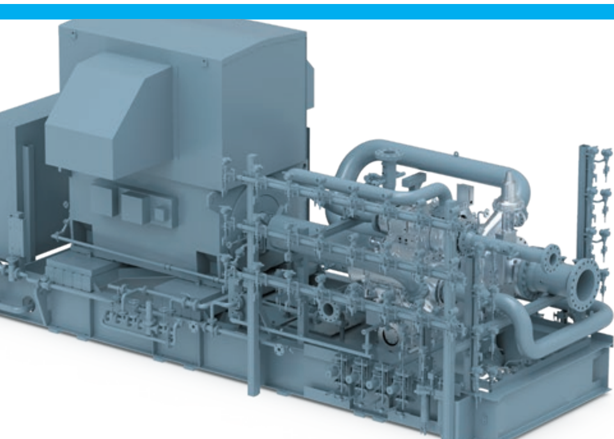
THE GLOBAL JOURNAL OF ENERGY EQUIPMENT

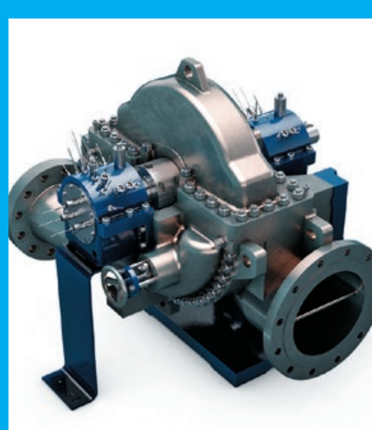
INTERNATIONAL Turbomachinery

NOVEMBER/DECEMBER 2019 • VOL. 60 NO. 7 • $7.50

turbomachinerymag.com




NEW PRODUCTS DOMINATE THE TURBO SYMPOSIUM


Also in this issue:

Turbines • Auxiliaries & Components • Compressors
Maintenance & Repair • Software & Controls • HRSGs
Condition Monitoring • Turboexpanders • Oil & Gas

Features

CONNECT WITH US:

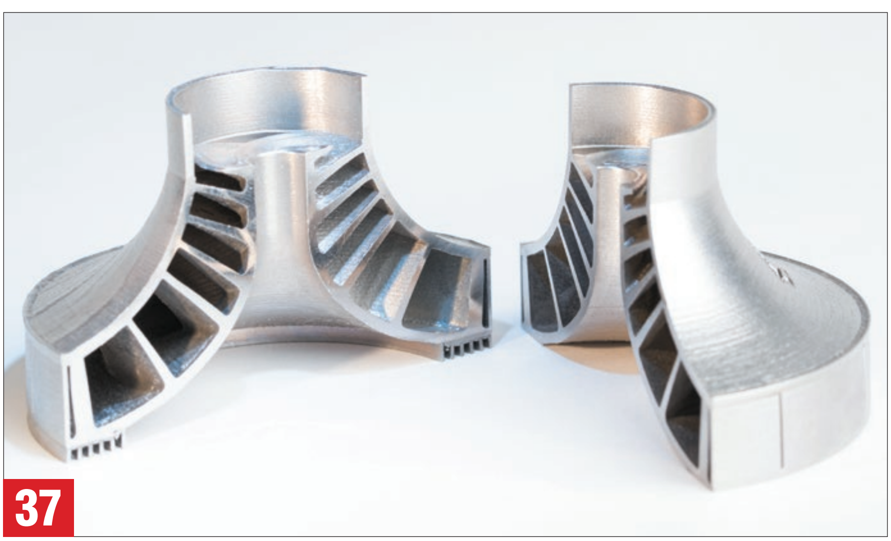
www.turbomachinerymag.com
www.turbohandbook.com
RZanetti@mmhgroup.com
ARobb@mmhgroup.com

Cover images: Atlas Copco BOG compressor, Doosan DGT6-300H GT, Bently Nevada Orbit 60, MAN ES MGT6000 GT, Howden MONO CBA ST, Oerlikon HVOF coating

Departments

8

8 INDUSTRY NEWS



37

37 NEW PRODUCTS

COLUMNS


PEOPLE
INNOVATION
WORLDWIDE
EFFICIENCY
TOGETHER

INTERNATIONAL
Turbomachinery
turbomachinerymag.com

ESTABLISHED IN 1959

Founders
G. Renfrew Brighton and R. Tom Sawyer

Publisher
Richard Zanetti, 203-523-7053
RZanetti@mmhgroup.com

Editor-in-Chief
Drew Robb, 323-317-5255
ARobb@mmhgroup.com

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

Handbook Editor
Bob Maraczi, 203-523-7040
RMaraczi@mmhgroup.com

Senior Director—Digital Media
Michael Kushner, 732-346-3028
MKushner@mmhgroup.com

Executive Correspondents
Klaus Brun, Amin Almasi

Contributing Editor
Mark Axford

Art Director
Steph Bentz, sbentz@hcl.com

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

Circulation
Subscription inquiries: MMHInfo@mmhgroup.com

EDITORIAL & BUSINESS OFFICES

Turbomachinery International
383 Main Avenue, 7th Floor
Norwalk, Connecticut, U.S.A. 06851
Tel: 203-523-7053

Subscription Service
For subscription/circulation inquiries, 888-527-7008.
Outside the U.S. call 218-740-7273,
email to fulfill@hcl.com or send via mail to:
Turbomachinery International, MultiMedia Healthcare LLC, PO Box 6000 Duluth, MN 55806-6000

ADVERTISING

WEST, MIDWEST, SOUTHEAST, SOUTHWEST U.S.A.

Gerry Mayer
5930 Royal Lane Ste E #201
Dallas, TX 75230
Tel: 972-816-3534 Fax: 972-767-4442
gm@mayeradvertising.com

NORTHEAST, MID ATLANTIC U.S.A. CANADA

Richard Zanetti
383 Main Avenue, 7th Floor
Norwalk, Connecticut, U.S.A. 06851
Tel: 203-523-7053
RZanetti@mmhgroup.com

GERMANY, AUSTRIA, SWITZERLAND

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

UK, BENELUX, SCANDINAVIA, ITALY, FRANCE

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

JAPAN

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

INDIA, MIDDLE EAST

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

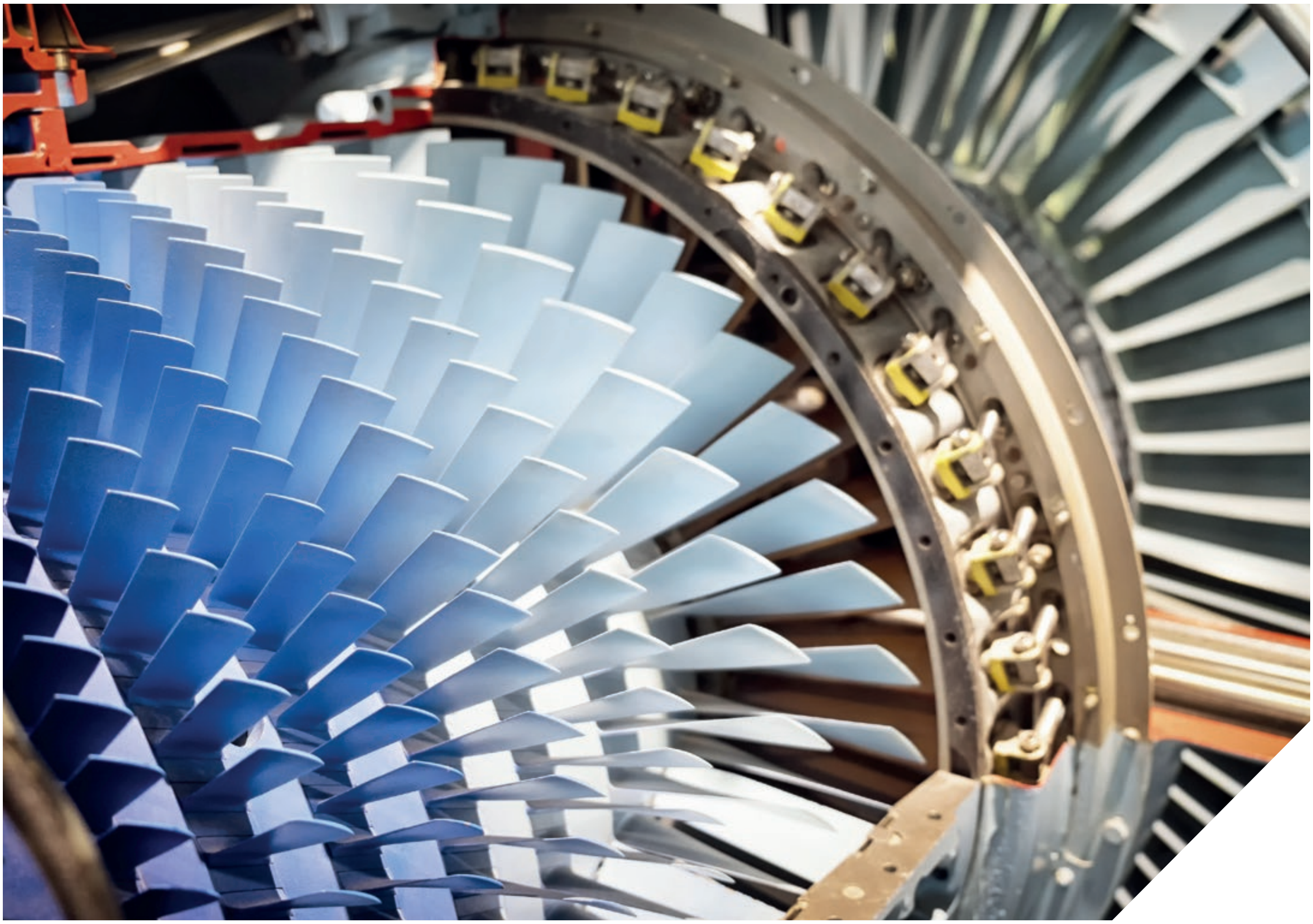
KOREA, SOUTHEAST ASIA

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

american business media

Alliance for Audited Media

Turbomachinery International (USPS 871-500 : ISSN 0149-4147) is published bimonthly, plus an extra issue in October, by MultiMedia Healthcare LLC 325 W 1st St STE 300 Duluth MN 55802.
Periodicals Postage paid in Duluth MN 55806 and at additional mailing offices. POSTMASTER: Please send address changes to Turbomachinery International PO Box 6000 Duluth MN 55806-6000, USA.
Publications Mail Agreement No 40612608. Return Undeliverable Canadian Addresses to: IMEX Global Solutions, PO Box 25542 London ON N6C 6B2.
Canadian G.S.T number: R-124213133RT001. Printed in U.S.A.



Keep it Clean.
Keep it Running.

Today, the advanced 'Hydro' product line repels water, oil, hydrocarbons and salt.

| Reducing compressor fouling and eliminating frequent offline water washing.

| Extending component life and reducing maintenance.

| Increasing machine availability and reducing operational costs.

Contact us today for more information and to discuss our unique pre-filter systems that extend filter life.

Yes, send me more information

+1 502 637 0254 | web@aafintl.com

AAF® INTERNATIONAL
BETTER AIR IS OUR BUSINESS®

GAS TURBINE SOLUTIONS

SIGNS OF HEALTH

There are promising signs around that the gas turbine market may be healthier than some would have us believe. The recent Turbomachinery Symposium in Houston, TX included major turbomachinery releases from several vendors. We are not talking here about an upgraded bolt or a new shim. When was the last time a new steam turbine was released? Howden unveiled one at the show. In addition, Baker Hughes held a press conference about the first new Bently Nevada conditioning monitoring platform in 20 years. GE, meanwhile, has upgraded its HA line of turbines to provide even more power and higher efficiency.

> "We haven't seen this many major new turbomachinery product releases for at least five years.

Not to be outdone, Doosan is taking its time to carefully nurse along a new gas turbine. It will provide 270 MW and the company says testing is 95% complete. And Altas Copco Gas & Process has brought out a high-pressure cryogenic boil off gas compressor. I don't think there's been an issue of the magazine announcing this amount of major turbomachinery product releases in the last five years or more.

And how about the fact that Siemens Gas & Power just invested a fortune to open an innovation center in Florida? The company is hard at work developing 3D printed parts and applying a wealth of other technologies to strengthen the economics of turbomachinery and bring new technology to market.

All of this might have something to do with the fact that the world, and especially the U.S., has an abundance of natural gas at its disposal. Propaganda to the effect that natural gas-based generation is going to largely disappear within a decade should be ignored. The poster-state for this idea, California, has among the highest residential electricity rates in the nation. Simple economics will eventually bring reason back into the equation. Renewables won't be able to cut it on the their on, either in terms of grid stability or the cost of power. They need natural gas to make a renewable-rich grid work.

Good issue

The current issue is full of worthwhile reads. Our report from the Houston event covers many of the new product releases mentioned earlier as well as valuable tips related to mechanical seals, improving turbine performance, optimization of bearings and how to deal with various gas turbine failure mechanisms.

We include, too, features on the Siemens Innovation Center and the new Bently Nevada Orbit 60 platform. On the maintenance and repair side, we have stories about compressor failures due to shim protrusion and liberation, an overview of how heat recovery steam generator operators need to deal with heavy cycling operation, and a column on paying more attention to the steel structures that support turbines.

Additional articles detail how to correctly test high-pressure compressors, how to use turboexpanders in energy recovery, and a Myth Busters column attacking the concept that one size fits all in oil and gas machinery applications.

By the time you read this, we will be attending the PowerGen shows in Paris and New Orleans. If we don't see you there, we wish you a happy holiday season, a merry Christmas and a productive new year. ■

Drew Robb

DREW ROBB
Editor-in-Chief


Flawless execution

MHPS order

Mitsubishi Hitachi Power Systems (MHPS) has received an order for refurbishment of a waste heat recovery boiler in operation at Philippine Associated Smelting and Refining Corporation (PASAR) in the Philippines.

The order calls for renewal of the pressure-resistant components of the boiler, which has been in operation since 1993. The waste heat recovery boiler generates steam from the waste heat produced during the copper smelting process. The steam is largely returned for use in the smelting process and used for in-house power generation.

Ansaldo digest

Taweelah Asia Power Company (TAPCO) has awarded Ansaldo Energia a 10-year structured service agreement for their Taweelah New B Extension (TNBE) combined cycle power plant (CCPP) in Abu Dhabi, United Arab Emirates. TNBE generates upward of 947 MW and 68.4 million imperial gallons per day (MIGD) of water using multi-stage flash desalination units.

The agreement covers three dual-fuel Siemens SGT5-4000F gas turbines (GTs) and SGEN5-1000A air-cooled generators, coupled with a Siemens SST5-6000 steam turbine (ST) and SGEN5-2000H hydrogen-cooled generator, including all related auxiliaries.

