.S. without spending time or money for travelling.

MAN uses Microsoft HoloLens glasses in VR training, and Realware HMT-1 glasses for onsite applications, as they are more robust, lighter and more comfortable to wear.


**Images taken with VR glasses on a Man Energy field service job in Portugal**

**Ubimax software enhances the value of AR glasses for a more immersive experience**

## Supplier perspective

Ubimax, a provider of AR solutions, offers the Ubimax Frontline platform to act as software that operates with glasses such as Microsoft HoloLens. As well as existing as in-house software, it can also make use of the Microsoft Azure cloud to obtain data from additional sources.

The HoloLens is well suited to showing PDF files, blueprints and manuals. Multiple windows with different information can be on display right in front of the user's eyes, enhancing the amount of information accessible when needed.

With its eye tracking functionality, it helps the user navigate through texts. The glasses adapt to reading speed and automatically scroll down as the end of the page is reached.

Ubimax software adds more 3D features to make the experience more immersive. As a result, 3D models of component parts can be touched, grasped and moved in ways that feel natural.

"Ubimax Frontline includes support in maintenance, repair and overhaul of turbomachinery equipment," said Percy Stocker, President Americas, Ubimax. "With a combination of augmented reality and wearable computing solutions such as smart glasses, the worker gains relevant instructions including safety warnings into the field of view exactly when needed and can use both hands for the task."

Additionally, workers can document problems via picture or video. Safety warnings and security procedures can be

*Continues on page 24*

included. Workers can also start video calls with remote experts to get help or receive decisions about finishing a task.

Airbus Helicopters, for example, implemented Ubimax Frontline to improve the inspection processes of helicopter gearboxes. Previously, the worker had to document every step, take pictures and upload them onto a computer.

Further, they had to leaf though manuals. The company achieved a paperless working environment in inspection processes with Ubimax Frontline. The speed of the inspection process was increased by 40% as data is automatically transmitted to enterprise systems.

"Errors through manual input have been reduced to zero because of data digitization," said Stocker.

She cited further applications of Ubimax software:

- BHGE's smart helmet is used for machinery inspection at its LNG plant in Qatar. By collaborating directly on-site with headquarters via video calls the number of trips for an inspection process is reduced
- In a BHGE facility in Florence, Italy, AR is used on the factory floor. For quality insurance matters, workers have to make around 100 measurements for gas turbine nozzles and enter them into a spreadsheet. With AR, the next measurement place is highlighted, the measurement automatically recognized and transmitted into the database. Workers are notified when problems occur. This leads to a reduction of errors and a higher process speed
- Siemens Industrial Turbomachinery uses AR for collaboration purposes in inspection, saving travel expenditures and reducing machine downtime.

As well as smart glasses, wrist computers can also be employed to make the job of the inspection worker more convenient. They can execute the tasks with both hands and full concentration, making the job safer, more productive and efficient. Smart glasses can also be combined with safety glasses and hard hats, depending on the working environment.

Stocker said it takes an hour or two to get used to wearable and AR technology. "After one to two weeks of on-the-job training, they are fully used to the technology and see an increase in productivity."

Daqri's smart helmet lets engineers see 3D images above assets and prompt them with instructions. Siemens partnered with Daqri on its gas burner assembly training application.

A proof-of-concept study helped to better understand how AR-based training affects assembly efficiency at the Siemens Power Service Training Center in Berlin. Four participants completed the assembly of a part using the AR application.

Two new employees were able to successful complete the tasks despite no experience. This approach can help OEMs and service organizations to avoid variability in assembly sequence, minimize errors, streamline data collection and make reporting easier.

Daqri Worksense software for smart glasses has a series of versions for different use cases. These include hands-free remote expert guidance and annotation, being able to attach notes or multimedia assets to assets, ways to map out the environment and equipment to create a 3D digital model, multimedia work instructions, and immersive walkthroughs of equipment and plants.

UpSkill Skylight's AR technology is

Microsoft HoloLens


DAQRI smart glasses

## GE Aviation case study

GE Aviation makes use of UpSkill Skylight and smart glasses from a company named Glass in conjunction with the WiFi-enabled Atlas Corco Saltus MWR-85TA torque wrench. This was all about reducing errors in assembly, maintenance and repair that were costing the company millions each year.

The goal was to minimize productivity losses, delays in testing, delivery slows, and cut down the number of man hours needed to troubleshoot problems or correct faults.

A key aspect of this were the B-nuts used on engine fluid lines and hoses. If torqued correctly, they provided reliable sealing. But if they were left too loose or tightened too much, flights might be delayed, and maintenance work would have to be redone.

AR technology provided workers with step-by-step instructions and images in their line-of-sight. Skylight verifies the correct torque value of the B-nut in real time before the mechanic moves onto another task.

This proved to be a big upgrade compared to trying to follow procedures on paper binders or on a computer screen. If a problem emerges, the technician can turn on a camera, call an engineer and have the work checked.

For compliance purposes, as each nut is completed, the torque value is documented, and the operator is prompted to take a photo. Data and reports are uploaded to laptops and from there to corporate systems and databases.

"We believe Skylight with Glass has the potential to be a real game changer in terms of the ability to minimize errors, improve product quality and increase mechanic efficiency," said Ted Robertson, Manager, GE Aviation.

As well as improving work speed for new staff, the technology also helped veterans. On average, efficiency improvements ranged between 8% and 11%.

said to cut production time by 25% for wiring harness assembly operations at Boeing. It is also used by oilfield works. Scope AR's WorkLink platform works in conjunction with Microsoft HoloLens.

PTC, too, is an AR innovator via its Vuforia platform, which is used in field service, maintenance manufacturing, collaborative design reviews, and virtual work instructions for assembly and training. Its 3D sales aids demonstrate how complex systems and equipment work in virtual reality. This enables potential customers to visualize the product in their own setting before it is built.

## AR challenges

Observers agree that it may take a few years before the technology reaches full maturity. Current AR devices can be bulky. Some technicians complain that they are uncomfortable to wear for hours on end.

There are also safety issues. Just as pedestrians engrossed in their smart phones or wearing earphones are liable to walk in front of a vehicle while crossing the street, some worry that operators equipped with AR glasses may lose track of their physical surroundings due to a lack of situational awareness.

Cost is another concern. The current user base is dominated by large OEMs. Ubimax smart glasses for industrial use start at about $1,500. Additionally, a software license of $1,000 to $1,500 per user is often part of the price. And integration into existing systems and 24/7 support can add further to cost.

"Creating an AR application is relatively expensive, but since a typical OEM has many similar machines to service, it has economies of scale to make this a sound business investment," said Rio of ARC Advisory Group. However, he expects that as the volume of users picks up, significant price declines are inevitable.

Butler of Elliott said VR is already becoming more affordable. He said a full setup including a high-end laptop and headset can be had for under $3,000. He kept costs down by using free software available from the open-source software community.

But one turbomachinery engineering company interviewed for this article said they did not use the technology due to various reasons:

- Some sites have strict 'no cell phone' policies near equipment. Refineries and chemical plants, for example, are reluctant to let outsiders use any of their electronics on their premises
- General safety concerns: operating (or wearing) a device may negatively affect worker's situational awareness to fall, slip and trip hazards
- Remotely located plants may not have good cell phone coverage, and reception quality inside buildings is further reduced due to walls and steel framing
- One user felt it was easier to take pictures on a smart phone than to use AR

## Pros and cons

AR and VR, then, may be right for some and not for others. At the moment, initial costs may prohibit many except for OEMs and large aftermarket service providers. But that is likely to change as prices come down and word of successful applications spreads.

Technology maturity is another factor. Over time, form factors will be reduced, systems will simplify further, and network connectivity issues will be resolved. Just as video took years to overcome bandwidth limitations and move into the mainstream, so it might well be with AR.

Additionally, VR and AR seem more suited to complex equipment and systems. For those engaged in relatively simple assembly or maintenance operations, they may not be needed. But the likelihood is that these technologies will earn a place in the toolbox in the near future. ■

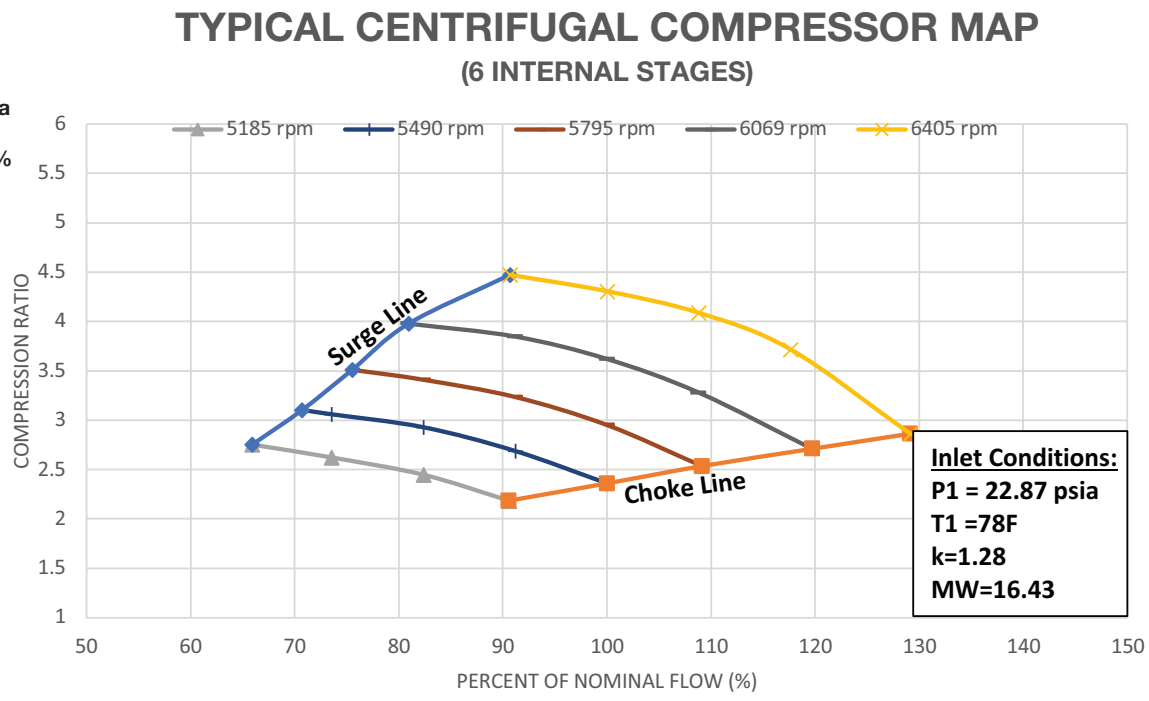



**Figure 1:** Typical centrifugal compressor map. The distance from surge to choke for a given performance curve is 25% to 40% of flow

# COMPRESSOR CHOKE

## THE CATASTROPHIC EFFECT OF CHOKE IN AXIAL COMPRESSORS AND PREVENTION MEASURES

**BY LEYDEN LOPEZ**

Axial compressors are used in large-scale processes where a significant amount of gas is required at a relatively low pressure. Typical applications are at the oil refinery's fluid catalytic cracking unit (FCCU) as the main air blower, at the steel-mill as the blower for the blast furnace or as part of an industrial or aeroderivative gas turbine. Centrifugal compressors are more commonly used due to their versatility: they can compress a wide range of flows to a high discharge pressure.

The stable operation of axial and centrifugal compressors is limited by surge and choke. Surge is a violent flow reversal that occurs when the process restricts the compressor flow below a certain minimum value.

Choke occurs when the process does not create enough restriction to the compressor flow and the compressor operates at its maximum flow for a given performance level. Control systems are available to protect the compressor from surge, but not always from choke.

Investigation of several catastrophic failures using diagnostics tools point to choke (not surge) as the root cause of the failure due to fatigue of a rotating blade or fixed vane. Operation in deep choke, especially of axial compressors during unloaded operation, therefore, should be avoided.

The effect of choke in centrifugal compressors is generally overlooked and is typically of no major concern. This is in great part due to the natural shape of the performance curve that represents a significant change in flow from the limit of surge to the limit of choke (Figure 1). In axial compressors, however, this distance is significantly less (Figure 2).

The more stages a compressor has, the higher the pressure ratio but the smaller the operational margin between surge and choke regions. Figure 2 shows the performance curves of a 12-stage axial compressor. The operational margin of a performance curve is significantly less than the one of a 6-stage centrifugal compressor shown in Figure 1.

OEMs are not always clear about the precise location of the choke line as most attention is given to the surge line. The same mistake is transferred to control systems, which focus exclusively on protection from surge.

However, ignoring the effect of choke in axial compressors has cost refinery owners months of production loss due to the catastrophic failure of the axial main air blower (MAB), one the most critical pieces of machinery in the refinery.

Compressor choke or stonewall is an unstable operating condition, which occurs when the compressor is operating at low discharge pressure and high flow rate. This leads to increased gas velocity in the compressor.

The increase in gas velocity occurs until it reaches sonic velocity or resonance at the blade throat (Mach 1). At this point, no more flow can pass through the compressor, causing high frequency and low amplitude vibration of the rotor blades or stator vanes.

During choke, the flow channels between blade rows may experience blockage effects.

Choke can occur at any performance level, i.e., speed or position of the variable stator vanes (VSV) for a constant speed machine. Although the choke increases with the performance level, long-term operation even at low-performance level in a deep-choke condition can be damaging due to its low visibility and cumulative effect.

Choke is difficult to detect by conventional vibration monitoring systems. When a compressor transits back and forth from the stable area to the choke area, a minor change in noise frequency can sometimes be heard specially at higher performance levels. Currently, no dedicated instruments are used for choke detection.

Therefore, an axial compressor can be operating in a deep choke condition for a long period of time during unload condition at low performance levels (low speed or closed VSV position) without being noticed by the machinery operator.

The opposite is true when the compressor is operating in surge condition. The negative impact on the process and the potentially damaging effects of compressor surge are clearly observable.

The cumulative effect of choke means that the most vulnerable part (rotor blade or stator vane) has a limited number of cycles prior to failure by fatigue. Material analysis of failed rotor blades has concluded that the initiation points of fracture related to operation in deep choke are located at the blade's suction side (convex or curved side).

Fracture begins to develop causing a continuous decline in the blade's moment of resistance, and bending stresses increase permanently until they exceed material yield strength. Fracture eventually occurs during operation at high load. Therefore, choke can easily go unnoticed for years until it produces enough cumulative cycles leading to component failure by fatigue.

In the case of an FCCU, operation in choke condition typically occurs during the startup of the MAB prior to or during the dry-out period. Since the process is not yet ready to accept the full amount of air, no attention is given to the fact that the compressor requires some back-pressure to operate safely.

Consequently, no pressure resistance is created from the process side. Further, the anti-surge valve may remain open. The MAB, therefore, is accumulating a significant number of additional choke cycles that will eventually lead to failure.

In many cases, catastrophic failure will not take place for ten or even twenty years of apparently stable operation after many apparently successful startups. The cumulative effect of choke-induced fatigue gradually leads to the failure of blower components. This is most likely to occur when the MAB is operating at a peak high load that is far away from the surge and choke regions. Without advanced diagnostic tools and proper analysis, damage is likely to be attributed to severe surging.

In industrial gas turbine applications, investigation has pointed to choke as the cause of premature fracture failure of blades in the first row of the axial compressor due to long and unstable operation of the combustion chamber during startup periods.

## Choke conditions

Operators should be aware of the various operating conditions under which a compressor is likely to get into a choke condition such as during failure (open) of the

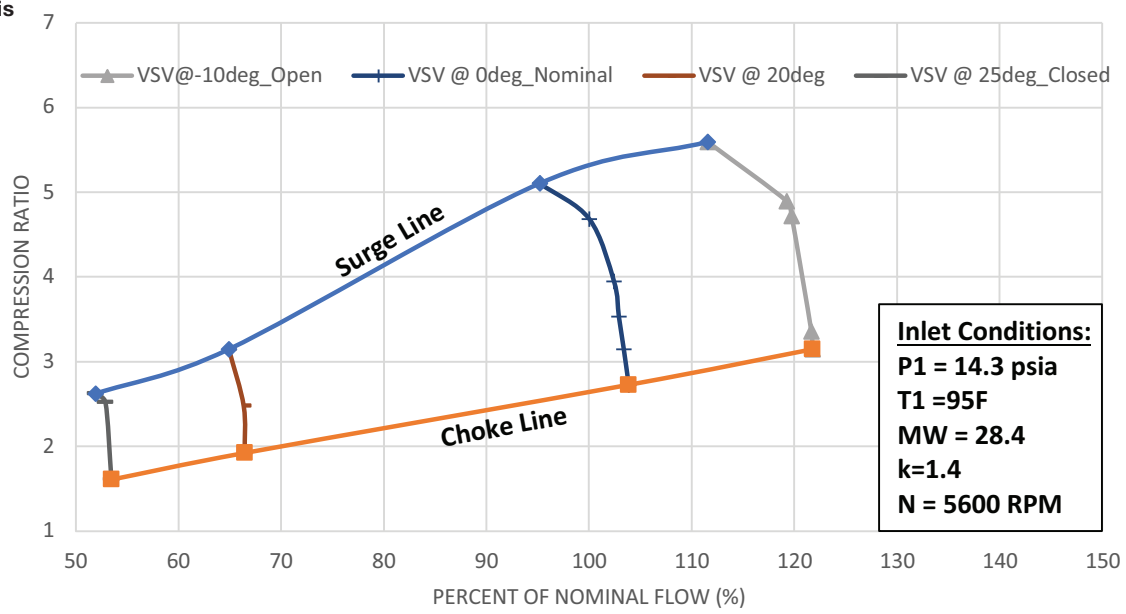



**Figure 2: Typical axial compressor map. The distance from surge to choke for a given performance curve is small (2% to10% of flow)**

anti-surge valve, or when the compressor is undersized for the desired operating conditions.