Coverage consists of all scheduled and unscheduled power generation and auxiliary equipment maintenance, a parts supply program including upgrades, repair and refurbishment of parts, and remote monitoring and diagnostics including Ansaldo's APEXTM digital predictive maintenance tools. To facilitate timely outage activities, a GT rotor exchange program has been established.

Terna and Ansaldo Energia signed a Memorandum of Understanding to identify, assess and implement joint research, development and innovation initiatives in the energy sector. The objective is to set up working groups dedicated to adapting the electricity system for a future that is increasingly interconnected, decarbonized and renewable.

Terna and Ansaldo Energia will focus on:

- Improvement of traditional electricity system technologies
- Study and analysis of new technologies to support the energy transition
- Identification of joint development opportunities in international markets
- Launch of initiatives in the field of energy efficiency.

The new Sulzer service center in Malaysia provides specialist rotating equipment services

Sulzer in Southeast Asia

Sulzer has opened the Semenyih service center in Malaysia, its 20th service center in the region. This is part of the company's localization strategy. Specializing in centrifugal pumps, compressors, STs and electric motors, the 850 m^2 center is especially suited to power generation, petrochemicals and oil & gas.

As part of Sulzer's global service center network, the Semenyih facility can access specialist services such as high-speed balancing and high-voltage coil manufacturing. It will retain experienced field service engineers to support on-site installation and commissioning as well as fault-finding and condition monitoring.

MAN ES in Africa

MAN Energy Services (ES) is delivering three packages using the single-shaft MGT6000 GT for a 20 MW plant, which supplies heat and power to BPL oil & gas facilities 30 miles southwest of Port Harcourt in Nigeria.

The order was placed by American EPC Combustion Associates. Together with Exterran Corporation, the company is responsible for the engineering, manufacturing and installation of the overall project.

The MAN turbine technology uses Dry Low Emission (DLE) combustion, as well as modified intake air-cooling for operation despite the high temperatures. All trains are equipped with an ATU Box (Analytics Telemetrie Unit) connected to the MAN CEON digital platform. It collects and evaluates operating and sensor data to monitor machine operation.

MAN MGT6000 gas turbine

News continues on page 10

Siemens is building a combined cycle plant in Germany

Siemens digest

Siemens will build a CCPP as a turnkey project at the Marl Chemical Park in North Rhine-Westphalia, Germany. The order was placed by the specialty chemical group Evonik Industries. The plant will consist of two units, each with an electrical capacity of 90 MW, and produce electricity and process steam, as well as district heat for about 2,000 homes. It is scheduled to go into operation in 2022.

Siemens' scope of supply includes the turnkey construction of two identical power plant units as well as one GT, and one ST for each unit. It also includes generators, auxiliary systems and the control system.

Siemens will carry out preventive maintenance work for 15 years. Heat recovery steam generators (HRSGs) and catalysts enable the system to operate on natural gas and re-gasified liquefied natural gas (LNG), and various other gases, such as residual gas from production processes.

Evonik and Siemens launched project Rheticus II. The goal is to develop an efficient and powerful test plant that will use carbon dioxide (CO_2) and water as well as electricity from renewable sources and bacteria to produce specialty chemicals.

The companies collaborated to develop artificial photosynthesis using a bioreactor and electrolyzers. Rheticus II will run until 2021 and receive funding from Germany's Federal Ministry of Education and Research. The test facility is scheduled to start operating in early 2020.

Siemens Gas and Power and Russian chemical firm PJSC Kazanorgsintez signed a contract for the turnkey construction of a 250 MW CCPP in Tatarstan. Commercial operation is planned for 2023.

Siemens signed two service contracts, one with Kazanorgsintez for the new plant and one for a 495 MW power plant with Siemens equipment owned by PJSC Nizhnekamskneftekhim. Siemens will act as general contractor for the construction of the new industrial power plant and will deliver a SGT5-2000E GT and a SST-600 ST.

The scope of supply includes generators, the SPPA-T3000 control system and power distribution system equipment. The new plant will be fired with syngas, a byproduct of production in pyrolysis ovens at the Kazanorgsintez ethylene plant.

Siemens and Orascom Construction signed an agreement to rebuild the Baiji 1 and Baiji 2 power plants in northern Iraq. They will have a combined output of 1.6 GW. The projects are expected to be completed within 28 months.

Siemens will supply four new SGT5-2000E GTs and will inspect and revamp six existing ones. The company will also provide two 400kV and one 132kV substations, along with generators, auxiliaries, automation and control systems, and related electrical equipment.

Siemens and the Ponemon Institute released a report that assesses the global energy industry's ability to meet the growing threat of cyberattacks to utilities and critical infrastructure connected to the electrical grid. The report, *Caught in the Crosshairs: Are Utilities Keeping Up with the Industrial Cyber Threat?* details vulnerability to cyber risk, readiness to address future attacks and provides solutions to better secure critical infrastructure.

The study identifies key vulnerabilities in energy infrastructure that malicious actors seek to exploit. This included common security gaps that are created as utilities rely on digitalization to leverage data analytics, artificial intelligence, and balance the grid with intermittent renewable energy and distributed power generation.

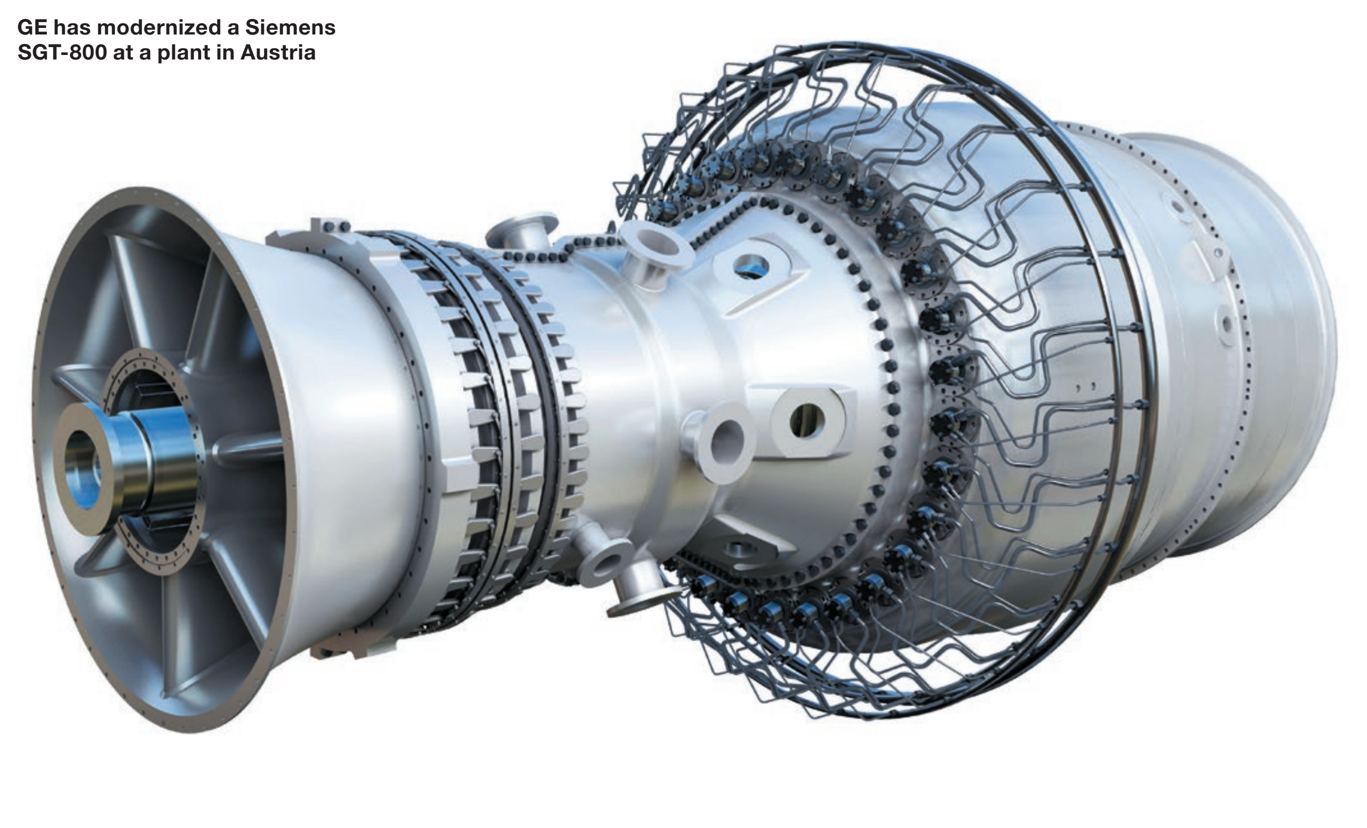
The survey found the risk of cyberattacks on the utility industry to be worsening with 56% of respondents reporting at least one shutdown or operational data loss per year, and 25% impacted by mega attacks, which are frequently aided with expertise developed by nation-state actors. Some 64% say attacks are a top challenge and 54% expect an attack on critical infrastructure in the next 12 months.

Three Siemens plants have been inaugurated in Bolivia. The company expanded the nation's three largest plants to combined cycle mode. They are owned and operated by Ende Andina SAM.

Together, they add more than one GW. They were already equipped with 13 Siemens GTs and the associated generators for operation in simple-cycle mode. Siemens added 14 SGT-800 GTs, 11 SST-400 STs with condensers, 22 steam generators, and the SPPA-T3000 instrumentation and control system. Efficiency rose from 40 to 51%.

The Termoeléctrica del Sur thermal power plant in southern Bolivia increased peak capacity from 160 to 480 MW. The Entre Ríos plant experienced a capacity rise from 120 to 480 MW. The Warnes plant's capacity rose from 200 to 520 MW.

News continues on page 12



GE has modernized a Siemens SGT-800 at a plant in Austria

GE digest

Greek industrial firm Mytilineos has ordered a GE 9HA.02 GT for the Agios Nikolaos CCPP in the Voiotia region. Construction on the 826 MW plant will be completed in two years. GE's deal includes an ST, generator and a 15-year service agreement.

GE announced an order for its GT26 HE (high efficiency) GT upgrade with Drax for Shoreham power station in the UK. GE will also provide digital solutions and plant improvement services.

The upgrade would increase combined cycle efficiency by about 2.5% and add more than 40 MW. The GT26 HE upgrade provides a rise in efficiency, output and maintenance interval extensions.

It embeds technology breakthroughs across every major component of the GT26 frame — turbine, compressor and combustor. GE's Asset Performance Management (APM) and Operations Performance Management software are being added.

GE Marine's LM2500 GTs now power the Littoral Combat Ship (LCS) USS Cincinnati (LCS 20), commissioned into the U. S. Navy's fleet in Gulfport, MS. Each of the two GE LM2500 engines produce over 29,500 HP for speeds beyond 40 knots. The LCS Independence-class fleet are built by Austal USA at its Mobile, AL shipyard.

Iraq's Mass Energy Group Holding (MGH) and GE Power signed an agreement that will help establish Phase 3 of the Besmaya Power Plant, taking capacity up to 4.5 GW. GE will supply MGH with four 9F GTs and four generators.

GE signed a multiyear services agreement with Sappi, a provider of wood fiber products and solutions based in Austria. GE will provide long-term maintenance services and performance upgrades on a 42 MW GT supplied by another equipment manufacturer used in industrial processes.

This will allow Sappi to reduce costs through a maintenance interval extension and performance benefits by modernizing its Siemens SGT-800 GT with GE materials and cooling technology, as well as improved an engine component architecture.

Sullair expansion

Sullair is expanding its North America operations and headquarters campus in Michigan City, IN. The project includes an 80,000 ft^2 manufacturing building, a canopied storage building and additional parking, as well as reconfiguring portions of the existing, primary 280,000-ft^2 manufacturing site. This allows the company to raise production of air compressors.

Sullair's new facility

John Crane service center

John Crane has opened a service center in Livorno, Italy. Its capabilities include customer training, and workshops for seal reconditioning, repair and installation. John Crane has a network of more than 200 sales and service facilities in over 50 countries. ■

HOW TO DESIGN & DEVELOP STEEL STRUCTURES FOR TURBOMACHINERY PACKAGES

BY AMIN ALMASI

Steel structures, such as base-frames and base-plates, play a major role in the operation and reliability of turbomachinery packages. Their design and manufacturing have been closely related to some critical topics, such as allowable nozzle loads, vibration and dynamic behaviour.

It is unfortunate to see an expensive turbomachinery package fail only because of a faulty steel supporting that costs less than 3% of the overall value.

If steel structures and the structural aspects of turbomachinery packages are neglected, many problems can result. Yet high-strength and high-ductility steels and alloys combined with recent advances in manufacturing technology have made it possible to build efficient structures with large strength-to-weight ratios.

As a rule, strong steel structure profiles and overdesigned schemes are preferred for turbomachinery. A complete set of loading cases should be identified and implemented for any steel structure. Conservative loads, supports and boundary conditions should be chosen.

For instability and buckling cases, smaller critical instability loads should be chosen. But as it is too difficult to identify all the possible cases of buckling and instability, the entire system and structure should be considered for a thorough simulation.

Structural steel is a ductile material and its fracture is ductile. For most stress states at ambient temperature several factors can influence material failure, such as temperature, strain rate, loading history and stress state.

This leads at certain conditions (like low temperature) to brittle fracture. Steel structures loaded to extreme limits will fail due to instability that prevents further loading, by tension failure or by a combination of both.

It is wise to make structure (such as a baseplate) repeatable, then tune for improvement and accuracy. In simple terms, tell the same story each time, then improve the story with enough details.

There can be many operating cases and loading situations. Strength is needed in any direction and any member to deal with known and unknown loading cases such as alternative loading conditions or emergencies.

An expensive turbomachinery package can fail because of a faulty supporting structure that costs less than 3% of the total value.

The number of points at which a body is supported ideally should be equal to or more than the number of degrees of freedom to be restrained. It is best to support a body with more compliant points than there are degrees of freedom to be restrained. In this way, the errors in the compliant support points will average out.

Steel structures may be broadly classified by their stability system, as braced or continuous structures. Long-span beams have been preferred in modern structures. Long spans result in flexible, column-free spaces, reduced substructure costs, and reduced installation times. This broad range of benefits means that they are commonly used in a wide range of modern structures.

The path that forces follow should be minimized, particularly the length of the path. A divergent path of forces means that the overall movements of parts and components can potentially be different. This can change the internal gaps or clearances in components and parts and lead to serious consequences.

In many cases, stresses and deflections are marginal compared to the specified limits. This can make it difficult to decide whether to further strengthen the structure or not.

It should also be understood that all stresses, deformations and simulations are estimates. There can be many sources of errors and inaccuracies. Loadings may not be realistic.

In many cases, actual forces and moments on a structure are far more than those simulated, both in terms of number of loads and their complexities. Models, therefore, are usually simplified versions of actual structures. This introduces errors and inaccuracies.

So how to make a decision?