During start-up and under unloaded operation, too, choke can occur when the anti-surge valve is opened too much or for too long, and no back-pressure is created by the process. If the anti-surge valve is oversized, high travel limitation (clamp) must be established in the controller to make sure the compressor operating point enters the stable operating envelope as soon as it starts and remains there during operation in unload condition. It is vital to avoid compressor operation in a deep choke condition from the beginning of startup (Figure 3).

Another choke condition takes place during loaded operation in combination with excessive opening of the anti-surge valve due to manual operation or by valve low travel limitation (clamp) set by the operator. The operator sometimes applies low clamping during startup while the process is stabilizing to add extra cushion and prevent surge or fast opening of the anti-surge valve by the control system.

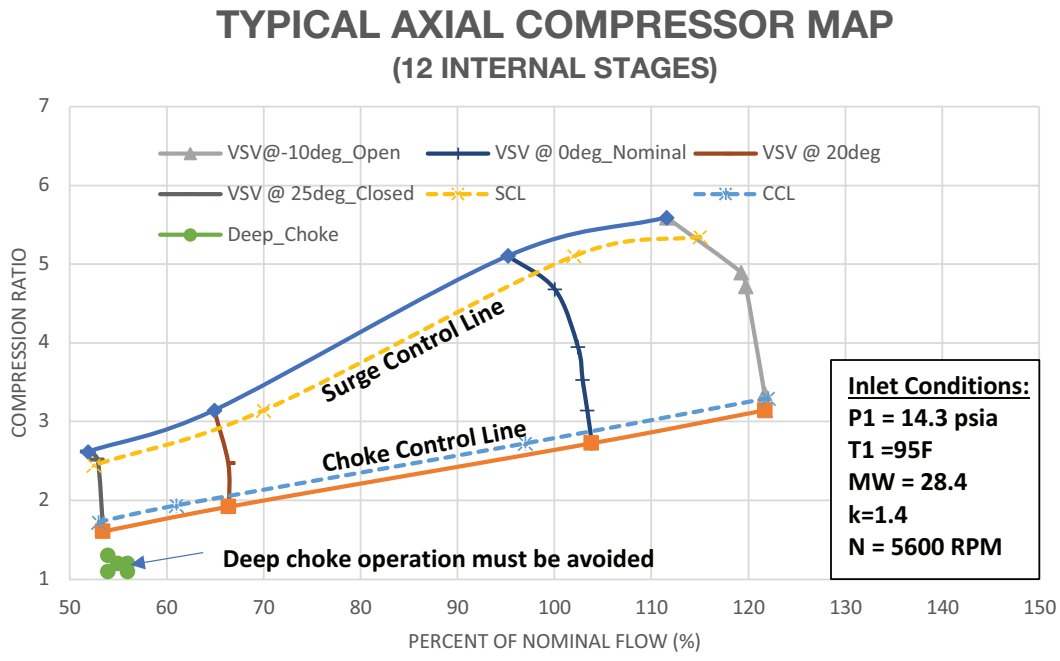
In centrifugal compressors, low clamping wastes energy. But in axial compressors, it may also push the blower into the choke area (due to the narrow operating area between surge and choke). Therefore, clamping must be avoided or used with special care with axial compressors.

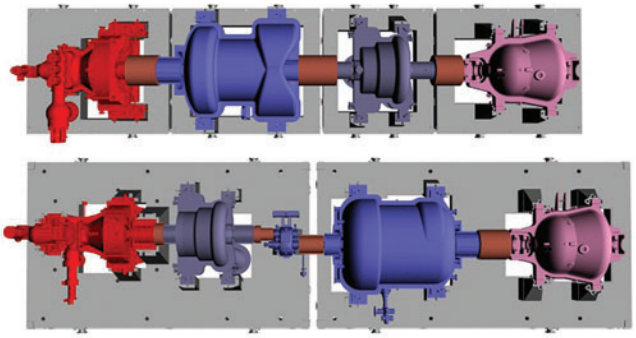
One further choke condition should be noted: In compressors operating in parallel, when one compressor trips, the natural response of a load sharing control system is to increase the performance of the running compressor to compensate for the loss. However, if process resistance remains unchanged, the running compressor will be pushed into the choke area.

To avoid such conditions, certain control measures should be implemented:

- Install an anti-choke valve immediately downstream of the anti-surge blow-off/recycle line and set up proper anti-choke control, which must be independent from the anti-surge controller. Separate transmitters must be used as the distortion of a shared transmitter signal may have conflicting effects on the anti-surge and anti-choke controllers
- Make sure the process is always ready to provide enough back-pressure for the compressor as soon as it is started. For example, place an initial set point of 10-15 psig at the FCCU regenerator. The slide valves should also be kept closed at the mechanical stop to help creating back-pressure. In the case of power recovery trains, the expander inlet and bypass valves can stay closed during startup of the train. If an anti-choke valve is present, start the compressor with that valve initially closed, then slowly ramp it open
- Perform a choke test in addition to a surge test to determine the choke line and establish a choke control line. Make sure the compressor can operate safely in the area close to the expected choke limit. A portable accelerometer can be used to determine if the axial blower is operating in a choke condition. In the author's experience, radial vibration or axial displace-

**Figure 3: A choke control line should be implemented in addition to a surge control line. Operation in deep choke condition during compressor unload condition must be avoided by applying control measures**



**Axial compressor,** courtesy of MAN Energy

ment do not increase in a deep choke condition. An accelerometer placed in the casing near the blower inlet has shown a clear acceleration peak when operating in a choke condition. At higher performance levels, choke can also be perceived by a variation of the normal operating sound

- Graphically illustrate in the HMI the exact location of the choke line, surge line and control lines. As choke is not noticeable (unlike surge), it is vital that it be graphically shown on a real-time compressor map
- When operation near choke is detected, the control system should generate an alarm. In the absence of a choke valve, the operator may be able to apply corrective measures, such as increasing the regenerator pressure
- Properly size and test the anti-surge valve to make sure it does not allow for operation in choke when 100% open in an unloaded condition. The selection criteria for the capacity of anti-surge valves may be different for axial compressors compared to centrifugal
- Have an advanced diagnostic tool that stores high resolution trends and events so catastrophic damage can be correctly attributed
- It is recommended that vendors develop and install an additional signal to the vibration system, such as an accelerometer from the compressor case to generate an alarm and trip due to operation in choke condition for a certain period of time. ■

*Leyden Lopez is Director of Leyden Turbomachinery Corporation of Houston, TX, providing commissioning and consulting services on turbomachinery controls. For more information, visit www.leydentcs.com*

# IMPROVING O&M IN TURBOMACHINERY

## CTOTF USER GROUP BRINGS OPERATORS AND OEMS TOGETHER

**BY DREW ROBB**

The spring Combustion Turbine Operations Technical Forum (CTOTF) user group meeting in St. Augustine, Florida attracted over 100 users. They wanted to hear from their peers about operations & maintenance (O&M) issues impacting their equipment.

But they also got to hear from Mitsubishi Hitachi Power Systems, GE, Siemens and PW Power Systems (PWPS) about the latest upgrades, developments and fixes for just about every possible type of gas turbine (GT).

Going back a decade or so, an us-and-them mentality was sometimes apparent between users and OEMs. Conferences, such as CTOTF break down those barriers. It was encouraging to see the OEMs actively participating in these sessions.

Not only were they promoting their latest and greatest turbomachinery, there were many examples of OEM representatives openly discussing thorny issues, such as lack of availability of spare parts, faulty components and poor turbine performance.

CTOTF Chairman Jack Borsch welcomed everyone to the 44th year of the user group. Its mission is to be the premier mechanism for the exchange of information to shape, lead and advise the power generation industry. As such, it offered tracks covering topics such as O&M, combined cycle, best practices, leadership, plant safety, environmental systems, as well as those dedicated to specific types of turbomachinery.

Chairman Jack Borsch addressing CTOTF users

### Siemens aeros

John-Erik Nelson, Principal Technical Engineer at Braintree Electric led the Siemens aeroderivative (formerly Rolls-Royce) roundtable, focusing on the Rolls-Royce Trent 60 (Siemens SGT-A65). This session was populated by the bulk of existing U.S. users.

Nelson's utility, for example, bought two Trent 60s that went commercial in 2009, each producing 58 MW (later models can produce as much as 66 MW, with future models planned to reach as high as 78 MW). Another three owners attended, representing more than half the fleet of 27 Trent 60 engines, including a user from an Oklahoma utility that owned seven machines.

Nelson launched a discussion of top fleet issues from the user perspective as well as outage management best practices. He brought up a recent Service Bulletin from Siemens that included a product safety warning about hazardous material found on combustor parts known as hexavalent chromium (hex chrome).

"We are finding hex chrome on most Trents," said Nelson.

Users traded tips about how to eliminate the problem and how to dispose of hex chrome properly. The session then turned its attention to the lack of availability of parts. Some users found the parts they needed from Turbine Tech while others used APM due to lengthy parts supply delays.

The acquisition of the former Rolls-Royce line of aeroderivatives by Siemens included a clause for Rolls-Royce to con-

John-Erik Nelson led the Siemens aeroderivative rountable

**Siemens SGT-A65 gas turbine (formerly Rolls-Royce Trent 60)**

tinue to provide spare parts, but that transition period is coming to an end.

The efforts of Siemens to take over have been hampered by various factors. A change to the Siemens Enterprise Resource Planning software led to unanticipated slowdowns. At the same time, the closure of its Mount Vernon, OH plant and a warehouse change in the UK caused a disruption to parts delivery. Siemens is bringing on new supply chain partners.

"We are in the midst of exiting from Rolls-Royce since the acquisition by Siemens," said Angelo Gazzillo, Head of Customer Demand at Siemens in U.K.

This is no easy task. Siemens has now sourced and validated the majority of the existing Rolls-Royce manufactured parts. But some components such as turbine blades remain a challenge. This is due to the complex nature of these parts, the validation process and expertise in suppliers takes time.

"We have introduced more participation with engineering and after sales to improve delivery," said Gazzillo. "We are also digitalizing our supply chain processes to improve efficiency to all levels of the supply chain."

*Continues on page 32*

## HA fleet status

In another session, Steve McHugh, 7HA Product Line Manager of GE Power covered the status of the GE's 7HA and its HA fleet. To date, there are 89 HA units sold, and 54 more under technical selection. While these units have been ordered all over the world, the U.S. holds the most with 33. McHugh said the fleet now has 300,000 operating hours.

The latest version is the 7HA.02, which can provide 382 MW and 42.3% simple cycle efficiency. It takes only ten minutes to achieve full power, with total combined cycle start times of 23 minutes.

The turbine can be turned down to less than 30% of load and maintain emissions compliance. It can also operate in single-shaft and multi-shift configurations.

Among the improvements to the latest HA version are new titanium R1 compressor blades, a 14-stage compressor, a DLN 2.6+ combustor, a two-piece turbine shell, squealer tips on airfoils to reduce tip stress and the elimination of shims in the compressor.

All hydraulics have been replaced by electronic systems, including inlet guide vanes (IGV) and variable stator vanes (VSV).

"It is now possible to carry out a rotor blade changeout in the field," said McHugh. "The new 7HA can achieve lower NOx at higher temperatures and has an improved turndown capability."

## Lessons Learned

The turbine has undergone successful full-speed, full-load testing in Greenville, SC and is monitored through GE's fleet leader inspections. Lessons learned led to several changes.

Number 2 bearing alignment was improved. The VSV torque shaft and IGV actuator mount were also upgraded, as well as a new combustor seal design, more effective cooling holes added to the Stage 1 Nozzles and a heavier damper pin was added to the Stage 1 buckets.

"We noticed an oxidation issue with a single blade component and are proactively replacing them across the fleet," said McHugh.

The 7HA now has combined cycle efficiency of 62% to 63%. McHugh said 9HA.02 upgrades are aimed at taking efficiency close to 64% via micro channel cooling, advanced sealing, new thermal barrier coatings, ceramic matrix composites, and additive manufacturing parts.

"3D printing has opened the door to parts with cooling microchannels that could never be cast or forged before," said McHugh. "3D printing has helped to reduce costs, speed development and produce more sophisticated parts that are more durable and lighter."

## Advanced frame roundtable

Olaf Barth, Engineer for Combustion Turbine Operations at Dominion Generation, led the advanced frame roundtable. He introduced Francisco Dovali-Solis, Service Frame Owner H-class for Siemens Gas and Power, for a presentation on the Siemens SGT-8000H Class gas turbines.

Francisco Dovali-Solis of Siemens

With a fleet of over 70 GTs in commercial operation, it has accumulated over one million operating hours since the first unit entered service in 2011. Some 70 units are currently in operation (12 being dual fuel) and another 20 under contract.

The 50 Hz and 60 Hz models use the same combustion system but there are more cans on the 50 Hz version. The rotor can be easily de-stacked on site due to it having a segmented disc assembly with Hirth serration and a central tie rod. Variable IGVs and three stages of variable pitch guide vanes on the compressor provide improved part load efficient.

"All rotating compressor blades can be replaced without de-stacking," said Dovali-Solis. "The turbine has active clearance control with hydraulic clearance optimization for reduced degradation and clearance losses."

The SGT-8000H class has a can annular combustor. It has a high-cycling capability due to a fully internally air-cooled turbine section. Overall, it has been designed to have fewer scheduled outages.

All turbine vanes and blades can be replaced without rotor lift. Stage 1 (vane, ring segment and blade) and blade 4 can be replaced without cover lift. To date, 61% combined cycle efficiency has been demonstrated on multiple units.

For example, on the 60 Hz SGT6-8000H startup can be done at up to 30 MW/minute. All units can provide frequency response and grid support.

The package sits high in the center line and has service lifting devices to facilitate maintenance of heavy components. The original 60 Hz version could generate 274 MW. Now, it can produce up to 310 MW. The latest 50Hz SGT5-8000H unit is capable of 450 MW (at ISO conditions).

"Performance increases were attained through small increases in the turbine inlet temperature, compressor mass flow, and combustion cooling air optimization," said Dovali-Solis.

The 60 Hz fleet has recorded 94.3% availability and 99.8% reliability. Configurations vary from 3 × 1 to 2 × 1 and single shaft, depending on customer and utility preference.

## M501J fleet

Barth said that Dominion Generation has several M501J units from Mitsubishi Hitachi Power Systems (MHPS) and all are doing fine. He introduced Yoshifumi Tsuji, Senior Manager of GT Engineering at MHPS to discuss overall fleet status.

Yoshifumi Tsuji of MHPS

There are 29 MHPS J-class turbines in operation with the JAC being the newest. The F-class achieved a TIT of F 1,400°C, the G-class reached 1,500°C, the J-class 1600°C and the JAC is targeting 1,700°C.

"Long-term operation is required to understand component behavior, TBCs and oxidation to achieve durability," said Tsuji. "Simulations won't find situations such as spallation of the TBC on a blade or oxidation of hot spots; field experience is required."

In the J-class, Tsuji said long-term operation at the T-Point facility in Japan led to a design change that eliminated a film hole at one spot to change convective cooling at that point.

Since its introduction in 2011, the MHPS J-class has almost 800,000 hours of operation. 57 have been sold, 39 are in service, and 28 have exceed 8,000 hours. Reliability sits at 99.5%.

The J-class is steam cooled, but the newer JAC has an air-cooled combustion system, as well as thicker TBCs and a directionally solidified last blade with larger flow area.

The compressor has a slightly increased inlet flow, a 15-stage design and a 25:1 pressure ratio. This harks back to the stable M501H design that has been around for 20 years.

"High speed balancing of the JAC been done and it is about to ship to a new T-Point plant for testing," said Tsuji.

He believes 65% efficiency is achievable in the near future. 3D printed parts will play a part in this as well as dual nozzles with an expanded heat insulating layer downstream which improves reliability.

Next spring's CTOTF will be held in Louisville, Kentucky in late March, 2020. For more information, visit CTOTF.com or org. ■


Figure 1. Compressor noise testing with no acoustic blanketing (left) and with acoustic blanketing (right)

# MEASURING MACHINERY NOISE

## EVALUATION OF ACOUSTIC BLANKETING TO MITIGATE COMPRESSOR NOISE

BY MARK PECHULIS

Exposure to potentially damaging machinery noise is an everyday risk for millions of factory workers. The U.S. Occupational Safety and Health Administration (OSHA) estimates that companies pay out more than $242 million each year in worker's compensation claims due to hearing loss.

Centrifugal compressors in refineries, petrochemical plants, liquefied gas services, and other industrial applications can be a major source of noise in plant operations. As a result, they are subject to noise standards established and regulated by OSHA to protect workers from exposure to elevated noise levels that can lead to hearing loss over time.

To meet OSHA noise standards, operators are required to manage plant noise levels for worker safety and comfort, and for environmental compliance in the communities where they operate. Plant operators rely on the manufacturer's estimated noise ratings to determine a unit's contribution to overall plant noise, and they require manufacturers to meet certain noise level guarantees.

Identifying and mitigating compressor noise is a complex process that can be addressed either through design engineering or by reducing noise from an already installed unit. For that purpose, manufacturers have developed noise-prediction tools to help determine the most cost-effective noise reduction methods.

Elliott began collecting noise data from its rotating equipment in the 1970s and initiated a noise-prediction program at that time. The program incorporates semi-empirical equations as a function of the operating conditions of the equipment, refined over time with the continuous goal of more accurate predictions. Recently, the company teamed with an acoustical consultant from Frank & Faibusch Strategies of Whitefish, Montana, on a two-phase project to validate noise prediction algorithms and testing methods and evaluate upgraded acoustic blanketing on compressors. Phase 1 included shop testing of a compressor and evaluation of acoustic blanketing (Figure 1). Phase 2, which includes field testing and acoustic blanket improvements and optimizations, will be completed in 2020.

During Phase 1, noise data from a large, back-to-back, two-section Elliott 70M compressor was collected during shop performance loop testing. Due to a high degree of background noise from untreated compressor and throttling valve

piping, and reverberant reflections from the shop floor, the background noise level exceeded the compressor's noise contribution by well over 10 dBA, the limit for sound intensity method.