A good recommendation is to look at other reports or observations, particularly those from actual structures of turbomachinery packages from the site, if available. If a structure has worked well, a slightly modified version of it is likely to work reasonably well under similar loading even if the stresses and deflections are marginal. ■

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.


PLATINUM FORECAST SYSTEM
trusted by the world's most successful corporations - is the premier market forecasting tool for the power systems industry. This user-driven interface allows you to quickly create new customized market assessments that identify both risk and future opportunities. This system was developed to greatly reduce the amount of time spent gathering intelligence so that you can devote more time to actual analysis.
Visit us at POWER-GEN International November 19-21, 2019
Ernest N. Morial Convention Center New Orleans, LA USA
Booth #3515
FORECAST INTERNATIONAL
forecastinternational.com
sales @forecast1.com

The Turbo & Pump Symposia featured 350 exhibitors

TURBOMACHINERY & PUMP SYMPOSIA 2019

NEW PRODUCTS DOMINATE THE SHOW—STEAM TURBINES, CONDITION MONITORING, BOG COMPRESSORS AND COATINGS

BY DREW ROBB

The 48th Turbomachinery and 35th International Pump Users Symposia (TPS 2019) is the premier event for oil & gas-related turbomachinery. Held in Houston, Texas at the George R. Brown Convention Center in September of 2019, it is organized by the Turbomachinery Laboratory at Texas A&M University.

The symposia promote professional development, technology transfer, peer networking and information exchange among industry professionals. This year's TPS attracted around 4,700 delegates from 45 countries as well as more than 350 exhibiting companies. They were treated to major new product announcements from the likes of Baker Hughes (BHGE) (p. 30), Howden, Atlas Copco and Oerlikon.

A rich technical program featured sessions from John Crane, Flowserve, Rotoflow, Solar Turbines, Petrobras and Mitsubishi Compressor. They covered mechanical seals, gas turbine (GT) performance, bearings, GT failures and more.

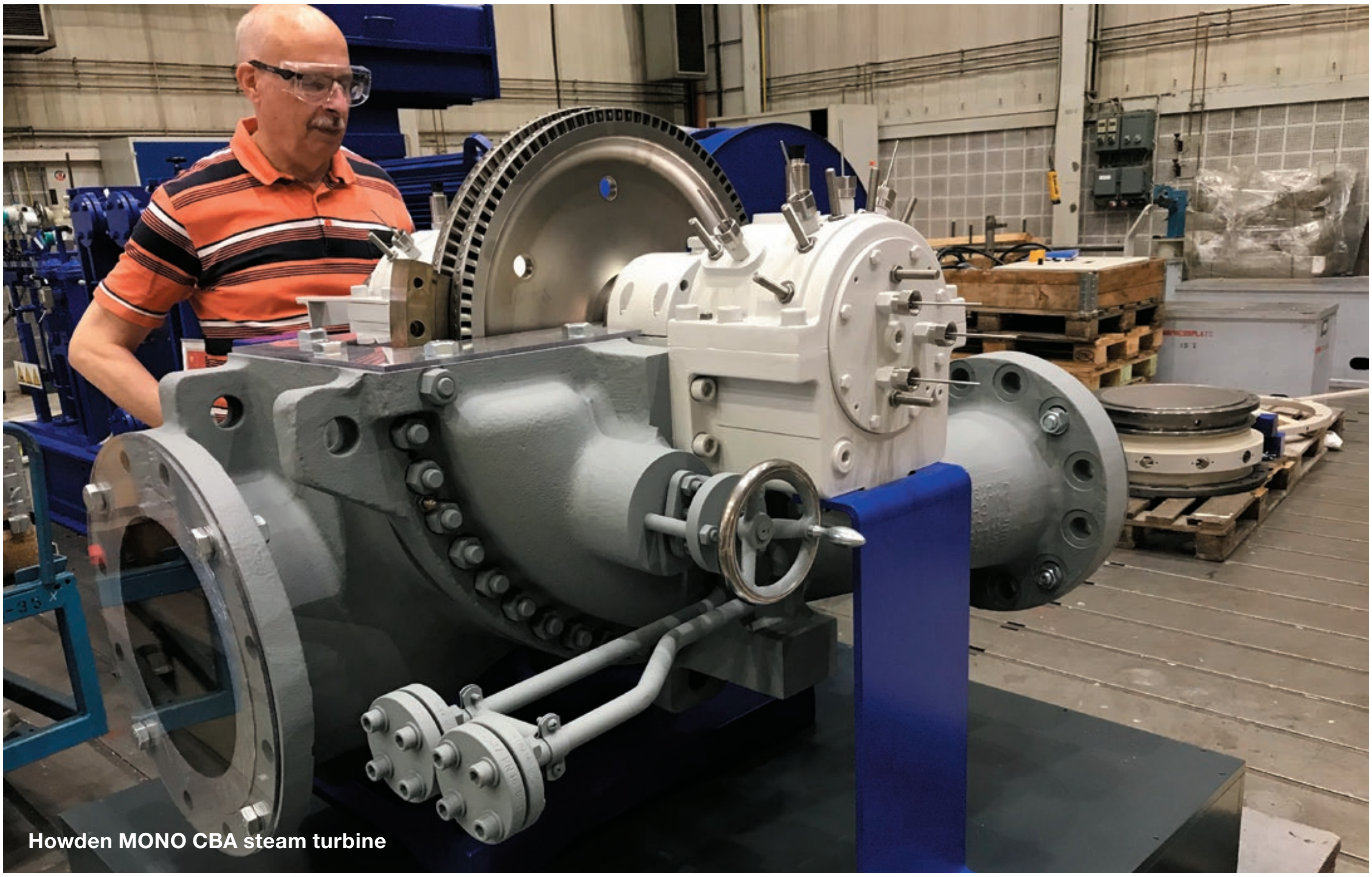
Steam turbine

It is not every day, or every year, for that matter, that a new steam turbine (ST) is released. Howden chose TPS 2019 to let the world know about its new MONO CBA ST.

"The MONO CBA steam turbine model is an API 611 solution for mechanical drive applications up to 2 MW output range," said Serkan Nane, Head of Sales, Steam Turbines, Howden.

This ST expands Howden's portfolio of small industrial STs for mechanical drive applications suited for the refinery and petrochemical industries.

API 611 standards (revision 5, 2008) is a mandatory specification for mechanical drives in the petrochemical, refinery and oil & gas markets. To meet this specification, the MONO CBA features a two-


Howden MONO CBA steam turbine

stage Curtis rotor, robust construction and operational reliability.

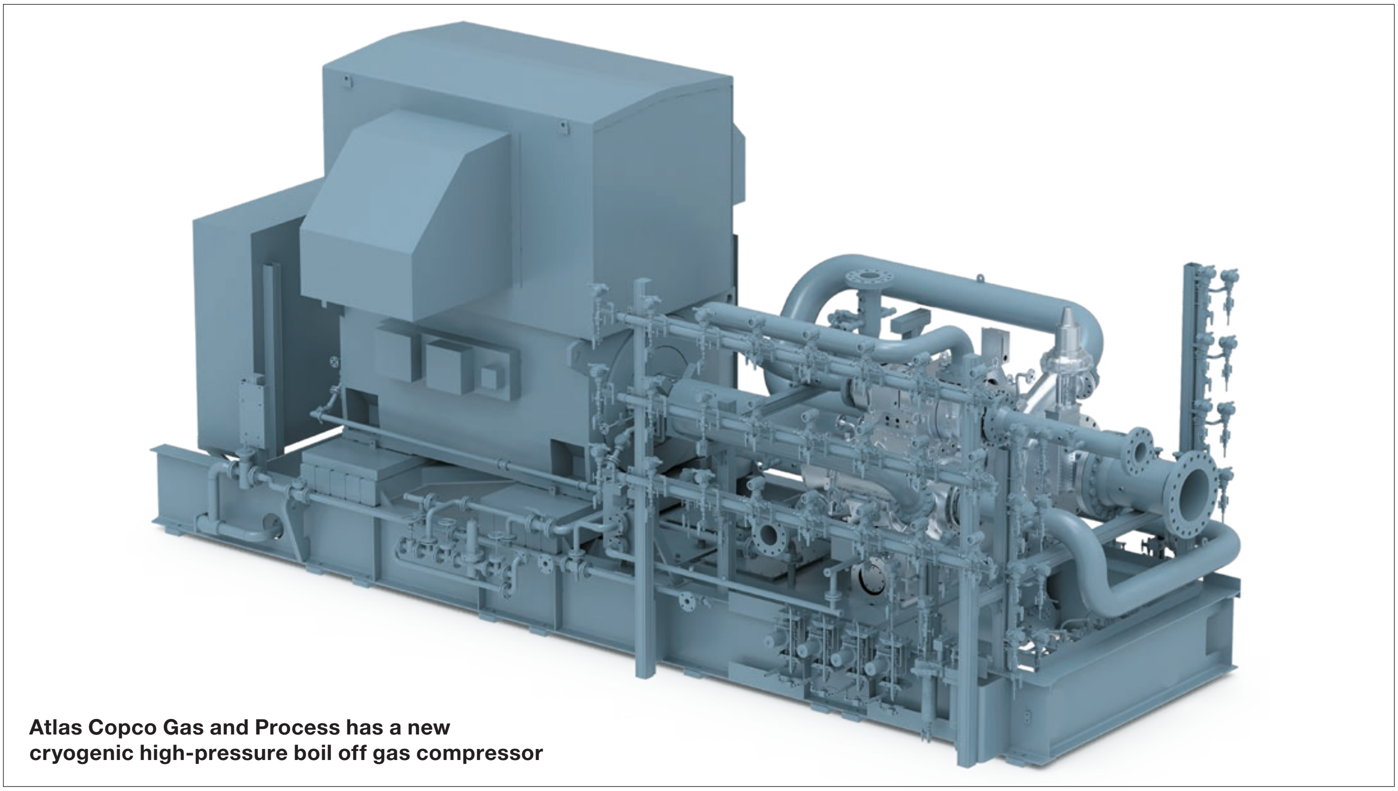
"Our axial Curtis stage shows a significantly higher performance than single-stage technologies at speeds typical in mechanical drive applications," emphasized Dr. Matthias Schleer, Director of R&D and Technology, Howden. "This is mainly achieved by applying inter-stage guide vanes and a second blade-row. To reduce tip losses, blade tips are covered with titanium shrouds."

CBA, which stands for Curtis impeller between Bearing Axial flow, is a one-piece bladed design that fits securely on the shaft. This allows the MONO CBA to outperform single-stage technologies while operating at speeds up to 6,000 rpm (up to 9,000 rpm possible).

Using elements from Howden's Kühnle, Kopp & Kausch product brand technology, the new turbine includes a modular design and is available as a bare-shaft assembly or as a full-packaged solution. Journal bearings are installed externally with a protective system. Inlet steam temperature can go as high as 440°C. Dimensions are one meter by one meter by one meter.

In the full-package option, the bare shaft turbine is fitted with a gear-and-oil lubrication system according to API 677 and API 614 standards, trip and control valves, as well as turbine control panel and


The High Velocity Oxy-Fuel thermal spray process from Oerlikon



Atlas Copco Gas and Process has a new cryogenic high-pressure boil off gas compressor

surveillance systems. The turbine can also be equipped with bearing temperature sensors, shaft vibration and position probes.

Coatings

Oerlikon Metco has released a family of coatings designed to reduce hydraulic fracturing downtime by increasing the lifespan and efficiency of centrifugal injection pumps that operate in harsh, demanding environments.

Centrifugal injection pumps transport water with entrained sand at high pressure. This generates erosive and abrasive wear throughout the pump. Pump failure within six months is common.

Metco Pump and Metco Sol pump coatings are said to extend mean time between failures by 300% to 700%. Coatings are designed for different pump substrates and operating conditions and applied using robotically controlled systems.

The High Velocity Oxy-Fuel (HVOF) application process combusts oxygen and a gaseous or liquid fuel to produce high kinetic energy with controlled heat input. The coating material, in powder form, is uniformly heated by the hot gas stream to a molten or semi-molten condition.

The flame and powder are accelerated by a converging/diverging nozzle (air cap) to produce supersonic gas and particle velocities, which propel the powder particles toward the substrate to be coated.

The powder particles flatten plastically upon impact with the substrate, cooling and solidifying to form the coating. High-particle velocities, uniform heating and low dwell time combine to produce coatings that are dense and tightly bonded to the substrate. Coatings have fine, homogeneous microstructures.

In the laser-clading process, a laser beam is defocused on the workpiece with a selected spot size. The powder coating material is carried by an inert gas through a powder nozzle into the melt pool. The laser optics and powder nozzle are moved across the workpiece surface to deposit single tracks, complete layers or even high-volume build-ups.

Atlas Copco Gas and Process has also introduced a new approach to cryogenic high-pressure boil off gas (BOG) handling. Drawing from experience manufacturing integrally geared turbocompressors for the LNG market, the company has adapted this technology to handle cryogenic high-pressure BOG processing. This six-stage compressor offers more than 98% reliability and availability combined with significant CAPEX and OPEX savings over conventional technologies.

Using cryogenic low-pressure BOG and fuel gas boosting reference machinery, Atlas Copco Gas and Process has engineered a compressor that handles cryogenic high-pressure BOG applications with greater reliability and efficiency than was previously attainable. This is the first process machine to combine two cryogenic and four warm stages on a single gearbox and skid, allowing for a smaller, more efficient machine. The six stages are said to have the industry's highest processing capability.

The application of dry-gas seals in a cryogenic high-pressure BOG centrifugal compressor is another first for this type of machine. Compared to traditional carbon ring seals, the dry gas seals allow for higher efficiency and lower methane leakage into the environment.

Session tracks

Beyond product announcements and a lively exhibit floor, TPS 2019 featured a technical program with a wealth of short courses, lectures, tutorials, case studies and discussion groups led by experts in their fields.

Kenichi Nishiyama and Rishav Jane, turbine engineers at Mitsubishi Heavy Industries Compressor (MCO), discussed stress corrosion cracking (SCC) in STs.

SCC occurs when a vulnerable material is exposed to a corrosive environment and tensile stresses. Remediation methods included how to reduce working stress, implementation of new materials and the best ways to eliminate corrosion. The authors recommended rotors be examined for signs of SCC damage by Phased Array Ultrasonic Test (PAUT) to mitigate the risk of failure. Residual life estimations were based on guidelines from the Electric Power Research Institute (EPRI).

Rainer Kurz, Manager for Systems Analysis at Solar Turbines, followed with a briefing on the performance of industrial GTs. He said performance characteristics depend on ambient and operating condi-

Lively Q & A followed many of the presentations

tions. Site elevation, ambient temperature and relative humidity, the speed of the driven equipment, the fuel and load conditions all have to be considered.

Kurz emphasized the need to understand the flow of energy between the various elements of the turbine. He also discussed control concepts, both for single-shaft and two-shaft machines, driving generators, compressors, or pumps.