As accurate sound pressure level or sound power measurements were not possible under those conditions, the test team constructed a large, relatively lightweight acoustical test enclosure sealed against the side of the compressor to isolate the background noise from the shop floor. The enclosure featured custom-fit acoustic blanketing on the internal frame.

The Phase 1 test team used three test methods to collect and compare noise data (Figure 2). In the first test, they used a sound-intensity probe with two microphones to scan equipment surfaces and record emitted noise.

For the second test, they used an acoustical pipe box with a single microphone inside to isolate machinery surface noise from outside contaminating noise. For the third test, the team used a soundtube to confirm the accuracy of the other test measurements. The soundtube consists of a microphone inside a Plexiglas tube sealed against a surface and with sound-absorbing material.

Phase 1 testing was performed with and without removable acoustic blankets on the compressor, and the insertion loss was determined for the acoustic blankets at different locations on the compressor casing (Figure 3).

Acoustic blankets on the main compressor casing, which were not actually required for the application, showed a nearly 20-dBA reduction for predominant impeller blade passing frequency components. Tests on the bearing housings and casing pedestals showed that blankets were not needed in this case, but in other situations, would further aid in meeting noise specifications.

**Figure 2. Noise measurement team collecting the sound intensity data inside sealed enclosure on the compressor casing**

Execution of Phase 1 testing was a first step toward more accurate prediction of equipment noise and improved confidence in noise guarantees. However, noise levels from turbomachinery have the potential to exceed site requirements, even with attenuating treatments, such as acoustic blanketing. To address this issue, Phase 2 of the noise prediction test will use data collected at design conditions to improve and optimize noise attenuation options.

Phase 2 testing has two main goals. The first is to review, evaluate, and optimize acoustic blanket treatment alternatives, and to develop an acoustic blanket application database to meet different design requirements.

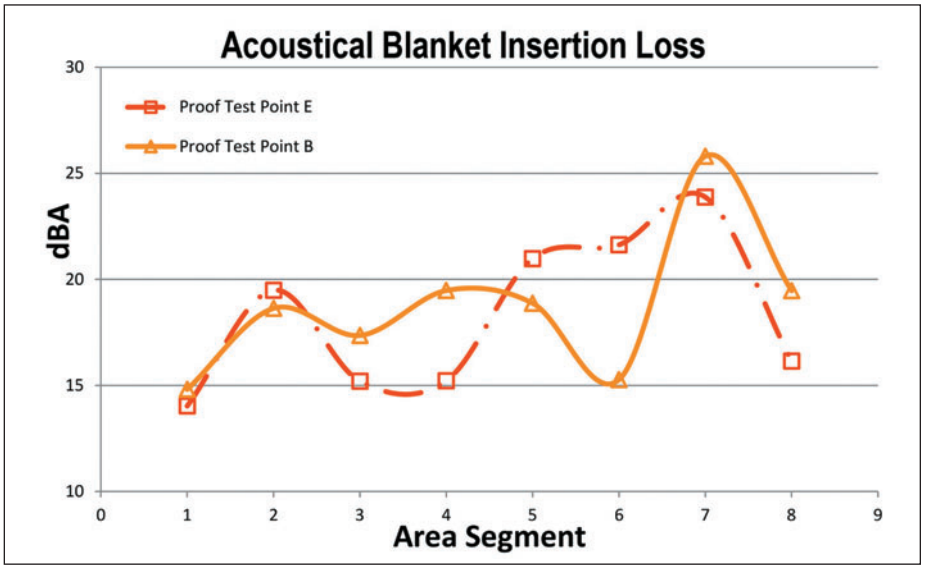



**Figure 3. Acoustic blanket insertion losses at locations on the compressor casing**

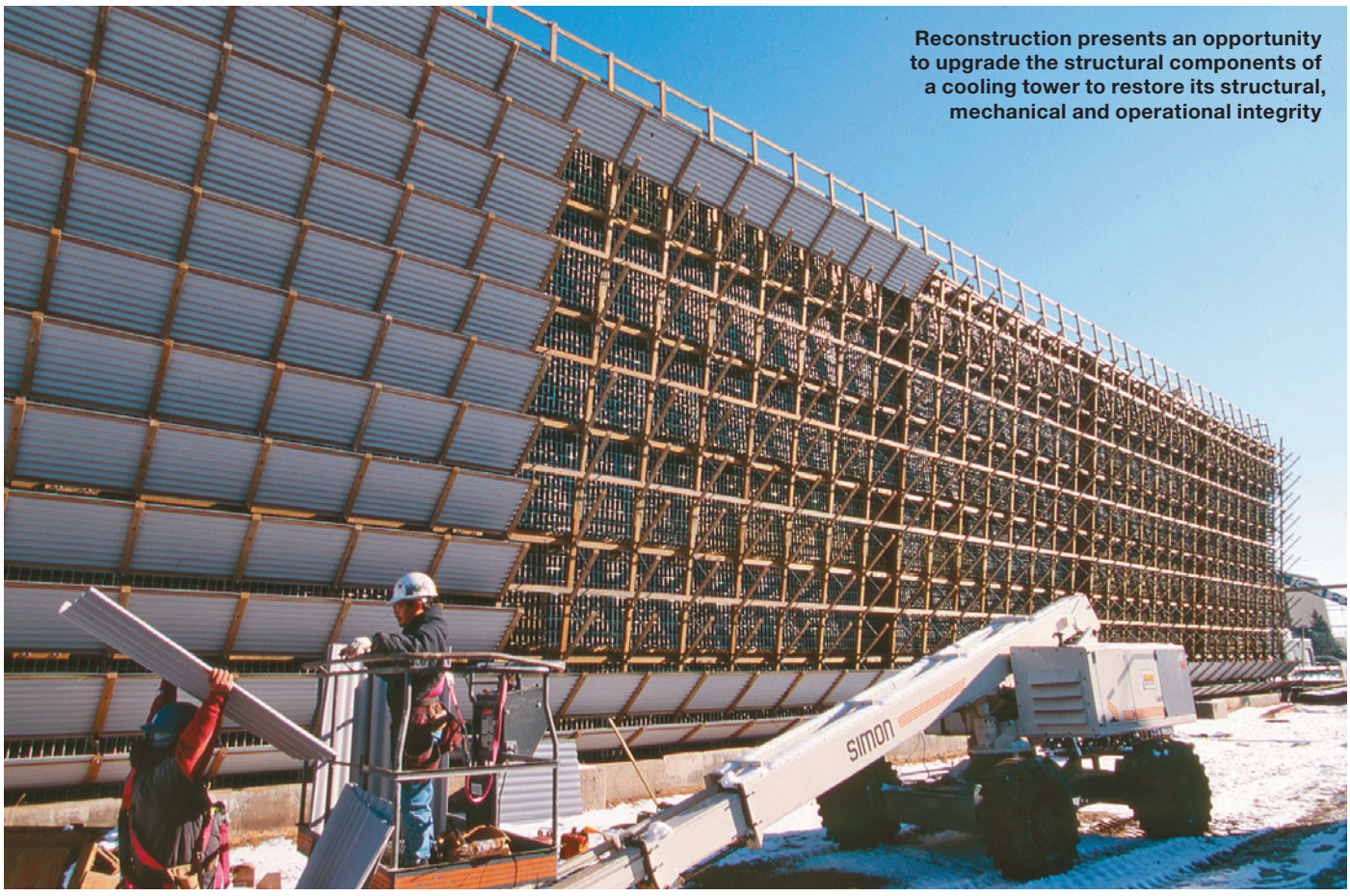
This information will provide more options when trying to meet noise requirements. Phase 2 testing will evaluate whether enhancements to certain areas of the blanketed coverage will reduce overall noise more than the current blanketing configuration. This will include a review of existing data and measurements from Phase 1 testing.

The second goal of Phase 2 testing includes collection of field noise data from the same 70M compressor tested during Phase 1, with installation and commissioning in 2020. The customer plans to treat surrounding piping and equipment acoustically to reduce noise emissions.

The test team will take noise measurements with and without acoustical blankets, as well as test the enhanced blanket configuration. Background noise should be low enough to use the noise-measuring instruments without the need for an acoustic noise enclosure.

Completion of Phase 2 testing will update and validate the noise prediction algorithms with the latest equipment acoustic data, and improve noise attenuation options to better meet stringent customer requirements for reduced equipment noise and accurate noise level guarantees. ■

***Mark Pechulis, a Research and Development Engineer at Elliott Group, Jeannette, PA. Elliott's lead accoustic engineer, now Frank Kushner Consulting, first established its noise prediction program in the 1970s.***




Reconstruction presents an opportunity to upgrade the structural components of a cooling tower to restore its structural, mechanical and operational integrity

# HOW TO RECONSTRUCT A COOLING TOWER

## THE THERMAL PERFORMANCE AND STRUCTURAL INTEGRITY OF AGING COOLING TOWERS CAN BE RESTORED

**BY ED SHUPERT**

Cooling towers play an important role in modern power plants. But there comes a time when aging cooling towers require more than routine maintenance and repairs or replacement of components, such as heat transfer media. Thermal performance can fall and structural integrity can become a major issue. It is time for a reconstruction project.

A Job Safety Analysis (JSA) is a recommended first-step before accessing the cooling tower. The JSA should address inherent dangers such as high voltage, fall hazards and trip hazards, and define appropriate mitigation efforts, such as lockout and tagout, personal protective equipment and fall protection.

Another smart early step is a performance test. This gives the plant operator a starting point to establish goals for capacity improvement, as well as a reference point for evaluating the final results.

The Cooling Technology Institute (CTI) has a published thermal test code, ATC-105, by which the performance accuracy can be determined. Specialized instrumentation is required to determine precise water flow rates, air rates and temperatures. Some vendors may offer this and outside agencies can also assist.

The scope of work should be developed based on a thorough inspection to identify:

- Deterioration of cooling tower structural elements
- Fill media clogging or damage
- Condition of drift eliminators and louvers
- Water distribution system — missing nozzles or leaking pipes
- Wear and corrosion of mechanical components
- Ladders and guardrail deterioration.

If a cooling tower's fill is clogged or damaged beyond repair, there may be an opportunity to replace it with higher per-

forming fill. A common reconstruction project where additional cooling capacity is sought involves replacing the original splash fill with PVC film fill (where water quality allows). In other cases, where the integrity of fill is sufficient and additional thermal performance is not sought, simply cleaning the fill may meet project goals.

Replacing wood with fiberglass reinforced plastic (FRP) is a way to increase tower lifespan. A coal-powered baseload plant, for example, replaced wooden elements, such as the hot water deck, deck supports, walkways, crossflow pipe saddle supports and structural splice plates with FRP. It also changed a carbon steel riser support beam to stainless steel.

After reconstruction is complete, a maintenance plan should be created for the cooling tower. At a minimum, every cell of the tower should receive an annual inspection of gearboxes, gearbox oil and seals, driveshafts, distribution water basins, fan cylinders, fans, fan tip clearance and pitch, fill, distribution piping and nozzles, ladders and other safety components. ■

**Any reconstruction effort should begin with an inspection of the cooling tower by an experienced cooling tower service provider. The scope of work should be defined by their findings and recommendations.**

*Ed Shupert is Manager of Reconstruction Project Management at SPX Cooling Technologies. SPX Cooling Technologies is a global manufacturer of cooling towers, providing full-service cooling solutions, components and technical support for power generation, petrochemical and industrial applications for nearly a century. For more information, please visit www.spxcooling.com.*

## AD INDEX

# TURBOMACHINERY BEARINGS AND SEALS

*Mark Hinckley, Director of Strategic Projects at SKF USA, discusses trends in the marketplace as well as the latest bearings, seals and monitoring services available.*

## Tell our readers briefly about SKF.

SKF is a global supplier of bearings, seals, mechatronics, lubrication systems and services which include technical support, maintenance and reliability services, engineering consulting and training.

SKF continuously develops new technologies, enabling customers to use them to create products that deliver rotating equipment performance that offers a competitive advantage. Our company is represented in more than 130 countries and has around 17,000 distributor locations.

## What products do you produce for the turbomachinery marketplace?

The company is best known for high-performance, rolling element bearings, which include bearings with special steels and heat treatments. SKF also manufactures bearings and seals with materials and coatings for pumps, compressors and other turbomachinery in aggressive environments.

We also provide seals, lubrication systems and monitoring equipment. Additionally, new centrifugal compressor designs take advantage of efficiency gains from higher speed, non-contacting rotation. Magnetic bearings paired with high-speed motors, therefore, have become increasingly prevalent and SKF is a leading supplier of magnetic bearing technology.

## What recent product would you like to feature?

SKF high-nitrogen stainless steel hybrid bearings have rolling elements made from bearing-grade silicon nitride and a glass fiber reinforced polyetheretherketone (PEEK) cage. It greatly improves performance, enabling bearings to run longer than conventional hybrid bearings, particularly in harsh conditions like those found when handling sour gas ($H_2S$).

## What trends have you observed?

We have noticed several evolving trends. Speeds are increasing to take advantage of improvements in centrifugal compression efficiency. The operation of compressors in aggressive environments that would kill traditional bearings is also becoming commonplace due to the use of magnetic bearings. As there is no contact, the bearings can operate even when exposed to harsh conditions.

In addition, we're seeing an increase in high nitrogen stainless steel hybrid bearings that extend the life of a machine compared to traditional rolling element (RE) bearings. Since these bearings are manufactured to the same dimensions as traditional RE bearings, it can be a relatively straight forward upgrade for applications suffering from failures due to an aggressive operating environment.

## What trends have you observed related to seals?

There is a never-ending push to optimize the life and performance of seals. Smaller packaging, longer life and lower friction are all important elements. Magnetic bearings that don't require seals to keep lubrication in can be designed to operate where they are exposed to the process gas without degrading the bearing or its performance. Tight air gaps and seals can still be used to optimize fluid dynamic efficiency by isolating the process and the more effective the sealing of the compressed fluid.

Further SKF's Kaydon rings and seals serve demanding applications in the oil and gas, aircraft, aerospace and other industries. This includes dry gas shaft seals, mechanical seals, aircraft gas turbine engine carbon seals, critical sealing rings, diesel engine piston rings and natural gas engine power piston rings.

## What trends have you observed on condition monitoring?

Condition monitoring solutions for turbomachinery are becoming more compact and powerful. For example, the SKF IMX8 Multilog Condition Monitoring System provides early fault detection, prevention, automatic advice and advanced maintenance for improved reliability and performance. It offers eight-channel health monitoring and is internet-enabled for remote access. It provides up to 16 channels per device for early fault detection and prevention.

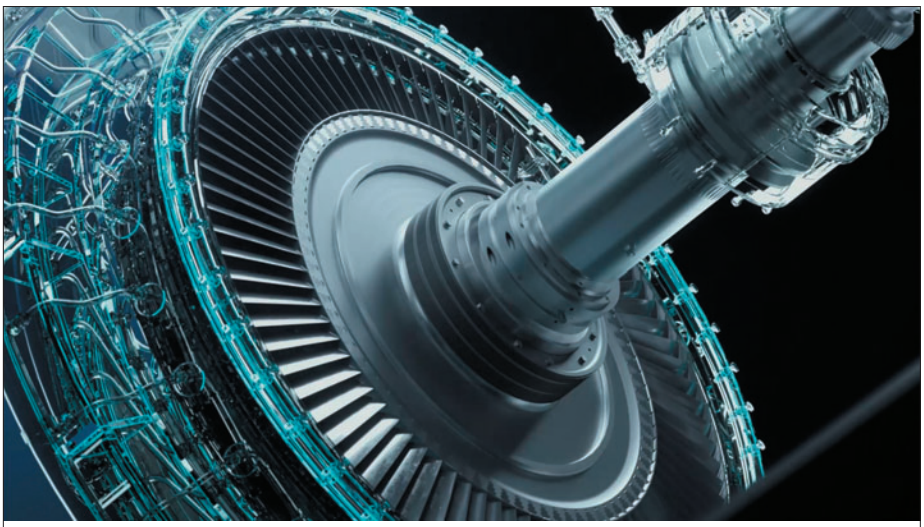
In addition, magnetic bearings can be a game changer in this arena. As part of the normal operation of a magnetic bearing, a tremendous amount of data is processed regarding machine operation. This data can provide insight into how the process is performing, not only the condition of the rotating equipment.

## How are AMBs doing in the marketplace?

Active Magnetic Bearings (AMBs) are growing in acceptance and use. In areas like HVAC, end users are moving from having a preference to an insistence upon magnetic bearings. Their price point, paired with higher levels of functionality and feedback, are appealing to a broader audience. In applications such as water-cooled chillers, magnetic bearings are now part of the standard offering.

Magnetic bearings are deployed with success in a wide range of applications. One example is the Åsgard Subsea Gas Compression facility. Our lubrication-free magnetic bearings were chosen for their strength, reliability and compactness with zero-maintenance requirements.

These bearings have been operating problem free with ~100% availability since they were installed in September of 2015. The two 11 MW compressors have more than 60,000 accumulated hours since installation. Magnetic bearing technology has also been installed and tested in over 115 naval applications, including nuclear submarines. ■



Siemens RT61 and 62 upgrades are now available for older RB211 turbines

## SGT-A35 upgrades

The Siemens SGT-A35 (formerly Industrial RB211) has two variants of free power turbines — the RT61 and RT62. They are close-coupled to the rear of the gas generator. Siemens recently introduced two enhancements, coined RT61X and RT62X that offer increased throughput, lower fuel consumption and fewer overhauls over the product lifecycle.

The RT61X upgrade doubles the meantime between overhauls from the original RT61 (now 100,000 hours). The RT62X upgrade offers up to an 8% increase in power output and up to a 1% increase in cycle efficiency compared to the original RT62.

The RT62X turbine improvements introduce several aerodynamic design features on first- and second-stage blades and vanes and a new shroud design. The time between overhauls for the RT62X is 132,000 hours compared with 100,000 hours for the original RT62. It is recommended that these upgrades be installed in conjunction with a scheduled overhaul.