"GTs are efficient, have attractive operating and fuel costs and their maintenance requirements are low," said Kurz. "Their power density offers a lot of horsepower per given amount of weight."

He detailed the differences between single-shaft and two-shaft machines. A two-shaft design has a free power turbine. This enables the operator to change the speed of the driven equipment independently of the gas generator turbine. Single-shaft designs are used more for driving generators with constant speed.

"Two-shaft equipment can drive generators, pumps or compressors," said Kurz. "There are exceptions, but single-shaft machines tend to be mainly for driving generators."

Revamps

James Sorokes, Principal Engineer, Siemens Gas and Power, Oil & Gas covered the revamping, re-rating or upgrading of centrifugal compressors. He considered aerodynamic factors as well as reasons to revamp existing turbomachinery rather than purchasing new equipment.

Sorokes explained that a revamp deals with replacing all or some of the compressor internals, which can often be completed in a week or two. A revamp or rerate typically means a change in process conditions that requires the introduction of new impellers, new diffusers or drive train changes for speed or power.

An upgrade is different. It entails no changes to process requirements but an upgrade of the components. Examples include a switch from riveted-to-welded impellers or moving from machined-to-cast manufactured parts.

Continues on page 20

The exhibit floor features separate sections for pumps and turbomachinery

Various geometric constraints must be addressed in a revamp, such as how much axial space is available for the flow path. Nozzle locations, too, may impact placement of internals. Many old machines have cast casings with return bends cast into the casing, which can limit a revamp. Pressure and temperature raised by a revamp could represent an unacceptable risk.

"Will the casing be able to withstand new pressure loads?" asked Sorokes, "It is important to do an FEA analysis of the casing under the new conditions." Another caution: Inspect old parts for damage, faults or other signs of compromise.

Available space

Sometimes everything must fit in available space. He gave examples of putting new bends and channels inside the old ones to make it work.

"The motivation for a revamp is to re-purpose the equipment you have," said Sorokes. "This might mean more or less flow, higher or lower pressures or reduced power consumption." A revamp is likely to cost less than a new equipment order.

When considering an existing compressor for alternate operating conditions, you have to evaluate changes to the surge and choke margins, the design point, efficiency and the head coefficient. For example, you might experience a change in the gas conditions that the compressor is handling.

If you raise the molecular weight of the gas, the performance maps for the individual stages get narrower. That is, the overall flow range of the stages is reduced. Similarly, if higher speeds are required, the stage maps become narrower.

Those carrying out a revamp should also determine whether to increase or decrease the capacity, and whether to introduce state-of-the art blading or make changes to diffusers. Each decision can affect performance.

"Be careful when increasing capacity or the number of stages," said Sorokes. "When upgrading impellers, consider blade thickness, blade accuracy and different shapes to improve efficiency."

Many revamps, he said, achieve superior mechanical integrity by moving from a riveted to a welded design. Natural frequencies, too, can change when new impellers or blades are implemented.

Installing inlet guide vanes (IGVs) in old machines may be a quick way to revamp a compressor. IGVs add tangential velocity to the flow entering the impeller. You can achieve a capacity increase or decrease by adjusting the guide vanes without altering the rotor.

This is far less costly than changing impellers. But there are limitations to this approach as it can reduce efficiency or increase the amount of horsepower consumed by the compressor.

"Diffusers are often the key to the success of a revamp but watch out for impeller/diffuser misalignment or obstruction of the flow exiting the impeller," said Sorokes. "This can create unbalanced forces on the rotor and lead to sub-synchronous radial vibration."

He offered advice concerning nozzles, inlets, volutes, sidestreams and balance pistons. An undersized volute, for example, can be detrimental to the overall flow range of the compressor.

The end user and the company performing the revamp must understand the schedule, the extent of the changes being made and agree on what defines success at the end of the revamp effort.

Mechanical seals

Variable speed pumps are being used more frequently to improve the efficiency and operational flexibility of centrifugal pumps, said Flowserve's Michael Huebner. Operating these pumps over a range of speeds can allow the end user to tailor the pump output in real time to meet the changing process demands. But mechanical seals are often overlooked, or they are only evaluated at the highest operating speed.

The range of operating conditions, he said, can impact seal performance as well as the requirements of the mechanical seal piping plans. It is important for end users, pump OEMs, and seal OEMs, therefore, to understand how to evaluate the mechanical seals present in variable speed pumps.

This should include an evaluation of speed, pressures, temperatures and flow rates through the sealing system. Pump and impeller construction, too, can impact seal operating conditions and performance.

John Crane's Jack Bagain addressed midstream pipeline applications. He said there are few applications that place a demand on mechanical seals such as those associated with the handling of various fluids through pipelines. These applications typically encompass variable fluid properties as well as fluctuations in pressure, temperature and speed. The remote nature of installations and limited accessibility, too, must be considered.

Bagain outlined a variety of sealing strategies and best practices: The performance of a mechanical seal can be thought of as a compromise between leakage and wear. It is well known that the wear rate (and friction) of a leaky seal can be low.

In general, when leakage rates are reduced, wear rates increase. Within this relationship, and using modern designs incorporating high performance material, nearly any level of performance can be obtained through selection of the seal arrangement.

The discussion moved onto sealing materials. The use of carbon graphite at pressures above 1,200 psig requires thorough evaluation. Silicon carbide is hard and wear resistant with good mechanical properties, as well as pressure velocity (PV) characteristics. A silicon carbide/graphite composite has improved dry-run survivability and thermal shock resistance, as well as exceptional PV.

This material is often used when operating pressures might exceed the limits of conventional metal-filled carbon grades. Tungsten carbide is tough with good wear resistance, but its PV is limited, and susceptible to heat checking damage.

Bearings

Centrifugal compressors and steam turbines often use hydrodynamic journal bearings. They can either be fixed-sleeve or the tilting-pad type. While compressor manufactures push design limits to reduce costs and optimize machine performance, this can increase the risk of bearing issues.

Unfortunately, industry standards offer limited guidance on how to design or apply hydrodynamic bearings to prevent wear or damage.

"Guidance is needed on how to identify and avoid potential bearing issues with hydrodynamic journal bearings in centrifugal compressors and STs," said Patrick Smith, Air Products Fellow, in a tutorial co-authored by Robert Benton, Product Development Engineer for Rotoflow, an Air Products Business. "This applies to a new machine or when retrofitting a new bearing into an existing machine."

"Bearing failures are typically characterized by actual damage, such as babbitt fatigue, but this doesn't get to the underlying causes in design, bad installation, operation, maintenance or quality," said Smith.

He cited several API standards as well as an AGMA standard, but cautioned users that the API standards, in particular, do not include much to help the user in evaluating bearings. He cited three failed bearing examples that fell within acceptable limits per the standards in terms of surface speed, unit loading and clearance ratio.

Continues on page 22

Many booth presentations featured the latest in software and digital innovation

"When reviewing a bearing design for an application, the old method of applying simple limits to journal speed and unit load can be ineffective in preventing bearing issues or result in a more conservative design than is needed," said Smith. "Criteria to use should include minimum film thickness, bearing temperature, side leakage, oil supply, frictional (power) losses, maximum pad temperature and peak oil film pressure."

Rotoflow recommended: a calculated minimum oil film thickness of 0.8 mils under all design operating conditions; a maximum measured bearing operating temperature of 212°C in the shop and in the field under all process and oil operating conditions for tilting pad babbitt bearings; condition monitoring to provide early detection of bearing wear or damage; a protection system that includes appropriate protections during transient conditions; and an oil analysis program to detect early signs of oil degradation.

Case studies

Harris Sabri, a Staff Rotating Engineer from Petronas, discussed the impact of harsh environments on GTs in Malaysian offshore waters. The biggest issue, he said, is hot corrosion.

From the first failure in 2008, Petronas suffered 12 confirmed hot corrosion incidences across multiple sites. An individual address to each incident proved ineffective. Instead, a fleet-wide approach was instituted.

Sabri defined a harsh environment where alkaline metals combine with sulfur to create a corrosive molten salt in offshore and coastal locations. Contamination may come from air, fuel and water.

"Molten sales cause accelerated oxidation or a sulfidation attack on high-temperature alloys," said Sabri.

He described Type I high temperature hot corrosion (800 to 850°C) as happening typically at the blade tip. Type 2 hot corrosion (670 to 750°C) is generally a pitting attack that occurs under the blade platform. Type 2 was the issue at Petrobras.

Five primary GT models operate in the Petronas fleet of 225 GTs. Model C was the most affected by hot corrosion. Of its 29 units, 16 experienced failures. Among the many other turbine models, only five failures were found. Therefore, investigation focused on Model C.

Eight sites had the Model C turbine and only four had failures. Root cause analysis found fouling in the compressor air path. Traces of oxygen, sodium and sulfur were found, as well as clogged air filters, water ingress in the inlet duct, water in the diesel fuel and clogged liquid fuel filters.

Petrobras brought together operators from each affected plant as well as the GT OEM and users from outside Petronas with similar problems. The solution involved upgrading air filtration to prevent corrosive species ingestion from F7/8 filters to E10 hydrophobic filters. Petrobras added G4 pre-filters, too.

"The original filters became clogged at 9,500 hours," said Sabri. "The new ones were found to be in good condition after 19,500 hours."

In addition, blade alloys (higher chromium content) and coatings were introduced with better corrosion resistance. Fuel standards were raised to prevent corrosive species ingress from dirty diesel. Digital monitoring was also implemented as a preventive measure.

"We have had zero failures since we put in these preventive measures almost two years ago," said Sabri.

TPS 2020 will be held Sept. 15–17 in Houston with short courses on Sept. 14. For more information visit tps.tamu.edu. ■

NEW INNOVATION CENTER FOR SIEMENS

SIEMENS BRINGS ADDITIVE MANUFACTURING AND OTHER TECHNOLOGIES TOGETHER

3D printing, also known as additive manufacturing (AM) is front and center in cutting edge research and development (R&D). Siemens is betting heavily on the technology to drive the next phase of turbomachinery innovation with the opening of a new Innovation Center in Orlando, Florida.

This center combines multiple disciplines, such as design, manufacturing, robotics, rapid prototyping, scanning and digital tools under one roof. As well as supporting the customers of Siemens Gas & Power, it also provides parts and new developments for aerospace and Siemens partners.

Collaboration is a key facet of the facility. Instead of the usual workforce made up of mechanical engineers and designers, it also includes electrical engineers and specialists in manufacturing, turbomachinery services, software development, robotics, augmented reality (AR), AM, non-destructive evaluation (NDE), and simulation.

Our new innovation center is equipped with the latest digital technologies," said Mark Kamphaus, head of Technology & Innovation for Siemens Service Power Generation. "This enables us to rapidly develop repairs, new components and digital solutions."

Siemens intends to use the center to enhance the performance of its products and systems. With the market being more competitive than ever, cost reduction is another driver in technology development at the center.

With the opening of this center, Siemens now has a network of four AM-based sites. As well as Orlando, there is Materials Solutions in UK, a company Siemens bought a couple of years ago, but maintains as an independent entity.

Materials Solutions was purchased to save time in 3D printing development. This strategic purchase provided Siemens with immediate know-how to apply AM to gas turbines (GTs) and steam turbines (STs). The goal is to look beyond printing of parts to jointly develop new materials and new 3D printers. These services will be offered to the aerospace and energy sectors. There are also AM centers in Sweden and Germany.

Kamphaus does not envisage the Orlando site being used for production. Instead, its focus will be on R&D, prototyping and proving out concepts prior to implementing into production. There are two 3D printers already on location and another one on the way to the Orlando center.

A tour of the facility showcased the 3D printers and a host of other high-tech gear. The latest robots are used to mill, grind, pick and place components. Siemens is using the site to perfect robotic processes before they are implemented on the shop floor.

"We want to automate a great many actions that are currently done manually," said Kamphaus. "We can pilot them here, refine them and scale them to our manufacturing operations."

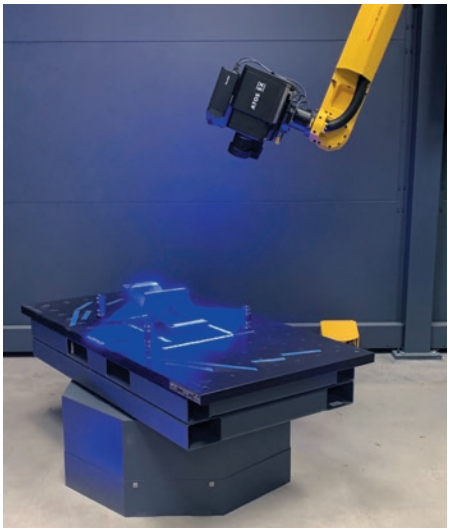
He sees this as one of many areas where turbomachinery costs can be reduced to make the technology more attractive in the marketplace.

Siemens has also invested heavily in NDE equipment and processes. NDE is useful in areas such as quality assurance, failure analysis and reverse engineering. The NDE team at the Innovation Center seeks to introduce a greater level of automation to NDE, qualify suppliers and optimize techniques. The center's capabilities include radiographic, ultrasonic, magnetic particle, eddy current, infrared and penetrant inspection.

The next part of the tour was the Collaborative Engineering Hub. Its purpose is to bring together many different kinds of engineers with scientists (in physics, computers and other disciplines) and experts in sensors, project management, logistics, production, aerospace, software, and computer-aided machining. About 35 engineers working there are seated in close proximity to these experts to encourage tighter collaboration.

A full machine shop at the site provides faster output and more streamlined workflows than could be obtained if Siemens had to send specialized components to outside partners. Kamphaus explained how long it might take to design something, including iterations back and forth between engineering and outside partners for many weeks until the part was correctly produced. This consumes too much valuable prototyping time.

This Fanuc CNC machine at the Siemens Innovation Center is grinding a part



This 3D scanner can scan any part to provide an accurate model

"We often make a plastic model for a component in a 3D printer and assemble it to see how it works," said Kamphaus.

The machine shop incorporates rapid prototyping, manufacturing, computer numerical control (CNC) milling, CNC turning, electrical discharge machining and waterjet cutting. Additionally, 5-axis and 2-axis machines are available to work in metal or plastic.

During the tour, a technician demonstrated an ongoing project to develop complex die cores in aluminum. Siemens wants to get it right before it goes into a production run by proving out all the tool paths.

"Our facility can now support some of our most urgent needs and prove out things so there are no delays," said Kamphaus. ■

COMPRESSOR FAILURES

ROOT CAUSES AND SOLUTIONS FOR GE GAS TURBINE COMPRESSOR FAILURES

BY RODGER ANDERSON & ROBERT TRAVER

Figure 1: Multiple rows of protruding shims

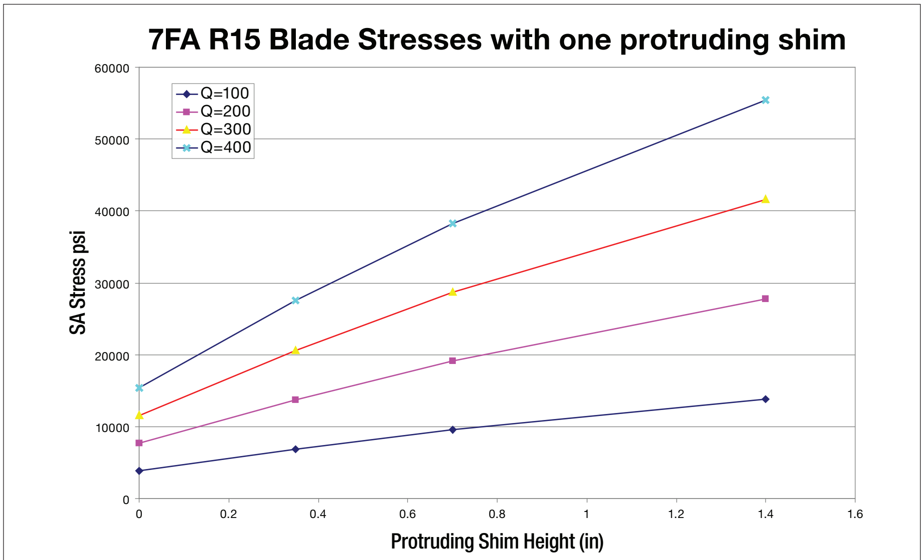


Figure 2: Blade vibratory response vs. protruding shim height for various values of damping

Most gas turbines have axial flow compressors with multiple rows of rotor blades and stator vanes that number into the thousands. Failure of any blade or vane can lead to severe collateral damage in both the compressor and turbine section of the engine.

Root cause analyses (RCA) often find foreign and domestic object damage and operational issues as among the usual suspects. However, shim protrusion and liberation and stator vane fretting wear are also becoming common reasons for failure.

Other factors that can accelerate fretting wear include flow disruptions from casing geometry changes, air extraction points, rotor blade clocking, and higher frequency of start and stop cycles due to the demand for plant flexibility to accommodate solar and wind power.

Protruding and missing shims are regularly found during boroscope inspections and overhauls on GE gas turbine compressors (Figure 1). In some cases, a protruding shim can create a flow blockage of more than 15%.

Blockage results in a force pulse which produces an alternating force or stimulus on downstream rotating blades. Since shims are generally located near horizontal joints, this produces one or two pulses per revolution.

At these locations, force impulse on the rotating blades is the result of the area change in the stationary vane flow passage. This is exacerbated by trailing edge vortices that can upset the flow path following the protruding shim.

As the force profile is narrow, there are multiple harmonics which can contribute to circumferential force distribution on rotating blades. If any harmonic frequencies are resonant with blade natural frequency, blade vibratory response is amplified at this resonant condition.

At a resonant condition, blade vibration stress is directly proportional to the magnitude of the stimulus or alternating force on the blade; it is inversely proportional to the damping of the bladed system, and proportional to the resonant response factor and steady gas bending load on the blade.

The resonant response factor is the attenuation in response due to the phase relationship between the alternating force, or stimulus on the blade, and the particular mode shape. This method for predicting blade response can be used to evaluate

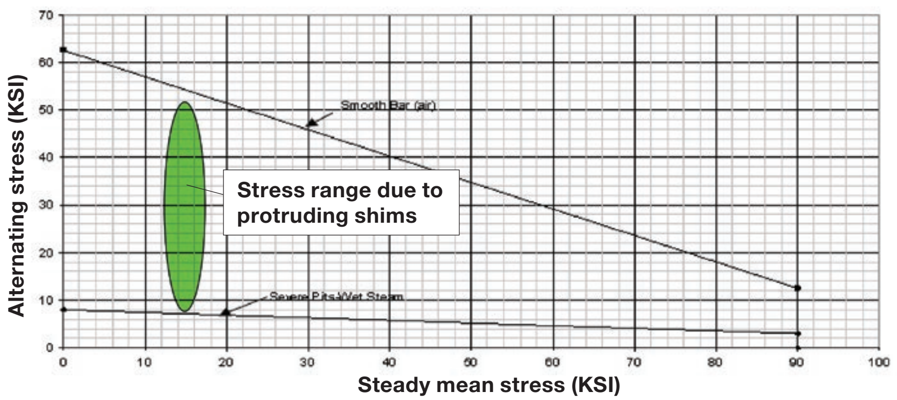


Figure 3: Goodman diagrams can help to evaluate the fatigue strength of a material under the combined influence of steady and alternating stresses

the dynamic response of a compressor blade due to protruding shims.

But it is important to understand that blade natural frequencies are dependent on several variables. They should not be predicted as discrete frequencies but as a range.

Temperature affects frequency due to the dependency of Young's modulus on material temperature. Furthermore, manufacturing tolerances can affect frequency due to vane envelope tolerances and dovetail fit variations.

Figure 4: Severe fretting wear in casing T-slot groove

This must be addressed by calculating all frequency ranges for the fixation point at the top and bottom of the contact area in the dovetail slot across the full range of operating temperatures. This information can then be used to construct a Campbell diagram to illustrate the relationship of blade natural frequencies with the stimulus frequencies from the rotational speed of the compressor.

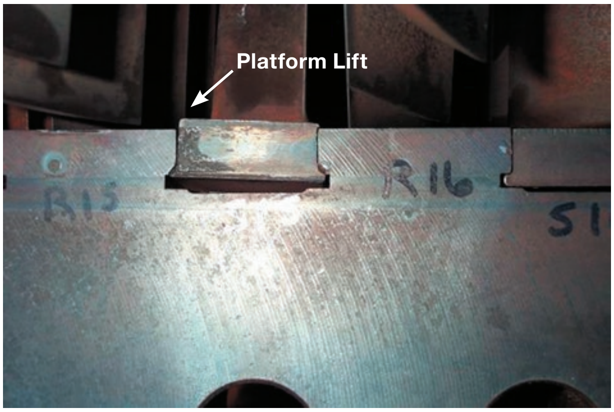


Figure 5. Fretting wear results in tip rock & platform lift

As an example, consider the evaluation of the row 15 rotor blade of a 7FA compressor.

One potential resonance was found with eight pulses per revolution (there is a stimulus force that occurs eight times for every revolution of the rotor) at the first tangential mode of vibration. Blade vibratory response was calculated as a function of different protruding shim conditions and assuming various values of damping (Q).

Damping can be variable and sensitive to various factors such as dovetail fit. However, previous research and testing suggests that the damping for this blade design should be in the range of Q=200–300 (Morgan P. Hanson. *Effect of Blade-Root Fit and Lubrication of Vibration*

Figure 6: Catastrophic compressor failure from casing hook fit failure and vane liberation

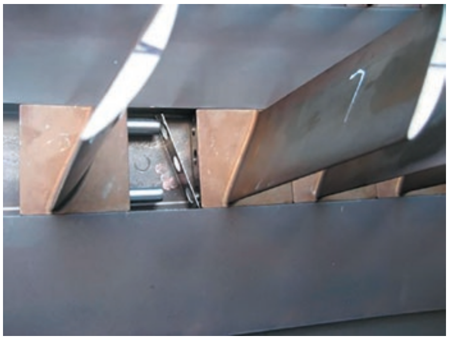
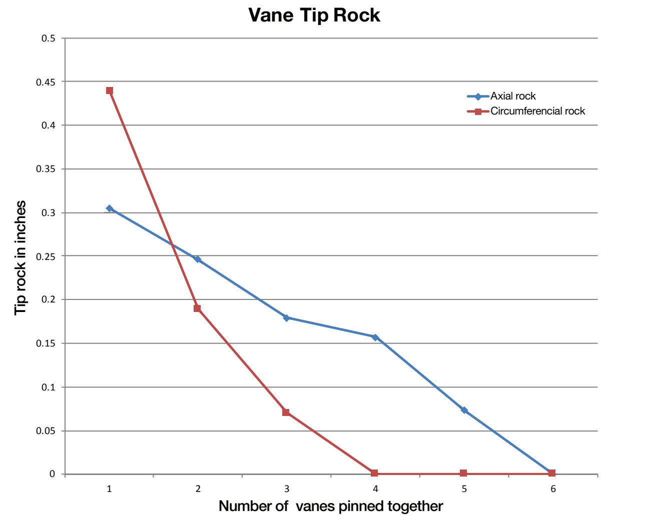


Figure 7. Stator vanes & shim assembled with dowel spring pins into a ring segment configuration within the compressor casing

Figure 8: No. of pinned vanes vs tip rock



Characteristics of Ball-Root-Type Axial-Flow-Compressor Blades. Cleveland, Ohio; Lewis Flight Propulsion Laboratory, National Advisory Committee for Aeronautics, June 1950).

The blade vibratory stress at the eight pulses per revolution resonance would be in the 20,000 to 30,000 psi range if there was only one shim protruding 0.75 inches (Figure 2). This response is about 2.5× the predicted response at resonance without a protruding shim.

For the case without a protruding shim, prediction was based on a random variation of stator forces (namely vane variable spacing and orientation) with a maximum variation of 1.5%. For two shims protruding at 180 degrees separation, the response is in the range of 40,000 to 60,000 psi.

The blade failure mode due to stimulus from the protruding shims is high cycle fatigue. A Goodman Diagram is typically used to evaluate the fatigue strength of a material under the combined influence of steady and alternating stresses (Figure 3 for blade material 403 SS).

It shows the potential blade response due to protruding shims is higher than the deteriorated endurance strength for the material. High cycle fatigue is a possibility depending on the operational profile and the number and height of the protruding shims.

Since the resonant frequency is 480 hz, fatigue cracking could occur in as little as ten million stress cycles which is less than six hours of operation on resonance.

Other major problems for compressors are loose vanes due to fretting wear in the casing T-slot groove (Figure 4), and severe wear on the vane attachment hooks.

The average and maximum wear is always greater in the upper half (UH) casing and vanes. The worst location is at the horizontal joint on the right side looking downstream. The reasons:

(1) Aerodynamic forces push all the vanes over against the left side keeper bar in the UH, thus allowing the right-side vane to be the last one in the pack, making it rather loosely held.

(2) This right-side vane in the upper half is notched to accommodate the keeper bar. Therefore, it does not have a full attachment hook in the base. This results in accelerated fretting wear (Figure 5). Typically, the average upper half vane looseness is nearly three times that of lower half vanes. Variations in vane spacing and orientation must be kept small to have acceptably small harmonic excitations on downstream rotor blades.

Platform lift creates a flow disturbance which will impact performance. An analysis was performed assuming a vane lift of 0.04" in half the rows of vanes can result in a ⅓% loss in efficiency. Left unresolved, tip rock can lead to vane clashing with the compressor rotor blades, vane liberation, and compressor failure (Figure 6).

Vane fretting wear and shim migration into the flow path are addressed by preventing vane movement. The lower half casing is where many vanes can be found solidly locked in place due to corrosion and deposits from the flow path.

One way to lock vanes is to pin them together (Figure 7). This procedure uses dowel spring pins inserted into holes drilled into the circumferential faces of the vane bases. Other vanes are attached, and more pins are added until a half ring vane segment is formed in both the upper and lower casing haves.

This forces the vanes into an evenly spaced condition that reduces the average harmonic stimuli on rotor blades. In addition, this greatly reduces fretting wear, the potential for liberation of vanes and shims, and protruding shims that can lead to rotor blade high cycle fatigue stimulation and failure. This process has proven reliable and has successfully been implemented on more than 200 turbines over a period of more than 17 years (Figure 8).

Other solutions include:

• A casing patch ring or weld repair and re-machining of the casing, as well as a complete replacement of the compressor vanes with a shim retention method. However, this approach does not address tip rock, i.e., wear of the hook fit and vane base due to fretting, which can occur over time

• Replacing individual vanes with a multi-vane segment with a shim retention method, i.e., multiple vanes are machined in to a common or continuous solid base.

Across the large, worldwide fleet of gas turbines, there will be a statistically small number of compressor failures due to variability and wear impacting Goodman stress capability. When potential blade stimuli are identified, such as protruding shims and vane looseness, it is a best practice to eliminate them.

The key to success of any solution is to have and maintain sufficient dampening over the wide variety of operating conditions. Taking care of shim protrusion, shim liberation, vane fretting wear and tip rock will improve the general health and performance of the fleet. ■

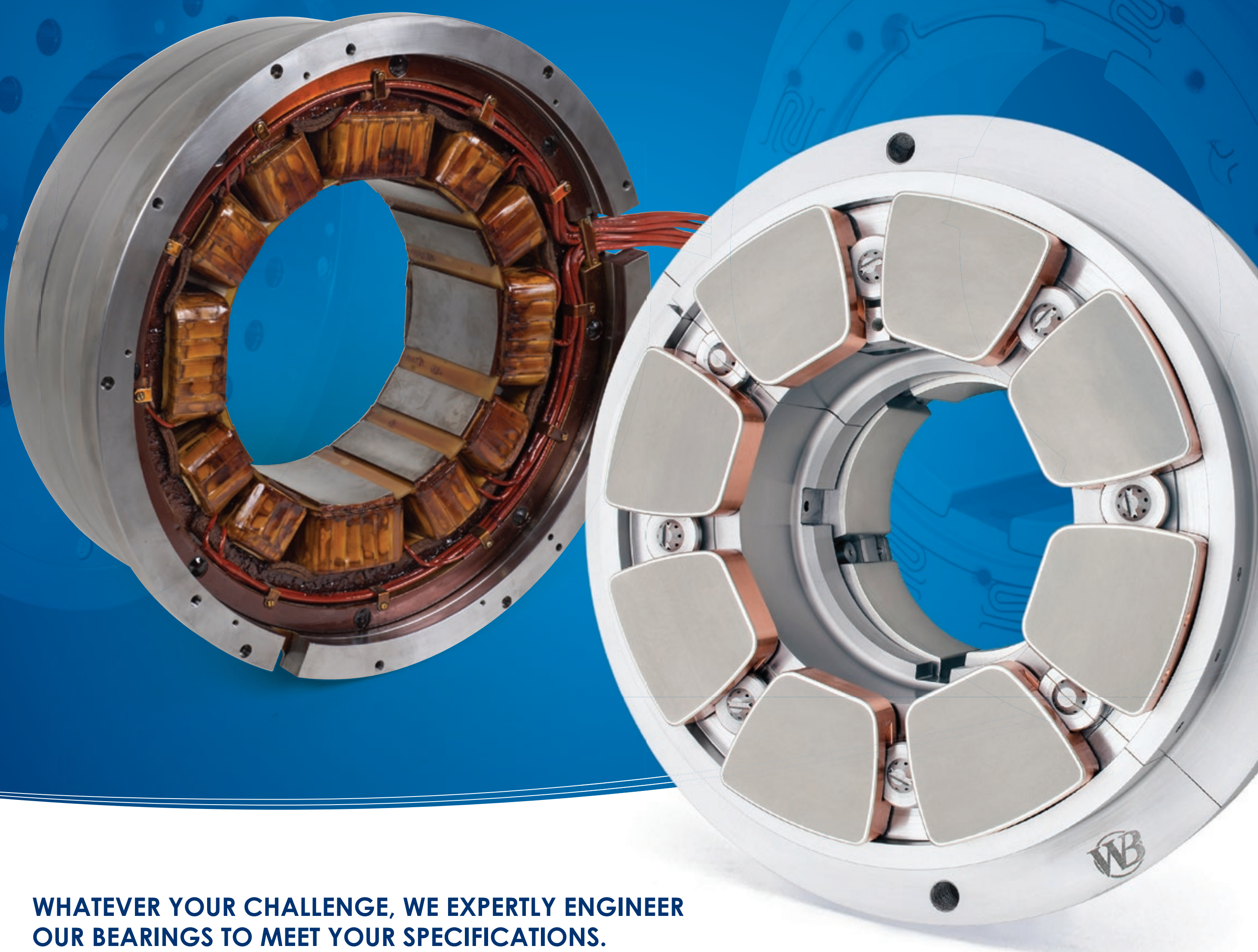
Robert Traver is Senior Engineer at CTTS, a company established in 2019 to provide on-going fleet support for compressor vane pinning.