*Siemens.com*

## TMEIC enclosure

TMEIC announced the latest enhancement in drive and thermal management technology. The TMdrive-Guardian is an outdoor enclosure for the MV Drives. The standalone enclosure eliminates the need to house the drive in a temperature-controlled industrial building or E-house.

It is designed to simplify installation and eliminate the cost of running and maintaining a cooling system to ensure proper VFD operating temperatures. The enclosure enhances the TMdrive-MVe2, delivering more ease of use and value to operators.

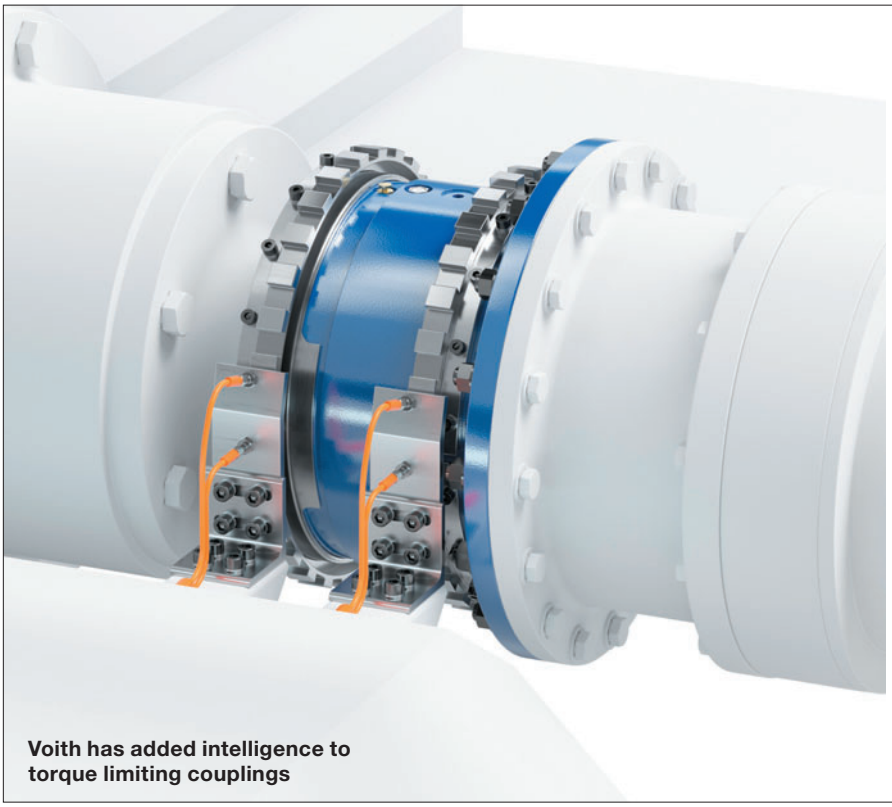
Introduced in 2014, the drive supports medium-voltage motors without the need for an output transformer and provides variable reactive power compensation for voltage support and line-side power factor correction.

*TMEIC.com*

## Smart probe

Vaisala HMP9 incorporates measurement accuracy and rapid thermal response time in a compact package. It weighs a few grams and the probe head is 5 mm of diameter. The low thermal mass of the probe offers better response time compared to other capacitive humidity measurement products.

The HMP9 is optimized for dryers, air-handling units, test chambers or other systems and processes where measuring humidity can make a difference in saving energy or improving the product or the process. It is designed for applications at



Voith has added intelligence to torque limiting couplings

## Voith coupling monitor

Voith introduces Dtect, its intelligent monitoring system that provides real-time data of driveline performance and coupling status. Based on this, the operator can take actions to prevent potential problems and avoid unplanned downtime.

Dtect helps to increase productivity as well as lower production and maintenance costs. It enables monitoring of a driveline's torque limiting couplings. Dtect was designed to work with couplings, such as Voith's SmartSet, which serve to prevent machine damage in high-value rotating equipment. It is also possible to upgrade existing couplings with this intelligent system.

Through continuous measurement of the slip angle, Dtect identifies and monitors coupling slippage caused by high-torque peaks in a driveline. It collects driveline performance data that can be analyzed to improve productivity. It uses an updated quadruple sensor setup that increases the sensing range without affecting the resolution of the expanded measurement. It is also possible to monitor multiple couplings at the same time.

*Voith.com*

temperatures below 120°C (248°F) that do not involve high pressure. The smart probe also provides measurements of parameters, such as dew point temperature, wet-bulb temperature, absolute humidity, mixing ratio, water concentration, water vapor pressure and enthalpy.
*Vaisala.com*

## ORC-GT hybrid

The Siemens Heat ReCycle solution is comprised of a GT power plant from Siemens with Organic Rankine Cycle technology (ORC) from Turboden. This provides efficient recovery of waste heat. Heat ReCycle allows remote areas to be provided with reliable power generation. It is water-free.
*siemens.com/heatrecycle*

## Data acquisition

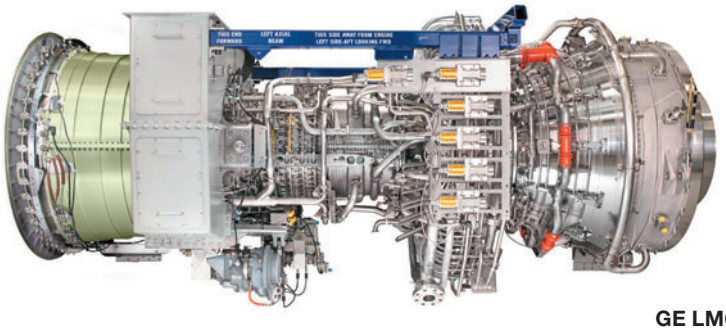
Kistler introduced measurement technology known as the KiDAQ data acquisition system. KiDAQ provides users with high fidelity measurements as standalone DAQ and optionally the complete measuring chain from sensor to cloud.

KiDAQ automatically calculates measurement uncertainty. It is modularly designed and can be configured to suit requirements or applications. Depending on the application sector, measurement technicians and engineers can choose from a range of versions.
*kistler.com/kidaq*

## New heat engine

SoftInWay and GTI announce a new kind of heat engine concept with the potential to achieve greater than 65% net electrical or mechanical power-conversion efficiency and provide low pollutant emissions at a competitive cost. In this DOE-funded project led by GTI, the partners are working together to further the sustainable use of fossil energy (FE) resources and reduce the risk and cost of advanced technologies.

The basic concept is a sub-atmospheric modular hybrid heat engine (MHHE) for FE applications. SoftInWay's engineers performed thermodynamic cycle simulations to determine MHHE's operating regimes. In addition, they designed the compressor and the turbine for low pressure and sub-atmospheric configurations and refined the integrated MHHE layout.
*Softinway.com*



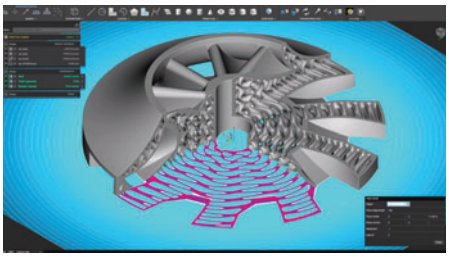
GE LM6000

## New LM package

There have been over 1,300 LM6000 units produced since the first ones appeared in the early nineties. To keep them operating efficiently, upgrades are needed. WattStock offers a refurbished LM6000 package in partnership with GE. Wattstock delivers refurbished LM-series units that are warranted as new units by GE and WattStock. These refurbished packages are called GE TRUEpackage turbines.

Replacing an existing GE Frame 5 GTG and auxiliaries with a GE LM6000 hot end drive can be achieved within 30 days with the rest of the plant still in operation. This can boost output by 25 MW. The TRUEpackage configuration includes a variety of elements including: a new LM6000 PF engine, an LM5000 to LM6000 conversion kit, a new turbine control panel and power control module, new batteries, a new operator interface, quick disconnect connections, pressurized access doors and pressurized HVAC with special filtration.

As GE's subcontractor, WattStock's responsibilities include: demolition of the Frame 5 and the installation of the LM6000 package; converting and refurbishing the LM5000 package to install the LM6000 PF engine; replacing the LM5000 52 MVA generator with a 68 MVA generator; conversion from air-cooled to a Totally Enclosed Water to Air Cooled(TEWAC) generator; refurbishing and testing the 68 mVA generator; replacing the exhaust transition piece with the LM6000 transition piece; a static test on the refurbished package; and supervision of the EPC subcontractor as well as installation and testing of the LM6000 package.
*Wattstock.com*



nTopology software for turbomachinery design

## Design software

Software company nTopology has commercially released its unified nTop platform for integrated product design, analysis and manufacture. It uses modeling and field-based design for rapid product development.

The nTop platform enhances automation and enables the creation and production of complex products. This includes 3D printed components. Design teams can use the platform to simultaneously evaluate and modify product concepts to quickly arrive at optimized designs. In addition, engineers can create lightweight parts with multifunctional requirements built in.
*Ntopology.com*

## Simulation software

Increased demand for pumps, fans, turbines and compressors has turbomachinery companies assessing ways to reduce the cost and time it takes to design better products. Rand Simulation (Rand SIM) is a division of Rand Worldwide that provides Ansys software and consulting services, Computational Fluid Dynamics (CFD), Finite Element Analysis (FEA) and Electromagnetic Simulation (EMAG). It has launched new capabilities to help manufacturers leverage simulation to drive innovation.