Rodger Anderson is a Consultant who recently retired from DRS Technologies.

For more information visit: cttsus.com

IMPROVE OPERATION, REDUCE COSTS

With Custom Bearing Solutions



WHATEVER YOUR CHALLENGE, WE EXPERTLY ENGINEER OUR BEARINGS TO MEET YOUR SPECIFICATIONS.

MAGNETIC BEARINGS

Achieve high reliability and availability with active magnetic bearings that come standard with remote connectivity and the most advanced digital control systems.

FLUID FILM BEARINGS

Carry high loads at high speeds with optimized thrust and journal bearing designs supplied with 'Directed Lubrication.'

WB® WAUKESHA BEARINGS

www.waukeshabearings.com

Waukesha Bearings is a proud part of Dover Precision Components

DOVER® PRECISION COMPONENTS

HIGH-PRESSURE COMPRESSORS

HOW TO SELECT THE RIGHT TESTS

BY JAMES SOROKES

An obvious objective is to confirm the compressor will perform as predicted. But an equally important goal is to minimize the risk of unexpected aero-mechanical issues during field installation, especially in remote locations such as offshore platforms. It is far better to uncover potential problems before the equipment leaves the original equipment manufacturer's (OEM) facility.

High-pressure and high-power density compressors typically experience rotordynamic (instability) and aerodynamic (stall) complications more often than compressors intended for petrochemical service. Thus, the demand for more rigorous in-house testing has grown.

In response, OEMs and the turbomachinery community developed a variety of test programs and facilities to demonstrate that equipment meets end-user requirements. These options include:

- Volume reduction, inert gas tests using small open- or closed-loops (typically called Type 2 testing according to PTC 10, "Performance Test Code on Compressors and Exhausters," ASME International, 1997)
- Full-load, full-pressure, full-power testing with the contract drivers, gears, auxiliaries, complex piping systems, and so on (typically labeled Type 1 testing)
- Each type of test offers insight into a compression system's aerodynamic and mechanical behavior. Type 2 low-pressure inert gas performance tests are set up based on compressor volume reduction (i.e., exit volumetric flow divided by inlet volumetric flow).

A critical parameter in assessing multi-stage compressor performance is the combined volume reductions of the individual stages to determine the overall volume reduction of the compressor. Thus, the volume reduction of stage 1 determines the volumetric flow into stage 2, which sets the flow into stage 3, and so on.

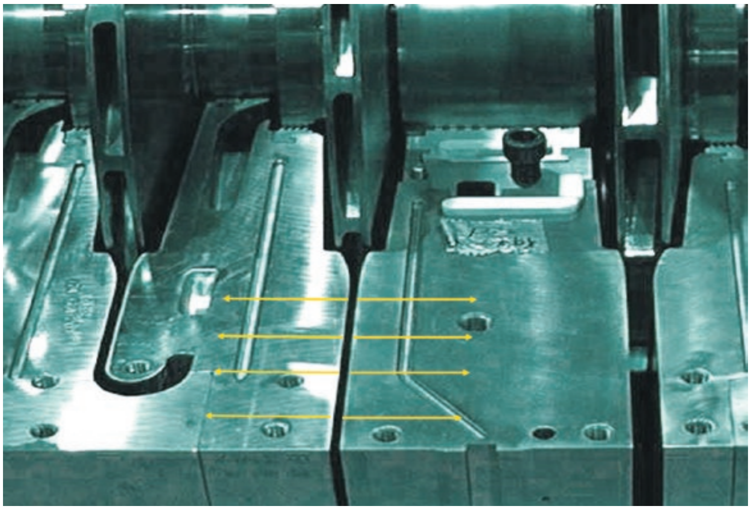


Figure 1: Last-stage diffuser deflection at high pressure during testing

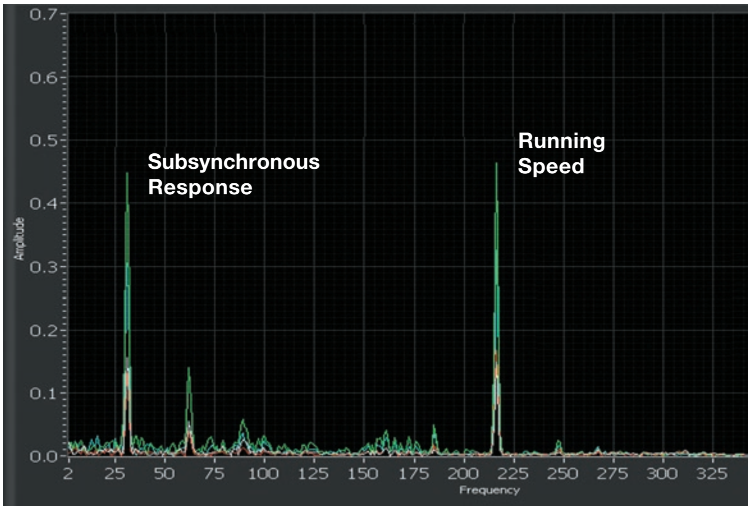


Figure 2: Onset of diffuser stall during a Type 1 test

Volume reduction tests use readily available gases, such as nitrogen, helium-nitrogen mixtures, carbon dioxide and R-134A refrigerants. The selection of test gas or gases, operating speed, and so forth are made to match as closely as possible the volume reduction the compressor will experience in the field. Type 2 tests are also run at lower pressures than the compressor will experience in field operation.

A Type 1 test, per the ASME code, is run with a gas mixture close to the gas compressed at or near operating conditions expected at the site. If it is possible to conduct the test using the actual field gas and field inlet conditions there may be no deviations between the field and test conditions; however, this is rare. In most instances, the inlet temperature at the specified condition cannot be achieved due to an OEM's test stand cooling capacity limits, and it is often impossible to exactly match the field gas.

While a different gas can be used, it must have a k-value (a measure of thermal conductivity) close to the field gas to ensure test and field Mach numbers are equal and the thermodynamic conversion of the work input to the gas produces the same pressure ratio.

Generally, Type 1 test results accurately reflect field performance levels and end users should expect little or no difference between the performance measured during Type 1 testing and those in the real world.

The Type 1 test exposes compressors and their auxiliaries to near field conditions. It offers a greater likelihood of uncovering abnormalities in performance (mechanical or aerodynamic) compared to Type 2 tests. Therefore, end users must weigh the higher cost of the Type 1 tests (as much as 10 times) against potential production loss that might arise.

Test selection

Numerous factors can impact the aerodynamic and mechanical behavior of turbomachinery and the selection process for Type 1 or Type 2 tests. These mostly relate directly or indirectly to the higher pressure and aerodynamic loading experienced on the Type 1 test.

Primary among these are deflections or relative movement of parts. As a result, there can be subtle differences in the primary and secondary flow path geometries under Type 1 and Type 2 test conditions.

For example, one of the most common geometric changes that might occur during a Type 1 test (but not under Type 2 test conditions) is bundle deflection due to manufacturing tolerance stack-up.

In a typical re-injection compressor, the highest pressure occurs in the last-stage diffusers (for both straight-through and back-to-back arrangements). Thus, forces on the sidewalls of the last-stage diffuser will cause the diffuser walls to move apart (Figure 1). As the last-stage diffuser is also typically the narrowest in a compressor, its behavior is more sensitive to axial deflections.

The amount of deflection depends on the machining tolerances of the bundle components and the fits, as well as material deflections that might occur from pressure forces or thermal effects. Typically, maximum deflections are in the tens of thousandths of inches (or tenths of millimeters) and of little consequence in most compressors.

However, if the design diffuser width is narrow (often the case with high-pressure reinjection compressors), tens of thousandths of inches can be a large percentage of the diffuser width.

It is possible for the width to increase sufficiently for diffuser rotating stall to occur, resulting in high levels of subsynchronous radial vibrations (Figure 2). This probably would not be evident during a lower pressure Type 2 test.

In one instance, had a Type 1 test not been run at the OEM facility, this exact problem would not have been discovered until the compressor came on-line in the field. The significant warranty implications to the OEM and lost revenue to the end user due to production disruptions would likely dwarf the cost of a Type 1 test.

It is advisable, then, that end users, process engineers, and OEMs discuss compressor testing at the OEM's facility to address aero-mechanical concerns prior to shipping equipment to the site. ■

James Sorokes, is Principal Engineer at Siemens Oil & Gas in Olean, NY. A paper on this topic, "A Comparison of Type 1 versus Type 2 Testing – Recent Experiences Testing A High Pressure, Re-Injection Centrifugal Compressor," (Sorokes, Kocur, et al) was presented at the 2019 Texas A&M Turbomachinery & Pump Symposium. For more information, visit Siemens.com

BENTLY NEVADA'S NEW PLATFORM

THE COMPANY'S FIRST MAJOR CONDITION MONITORING PLATFORM RELEASE IN 20 YEARS

BY DREW ROBB

Bently Nevada, part of Baker Hughes, pioneered the condition monitoring field in the 1960s. Its 3500 series hardware can be found in facilities around the world.

BHGE chose TPS 2019 to unveil its next-generation platform, the Orbit 60 Series. It collects and processes data, equipping operators with analytics to determine the health of machines. It is designed with cybersecurity in mind.

"Current approaches to condition monitoring can sometimes be inaccessible," said Terry Knight, President of Bently Nevada. "Orbit 60 is a digitally integrated and cybersecure system."

One challenge Bently Nevada had was how to ensure machinery protection while still being able to share condition monitoring information widely. This required complete separation between the protection and the monitoring architectures.

Accordingly, the new system has a built-in data diode — a method that enables secure one-way data transfer from the device to Bently Nevada's machinery management software System 1 for monitoring and diagnostics.

"Even if hackers got into the condition monitoring system, they couldn't get a signal down to the protection system," said Knight. "They have no way to communicate to the protection side of the Orbit 60 due to the data diode." As well as cybersecurity, the platform complies to high standards of safety. It will be SIL 2 and 3 certified, and API 670 compliant.

Extensive customer input was gathered to make improvements to Orbit 60 and provide it with the latest technology. As well as security upgrades, users wanted greater flexibility and for the system to measure a broader range of equipment.

Users can provide more sensors than before to add condition monitoring functionality. They will also be able to write their own rules and customize the software to their own needs.

"We went around the world and discussed the 3500 platform with more than fifty customers to find out what they liked about it, what they wanted it to do differently, and what problems they faced," Knight said.

Bently Nevada Orbit 60 Series

Orbit 60 close up

It now offers 80 data channels compared to an industry average of 50. The company claims that it has 100 times more signal processing power and a smaller physical footprint than the industry standard. It can be placed inside an instrument cabinet or distributed throughout the plant. Operators can connect it to a wide range of assets.

"Orbit 60 Series offers powerful analytics with enhanced flexibility and scalability, along with a built-in cybersecurity features, reducing overall investment cost, and giving operators full visibility of a plant," said Knight.

Those with 3500 series devices and other Bently Nevada systems will find the Orbit 60 complementary. With over 85,000 of the 3500 racks installed worldwide supported by inputs from six million sensors, this platform will continue to be available and will be supported for many years to come, said Knight.

"Orbit 60 can be deployed at the edge of the network to perform analytics specific to a particular piece of equipment, or that data can be transmitted centrally for overall fleet analytics," he said.

The initial release of Orbit 60 will enable it to connect to the System One software platform. Future releases will allow it to integrate with other software and systems. ■

HOW TO USE TURBOEXPANDERS IN ENERGY RECOVERY

NEW DESIGN FOR NATURAL GAS PRESSURE LETDOWN STATIONS

BY FREDDIE SARHAN

Natural gas from producing wells and storage facilities is typically pressurized to facilitate efficient transportation in pipelines across long distances. The pressure is stepped down at pressure letdown (PLD) stations at various stages across the network.

The PLD station depressurizes the gas to lower levels for safe delivery through local distribution networks such as local gas mains, smaller-diameter service lines and individual meters for industrial, commercial and residential end users.

Pressure reduction is most commonly accomplished through the installation of Joule-Thomson (JT) regulating valves, which reduce the gas pressure to the desired level. A simplified JT valve is shown in Figure 1. It consists of a mechanical valve, which is throttled to create the desired pressure differential between the inlet and outlet The JT PLD device is a simple and generally effective tool for pressure reduction, but a by-product is waste heat.

A turboexpander and generator can be used to capture this waste energy. The turboexpander generator reduces gas pressure and converts the resulting kinetic energy into electrical energy, which can be sold to the grid.

Turboexpanders have been successfully deployed for energy recovery in air separation, refineries, geothermal power recovery, steam pressure letdown stations, turbochargers and gas turbine waste heat recovery, as well as in nitrogen, helium and hydrogen liquefaction. However, such systems have had difficulty in attaining viability for natural gas PLD applications due to capital costs and operating expenses.

The turboexpander generator reduces gas pressure and converts the resulting kinetic energy into electrical energy.

Traditionally, the turboexpander uses a large gear box to adjust the speed of the expander turbine, which is coupled to a synchronous generator. It requires a lubrication system that includes an oil reservoir, pump cooler, filters and piping.

Seals are needed to separate the lubricant from the high-pressure natural gas to prevent contamination. The lubrication system is the least reliable component in the overall installation, entailing ongoing maintenance.

These drawbacks can be largely overcome through the use of new magnetic bearing technologies that eliminate the lubrication subsystem. A cutaway model of an alternate turboexpander system is shown in Figure 2, known as the FreeSpin Inline Turboexpander (FIT). The hermetically sealed unit consists of an integrated high-speed turboexpander and a permanent-magnet generator, both driven by a single spinning rotor levitated on non-contact magnetic bearings.

The direct-drive, permanent-magnet generator has variable speed and load capabilities and can run at rated speeds up to 30,000 rpm. The flow of the natural gas is used to cool the stator, rotor and magnetic bearings.

Since moving parts do not come into direct contact, there are no friction losses. No auxiliary lubrication system is needed. This eliminates risk of oil contamination, provides a smaller footprint and lower installation and maintenance costs.

The FIT works as follows:

1. The pre-heated high-pressure gas flows into the turboexpander
2. The gas expands through the radial turbine wheel
3. The low-pressure gas exits the turboexpander and is ready for

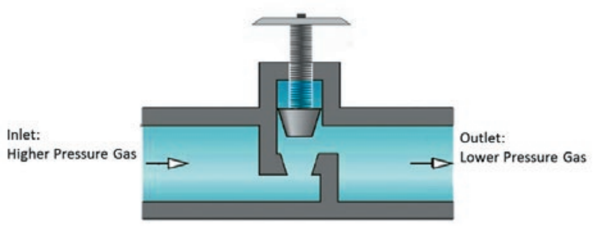


Figure 1: Simplified model of a Joule-Thomson pressure regulating valve

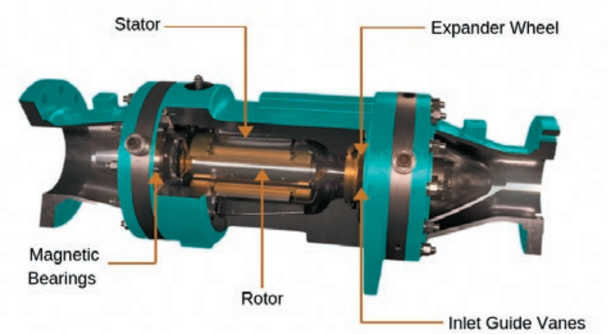


Figure 2: Cutaway model of the Calnetix FreeSpin Inline Turboexpander

flow into the distribution and delivery network for end users

4. The energy wasted during the pressure reduction process is recovered by the turboexpander and converted to electrical power

5. Any excess high-pressure gas not directed through the turboexpander is expanded by the conventional Joule Thomson pressure regulator, which is installed in parallel with the turboexpander

6. The produced electricity enters the Vericycle Bi-directional Power Electronics Unit, which can be programmed to specific power requirements.

Pressure drop is often accompanied by a temperature drop, and this can cause vapor condensation. As a result, the FIT system can include an inlet heating source (i.e., waste heat recovery). The flow through architecture of this system is scalable to approximately 500 kW.

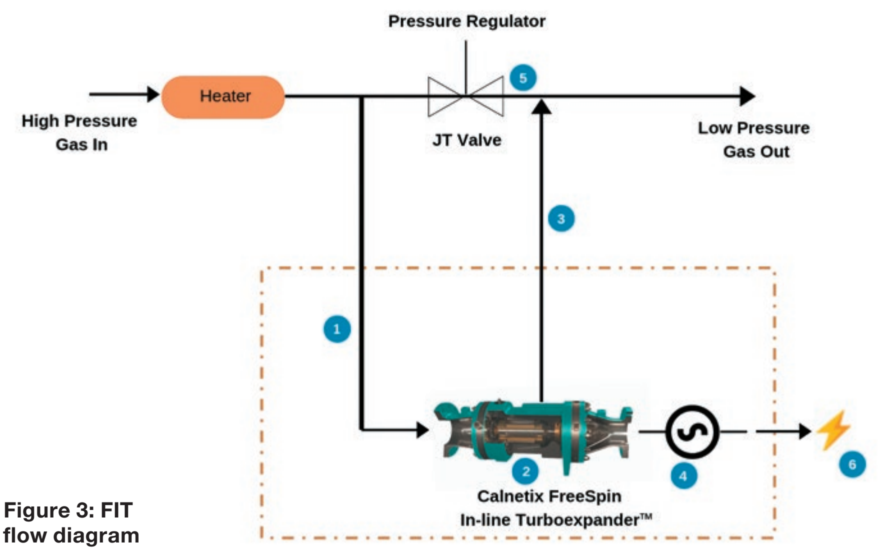


Figure 3: FIT flow diagram

Initial prototype

Collaborating with Baker Hughes, a prototype 300 kW unit was built and tested at a PLD station in Bologna, Italy. The unit is designed for a life of over 10 years without maintenance. Based on preliminary data, Baker Hughes projects an estimated potential energy recovery of over 1.6 million kWh per year. ■

Freddie Sarhan is Vice President of Business Development at Calnetix Technologies, the developer of the FreeSpin In-line Turboexpander with many years of experience in turbomachinery and industrial ORC heat recovery systems. For more information, visit calnetix.com

HEAT RECOVERY STEAM GENERATORS

FAST START AND PEAK CAPACITY CONSIDERATIONS FOR COMBINED CYCLE POWER PLANTS

BY JORDAN BARTOL

As renewables such as wind and solar continue to ramp up in the U.S., the need for faster start-capable grid augmentation is on the rise. In the Heat Recovery Steam Generator (HRSG) realm, many new unit construction projects are touting fast-start capabilities.

Early-to-mid 2000s combined cycle plants are struggling to stay relevant in an ever-changing market. A combined cycle plant in California, for example, succumbed to the renewable push by indicating it plans to shutter its doors nearly 20 years prior to its design end-of-life. The closure is a result of legacy technology that made the plant no longer economically viable.

What can other mid-life plants do to stay relevant into the 2020s and beyond? A smart place to begin is with a review of start-up procedures to determine bottlenecks that might exist in the sequence.

For one plant, the need for steam turbine seals kept them from bypassing steam to their condenser early on. An earlier source of steam using an existing let down station was identified. This cut about 20 minutes off the start-up timeframe.

Another fruitful area to investigate is gas turbine purge time. In many cases, GT OEMs use a conservative timeframe for their purge requirement prior to light-off of the turbine. Fifteen minutes is a commonly seen number.

The National Fire Protection Association (NFPA) Section 85 code requires, "at least five-volume changes at purge rate and for a duration of not less than 5 minutes." There are also specifics on purge volume requirements and purge rate.

Analysis reveals that OEM timeframes are conservative and can likely be reduced. Several recent projects calculated the required purge time at a range of 5-to-8 minutes for F-Class sized HRSGs.

If equipment and control upgrades are in place, it may be possible to eliminate the purge cycle altogether. To satisfy the purge credit requirements, experience indicates that it is necessary to conduct a detailed review of the plant piping and instrumentation diagram (P&ID) surrounding the gas turbine, duct burner and emissions equipment valving.

For most existing plants, this often means retrofitting triple block-and-bleed systems along with controls upgrades which make the purge credit cost-prohibitive unless it is factored in during new unit construction.

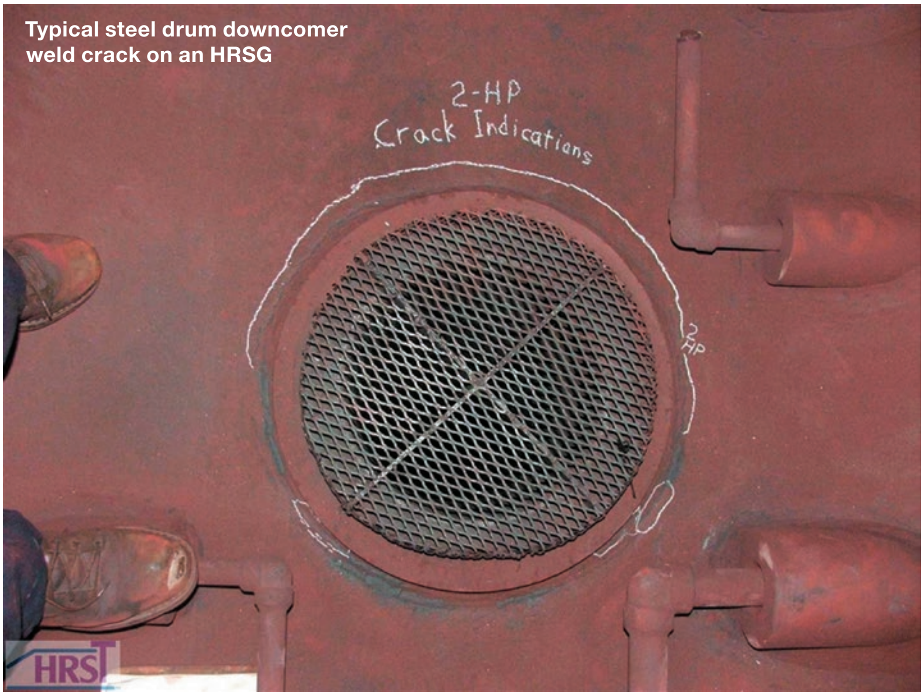
For plants with Selective Catalytic Reduction (SCR) emissions technology, the ammonia flow control valve can be a start-up hindrance as it correlates to NOx emission block average requirements.

Gas-side temperatures at the inlet to the catalyst may not reach their permissive requirement (typically 480°F for natural gas operation and 550°F for fuel oil operation) until late in the startup due to steam turbine interaction.

For one plant no longer fired on fuel oil, collaboration with the catalyst supplier safely reduced the ammonia flow control valve setpoint from 550°F to 480°F, allowing it to meet emissions block average requirement on a more reliable basis.

Additionally, ammonia vaporization on systems with hot gas recirculation (HGR)

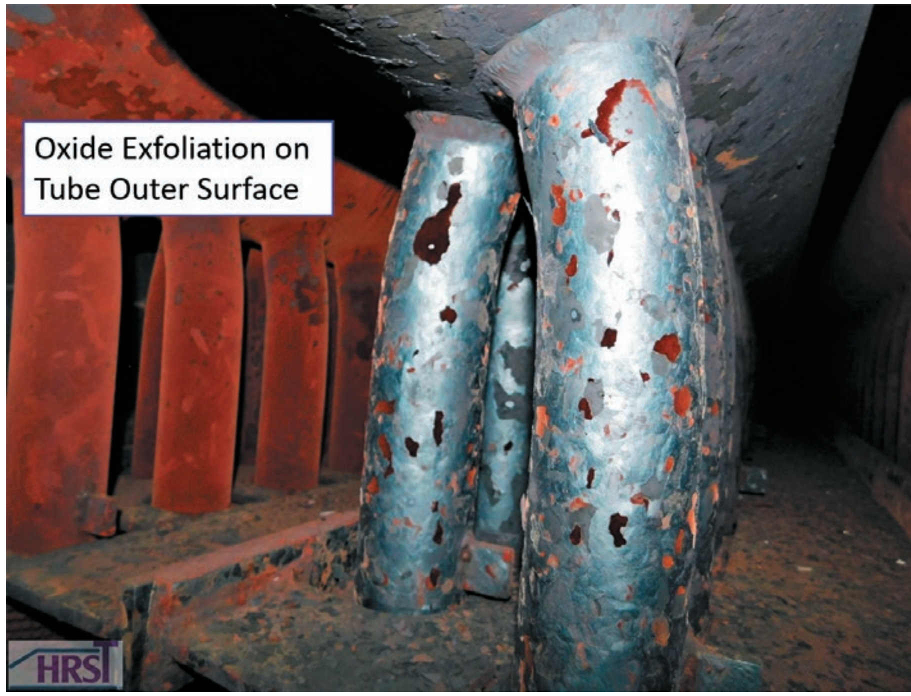
Typical steel drum downcomer weld crack on an HRSG



HRSG inlet

Typical hot gas recirculation pipe

Typical ammonia injection grid



may become problematic. Find out if the start-up gas temperature at the HGR is hot enough to properly vaporize the ammonia. If not, is it possible to use an upstream (hotter) gas source during start-up to satisfy the vaporization equipment?

Steam drum ramp rate

It is no surprise that the HRSG industry is dealing with more and more fatigue damage in high-pressure steam drums as a result of cycling load profiles and quicker starts.

When the rate of pressurization changes quickly, large temperature gradients manifest at the inside/outside drum interface. If the temperature gradient becomes too large, stresses can start cracks at discontinuities like large downcomer and riser nozzles.

When looking at a steam table, a disparagingly large difference in saturation temperature is seen when comparing a cold start with a warm or hot start. For instance, the change in saturation temperature from 0 to 400 psig is about 236°F; from 800 to 1,600 psig is approximately 86°F. What does this mean? There is a larger potential for damage during a cold start compared to a warm or hot start.

Bottom line: Adhere as close as possible to your HRSG OEMs guidelines for cold start-up ramp rates. It is likely that OEM figures for warm and hot starts are conservative. If looking to optimize start-ups, therefore, consider implementing a system to monitor drum stress by measuring the rate of change of shell and nozzle temperature and using DCS alarms.

Performing a remaining life assessment may also provide valuable information regarding safe ramp rates and amount of weld fatigue life left.

Tube metal temperatures continue to rise as gas turbines are upgraded and duct burner systems are pushed to the limit. Practically speaking, the tube metal temperature is a fraction of the steam/water temperature in the tube and the exhaust gas temperature acting on the outside of the tube. This means as gas temperature increases, so does the tube metal temperature.

For large units, the first tube module typically experiences its highest metal temperature during start-up or low-load unfired operation. In HRSGs with duct burner systems, the highest tube metal temperatures in the second module occur while the duct burner is operational (for those with a split superheater (SH) reheater (RH) arrangement.

Most creep or overheating failures have been found downstream of the duct burner system. It is likely, then, that more failures are coming down the pike as duct burners continue to fire harder than ever.

One way to visually inspect for evidence of tube metal temperature problems is to look for oxide growth on ferritic pressure parts. Inspect superheater and reheater tubes looking for oxide layer growth. As tube metal temperature increases, so does the rate of oxide growth. Oxide insulates the tube wall, further driving the metal temperature up.

Key point: even a small (nominally 10°F) increase in tube metal temperature (from 1,070 to 1,080°F for Grade 22 steel or from 1,110 to 1,120°F for Grade 91) can reduce creep life by as much as 40%.

Nameplate capacity

Gas turbine upgrades affect more than just tube metal temperatures. Through analysis, it has been determined that HRSGs often increase steam flow in one or more pressure levels. In one case, a 2% to 5% increase in high-pressure steam flow warranted re-rating the stamped name plate capacity of the HRSG along with pressure safety valve capacities.

Moral of the story: If performing a gas turbine upgrade, do not forget to analyze the effect on downstream HRSG equipment. Questions to ask:

- Is there enough boiler feed pump capacity?
- Will the SH/RH tube/header metal temperatures remain within their design margin?
- Is the steam drum separation equipment still adequate with the additional steam flow?
- Are my safety valves able to relieve properly? ■

Jordan Bartol is Systems Engineer at HRST. Since 1998, HRST has specialized in technical services and product designs for heat recovery steam generators (HRSGs), waste heat boilers, and smaller gas/oil-fired power boilers globally. For more information visit hrstinc.com

SIEMENS GAS & POWER BETS ON INNOVATION

Markus Seibold, Vice President of Additive Manufacturing (AM) at Siemens Power Generation Operations, discusses 3D printing, advanced manufacturing, innovation and how to make turbomachinery more competitive in the coming years.