Rand SIM tools help turbomachinery companies via simulation technology discover potential problem areas with designs, and identify and test a variety of alternative solutions. The result is a design ready for prototyping with reduced costs. This includes proof of concept, problem detection, baseline comparison and benefit quantification.
*Randsim.com*

## Non-destructive testing

The quality inspection of products and processes is time consuming and expensive. The German Fraunhofer Institute for Digital Media Technology (IDMT) has developed a solution for acoustic quality inspection. It allows contact-free, non-destructive testing of manufactured parts and components. The method is currently being tested by industrial partners.
*idmt.fraunhofer.de* ■

# MYTH: GAS TURBINE BLADES ARE VULNERABLE

Many people who operate or otherwise work with gas turbines (GTs) are in awe about the extraordinarily harsh environment in which compressor and turbine blades operate. Yet these blades prove to be incredibly sturdy and reliable.

Just to put things in perspective: A single turbine blade, only a few inches in height and width, mounted in a 30,000 hp GT produces about 500 hp of power. It achieves that while operating at a pressure that's the equivalent to being 700 ft underwater at the temperature of hot molten lava while running at speeds of more than 10,000 rpm. And we expect these blades to survive this ordeal for tens of thousands of operating hours.

Design trial and error methods are a thing of the past. Combining computational fluid dynamics and heat transfer calculations allows for the precise determination of local blade pressures and temperatures.

From this, stress levels, vibration modes and vibration frequencies can be predicted precisely. Moreover, it is sometimes possible to measure the blade temperatures, or blade vibrations and stresses in the running engines.

New and exciting methods have been developed to accomplish this, like measuring blade surface temperatures with irradiated silicon carbide crystals, or non-intrusive stress measurement systems that use laser sensors to determine blade vibration behavior in an operating development engine.

Real-time modal response of the rotor is evaluated using laser sensors, and the stress level is measured for each blade in situ. Modern engineering analysis and design methods have undoubtedly improved the reliability and availability of the internal parts of the GT.

Yet turbine and compressor blades do sometimes fail and are destroyed: The failure modes and mechanics are often related to constituents in the fuel or the combustion air that can damage the engine. The most important ones are:

- Corrosion is the wearing away of surface metals due to a chemical reaction of the metal with the environment
- Oxidation is the chemical reaction between a component and the oxygen in its surrounding gaseous environment. The oxidation rate increases with temperature
- Hot corrosion, also called high-temperature corrosion, requires the interaction of the metal surface with another chemical substance at elevated temperatures. It is a form of accelerated oxidation that is produced by the chemical reaction between a component and molten salts deposited on its surface.

The molten salts can form if sulfur and sodium or potassium participate in the combustion process. Sulfur, sodium and potassium can enter the engine via the fuel or combustion air. It is important to recognize that corrosion processes are sometimes self-propagating and can continue even if the source is removed or abated.

**"A single turbine blade operates at a pressure that's the equivalent to being 700 ft underwater at the temperature of hot molten lava while running at speeds of more than 10,000 rpm."**

Consequently, GT materials need to be protected from the harsh service atmosphere by special material selection and coatings. Advanced high-nickel super alloys are used to make blades. Manufactures have successfully employed coatings in GTs to combat oxidation, corrosion, and erosion, and as thermal barriers.

Some coatings and pre-coated parts can even be added during routine maintenance, if economically and technically warranted. The use of coated parts, however, does not remove the requirement for good inlet air filtration.

Erosion usually requires relatively large particles, exceeding five microns in size, or liquid droplets to hit the blades, and is typically only a problem when the GT's air filtration system is damaged or inadequate, or if poorly designed inlet cooling moisture fog systems create large droplets.

High-cycle fatigue can be another failure mode. It is often tied to other component problems, such as damaged variable vanes, combustor instabilities or clogged fuel injectors. The resulting flow non-uniformities create high, cyclic forces for the subsequent rotating blades.

Another cause can be undetected blade-wake interactions that excite natural blade frequencies. Modern design methods, as described above, can prevent the latter issues, while the former are usually the result of damage to other engine parts, which can be detected by appropriate condition monitoring systems.

Fundamentally, all metals have fatigue limits that are a direct function of the combination of applied cyclic and steady loads. Any mechanical high frequency, high-amplitude excitation source, such as unsteady aerodynamics, vibrations, and even thermal cycling, can result in metal fatigue failures in a GT.

The creep life of blades and disks is determined by the exposure to high-temperature gases. It is one of the critical limiting factors in the engine life cycle and is well understood in the design process of the engine.

However, exposure of components to temperatures higher than their design temperature will reduce the creep life of the component and may require premature engine overhauls.

Yes, it is a dangerous world for blades. Yet the reliability and availability of GTs have significantly increased over the years as failure mechanisms are better understood, prediction and test methods have improved, and conditions monitoring provides valuable indications to identify problems before they lead to failure. ■

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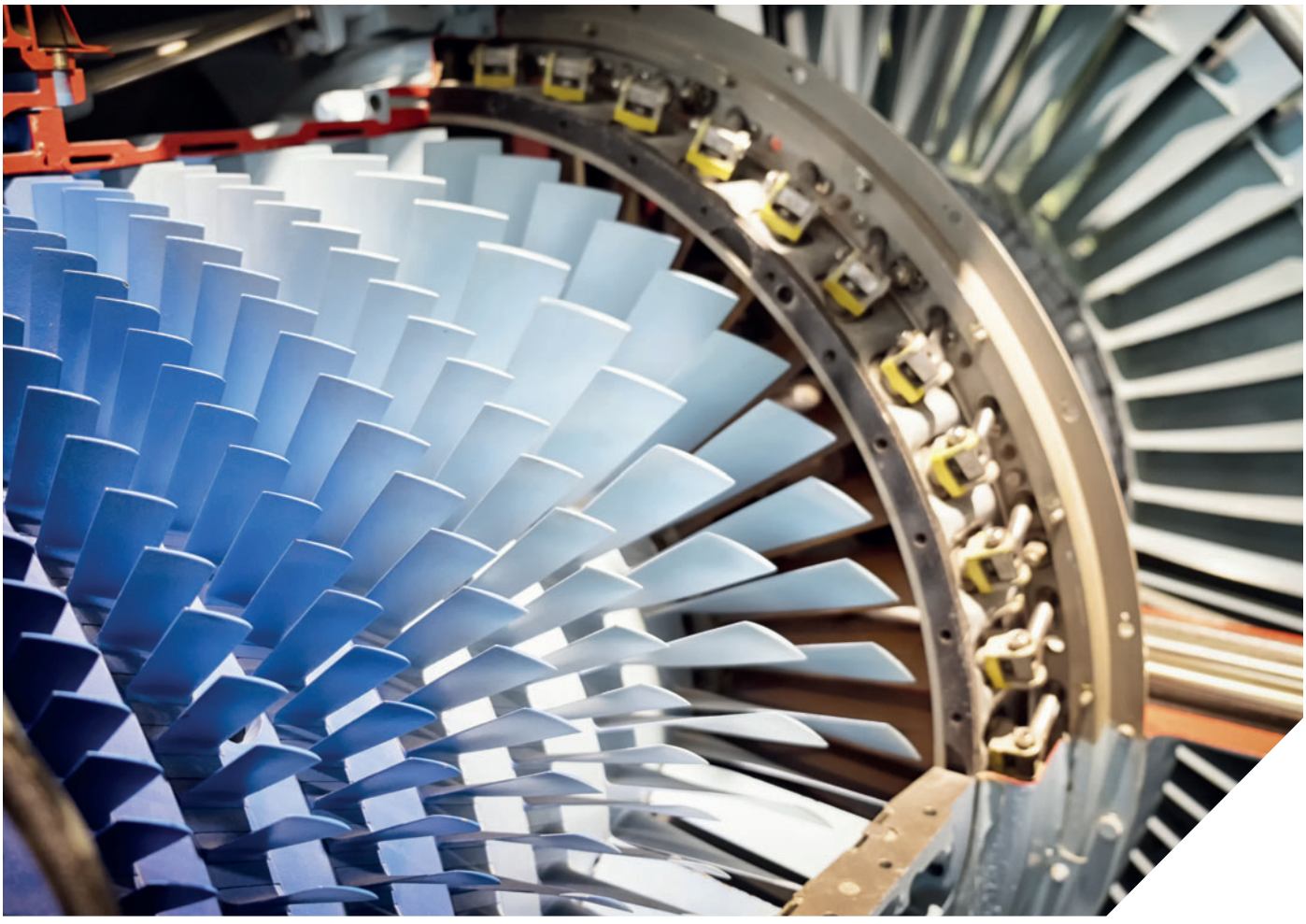
***Klaus Brun is the Director of R&D at Elliott Group. He is also the past Chair of the Board of Directors of the ASME International Gas Turbine Institute and the IGTI Oil & Gas applications committee.***

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

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



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