What role will 3D printing play in turbomachinery development?

AM offers a way to improve performance while lowering emissions. It can enable us to be far more competitive in terms of cost, lead times and development times. And it offers a pathway to better business models such as being able to make spare parts on demand rather than having to spend a fortune to build up a vast inventory of every component for every machine in the field.

How can it help improve turbomachinery service and repairs?

There are many gas and steam turbines out there from the eighties, nineties and even earlier. In many cases, parts are either difficult to find, or simply no longer exist. Yet many of these turbines continue to operate and need parts availability. AM gives us the ability to either 3D print those parts from existing drawings or reverse engineer them using 3D scanning. In many cases, we can actually make a better part than the original.

How about future turbines?

We have the Siemens 9000 HL engine in development. Its combined cycle efficiency will be pushed beyond 63% by including additive parts that could not be made otherwise. These new parts have complex geometries and intricate cooling paths that would be impossible to cast.

Another benefit of AM is speed of development. In the past, it perhaps took six or seven years to bring a new turbine to market. We can half that today with parallel development of technologies, rapid prototyping, virtual reality simulation of different parts and AM.

How about upgrades?

Vanes used to take us 18 to 24 months to develop the concept, design, cast, test and implement in production. Now, we can do it all in three months. Simulation enables us to compare different designs and pick the best instead of wasting time developing protypes for each. We may still cast the final part, but we can select the best design with 3D printing.

Additive manufacturing (AM) can enable us to be far more competitive in terms of cost, lead times and development times.

Can 3D printing help steam turbines?

Yes. While the technology will be used in gas turbines to enhance performance and lower emissions, we expect steam turbines to benefit more through obsolescence management and spare part availability. We can use AM to make valves that are no longer manufactured, solve supply chain issues and ease the strain on inventory.

How is AM used in compressors?

Our 3D printing facility in Sweden already produces some 3D printed parts for Siemens centrifugal compressors. This is helping us to drive more AM technology into our compressors, while enabling us to develop materials and parts that can cope with higher temperature operation.

What are your plans for collaboration?

We are very involved in cross-industry collaboration to advance AM technology. Traditionally, Siemens Gas & Power only looked at the energy market and developed components for itself. Fields such as aerospace did the same. Collaboration was rare. Yet everyone has similar challenges in materials, component durability and cost. Thus, we are actively working with people in aerospace and other areas to design new processes, develop the best materials, produce better components and then industrialize them to scale.

Looking ahead, it is vital that we develop strong and lasting partnerships in innovation. In some cases, the intellectual property (IP) will be ours and in others it will belong to a partner in aerospace. But we envision jointly developed IP, too. By bringing different mindsets together, great opportunities can happen. Active engagement with other companies can greatly speed the pace of development and innovation.

How does Materials Solutions fit in?

Siemens acquired Materials Solutions a couple of years ago but runs it as an independent company. This provided us with immediate know-how to apply AM to turbomachinery instead of having to spend many years trying to figure out 3D printing within Siemens. Materials Solutions brings +12 years of AM experience to the table. In collaboration with Materials Solutions, we have created a new Innovation Center in Orlando to develop new 3D printing processes, materials and applications. ■

GE gas turbine

GE has unveiled the 7HA.03, the newest model in its HA (high availability) gas turbine (GT) product line. Florida Power and Light (FPL) Dania Beach Clean Energy Center will be the first to showcase two 60 Hz versions of this model. Commercial operation is set for 2022.

The 7HA.03 will have a single-cycle net output of 430 MW, which represents a jump from the 7HA.02's rating of 384 MW. The first model launched in 2014 was 290 MW. In combined cycle, a 1×1 7HA.03 plant would be rated at 640 MW, and in 2×1, 1,282 MW.

Like previous HA models, the 7HA.03 features a 10-minute start-up and ramp rate of 75 MW per minute. The 50-Hz 9HA.01 at EDF's Bouchain plant in France clocked a 62.22% net efficiency and the 7HA.01 at Chubu Electric's Nishi Nagoya plant in Japan had a gross efficiency of 63.08%. The 7HA.03 is predicted to have a net combined cycle efficiency of 63.9%. Modular design shortens installation by eight weeks.

New design features include:

• A larger titanium R1 blade to enable greater airflow and output

• The adoption of the GE DLN 2.6e combustion system for higher firing temperatures and emissions compliance

• Turndown to 30% load while remaining in emissions compliance

• Ability to burn a greater variety of fuels.

The GE 7HA.03 comes with a 14-stage compressor and a 4-stage power turbine. It extracts air to cool the gas path without the need for aditional cooling.

GE.com

New Doosan GT

Doosan Heavy Industries announced that the development of its new GT is about 95% complete. First mentioned at PowerGen International at the end of 2018, it is about to undergo a product inspection.

The Doosan DGT6-300H S1 GT will have a capacity of 270 MW and more than 60% combined cycle efficiency. The first models will be supplied to a power plant at Korea Western Power. It will go into commercial operation in 2023.

Doosan.com

Accelerometer

PCB Piezotronics, a subsidiary of MTS Systems, released six extreme temperature charge accelerometers with UHT-12 sensing elements. These products have been developed for use in aviation and power research & development, and monitoring applications for the turbomachinery industries.

This includes models with measurement parallel to the direction of the mounting screw and perpendicular to the direction of the mounting screw. Features include crystal technology sealed in a hermetic package, no pyroelectric output, reduced thermal noise spikes, more consistent sensitivity over a wide temperature change and greater accuracy.

pcb.com

Starrett hardness tester

Hardness testing

L.S. Starrett has introduced two new digital hardness testers with automated load and unload procedures. These models use a closed-loop control unit with a load cell, a DC motor and an electronic measurement and control unit instead of traditional dead weights. This enables accuracy up to 0.5%.

The Starrett No. 3824 Hardness Tester, for example, has an automated Z-axis and is suitable for carbon steel, alloy steel, cast iron and non-ferrous metals. These testing solutions meet ISO 6508-2 and ASTM E18 standards.

They feature a built-in micro-printer, touch-screen control on a high-definition LCD display, USB output, and are furnished with PC-based software. For memory, a maximum of 400 items of test results are stored automatically. Testing capacity is 12" (300 mm) vertical and 8.8" (220 mm) horizontal.

starrett.com

Products continues on page 39

AD INDEX

New prefilters

One of the challenges in air filtration is to combine filter types and filter classes into a tailor-made system adapted to ambient conditions. In humid climates, Viledon coalescer prefilters from Freudenberg Filtration Technologies protect turbomachinery from moisture penetration. This applies to subtropical conditions characterized by high humidity, heavy rainfall and areas of extensive snowfall.

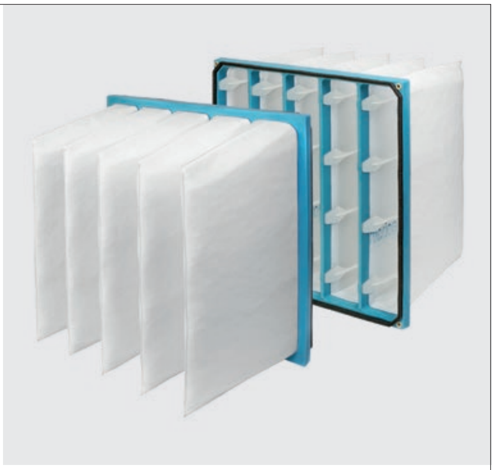
The prefilter must be capable of separating moisture from the supply air. This allows downstream filter stages to handle fine filtration and avoid an increase in pressure drop, often caused by saturated fine and EPA filters.

The Viledon hydroMaxx filter medium enables moisture to roll off. The individual filter pockets face forward in the direction of airflow, ensuring an optimum drainage effect. As droplets roll off the filter surface, they wash away dust particles that accumulate on the surface of the filter.

The self-cleaning process is achieved by the reverse arrangement of the prefilter with a safety distance to the next filter stage. Filters remain dry and function reliably.

Take the case of a power plant in Alabama. Prefilters proved their effectiveness in humid subtropical air, during severe thunderstorms and heavy rainfall, maintaining a lower pressure drop than the previous filter system. Filter replacement was extended from 3-to-18 months.

freudenberg-filter.com



A view of the upstream and downstream side of the Viledon hydroMaxx Coalescer pocket filter from Freudenberg Filtration Technologies

Support-free additive manufacturing was used by Velo3D to print this shrouded impeller

3D printing

Recent breakthroughs in industrial metal additive manufacturing (AM or 3D printing) are lifting key restrictions on how pumps and compressors are designed and manufactured. These restrictions apply to limits that even current-generation AM systems face in creating passageways, blades and channels.

The breakthroughs occur in AM optics, powder-bed quality, chamber environment, consumables, and real-time process monitoring-and-control for part validation in individual or series production.

The Velo3D AM system produces a shrouded impeller up to 12" diameter, with shroud angles down to 5°. No support structures are required to hold the blades and other features in place during manufacture in the 3D printer.

Externally, just the extruding lip on the outer rim and the bottom edge are anchored. The system is able to produce most shrouded-impeller geometries with a surface roughness lower than 10-micron SA on all surfaces, internal and external.

Closed-loop melt pool control and metrology systems provide real-time control and monitoring throughout the build. This helps ensure the structural integrity of each finished piece and consistency from build-to-build.

Challenges involved in making shrouded impellers for centrifugal pumps are a good fit for this technology. Unlike complex machining from a block of metal, AM technology for impeller creation uses only the material necessary for each part, with the elimination of supports, reducing extraneous material use even further.

Cutting costs as well as final part weight through optimized design, the new process for support-free 3D-printing shrouded impellers offers an alternative to traditional manufacturing.

velo3d.com

Laser safety

Rotalign touch EX is designed for maintenance professionals working in explosive atmospheres in the oil & gas, petrochemical and chemical process industries. This safe alignment system from Pruftechnik is ATEX/IECEx Zone 1 certified, reduces permitting and simplifies alignment in EX areas. SensAlign single-laser technology comes with a ruggedized tablet and touchscreen to perform laser-shaft alignment. It offers measurement accuracy and repeatability. Setup is fast and machine pre-alignment is unnecessary.

pruftechnik.com

Automated pipe sizing

Applied Flow Technology (AFT) has developed hydraulic flow tools to design and troubleshoot piping systems. The Automated Network Sizing (ANS) Add-on Module automatically sizes all piping and system components to minimize weight and system costs.

The ANS Module for AFT Fathom or AFT Arrow will help engineering firms turn existing steady-state hydraulic models into calculation tools to find cost reduction opportunities in pipe systems.

aft.com

MYTH: ONE MACHINERY SOLUTION FITS EVERY OIL & GAS APPLICATION

Reality has the nasty habit of undermining well-intentioned theory. If compressor stations would always work at one well-defined, constant operating point, the weather would never change, and units would never have to be shut down. The best thing one can do for any installation would be a single compressor train, without spares.

There are industrial installations where all these assumptions are true. But they are usually not found in oil and gas upstream and midstream applications.

This differentiates upstream and midstream applications from most downstream refinery, LNG, and petrochemical plant applications where a fully loaded, single machine is usually the best solution since operational flexibility and load swings are trumped by lower capital costs, higher efficiency and reduced maintenance.

Part of the discussion should incorporate the conceptual differences of different driver types. Drivers used in the oil & gas industry include gas turbines (GTs), steam turbines (STs), electric motors, gas expanders and engines.

Availability, part-load efficiency factors or the impact of changing ambient temperatures are different for each of these drivers. This impacts their usefulness for a particular application.

GTs typically have high reliability and availability, and their performance changes with ambient temperature and load. That, and the availability of natural gas as a fuel, makes them an excellent option for upstream and midstream applications.

Similarly, STs are widely used in refineries and petrochemical plants because of their reliability, ruggedness, and the availability of centralized steam production.

The demonstrated availability and reliability of GTs and STs is not size-dependent, at least not between 1 MW and 200 MW. More important factors are condition monitoring strategies, logistics strategies and OEM or 3rd party support capabilities.

The argument is often made that larger turbines are more efficient, and less expensive to buy and operate on a cost-per-power basis. If we compare the efficiency of different turbines, we will find that a 100 kW microturbine is less efficient than a 200 MW unit.

However, if we look into smaller scaling ratios this argument does not hold. Specifically, most GTs and STs above 10 MW and below 200 MW have about the same efficiency.

For upstream and midstream, a key consideration is flexibility of installation to adapt to multiple operating conditions. For example, pipeline studies show that the fuel consumption for stations with multiple units is generally lower than for single-unit stations, if the operating conditions fluctuate significantly.

Bigger is not always better for compressors and their drivers, especially in upstream and midstream applications.

Other studies indicate that outage of a single unit causes a more significant reduction in pipeline throughput than the outage of a unit in a multiple unit compressor station. Several published simulations show the annual pipeline capacity (accounting for established unit availability) tends to be higher for multiple unit installations.

But in most downstream and LNG applications, throughput and operating conditions are relatively steady. For compressor installations, such as refineries and ethylene plants, larger single-unit compression drivers and driven equipment are preferred, mostly because of reduced capital cost, less equipment and installation simplification.

When looking at the cost of operation of pipelines, we find that many compression stations have significant swings in ambient temperatures between day and night and seasonally. These swings are often large enough to shut down one train in a station with multiple units.

This improves fuel consumption since a GT at full load has better efficiency than a GT at part load. It also increases station availability as the unused unit can serve as a standby unit. Further, a unit that does not run does not accrue operating hours, reducing maintenance requirements.

Similar schemes have been discussed for single-unit stations by shutting down alternate stations along the pipeline. In general, where pressure losses rise disproportionally if one station is down, pipeline hydraulics rarely allow this. Also, initial design estimates of power demand may have to be revised later.

Pipeline hydraulics are sensitive to assumptions on roughness and soil temperatures. In many instances, then, compressor operating conditions do not match predictions once units are in operation. Additionally, true operating conditions may be different from design conditions.

It is relatively easy to construct a scenario that favors an argument for or against big units, but it largely depends on the application. Generally speaking, if a compressor train is sized for a narrow operating range, and temperatures do not affect performance, a single unit will look good.

This is often the case when STs or electric motors are used as drivers since their performance is not dependent on ambient temperatures and they require fewer overhauls. On the other hand, multiple smaller gas turbines are the preferred solutions in applications where a wide operating condition and operational flexibility is critical.

There is no simple answer. Bigger is not always better for compressors and their drivers, especially in upstream and midstream applications. The type and appropriate size of the equipment always depends on the application and the operational requirements. ■

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.


WE PIONEERED THE TURBOEXPANDER INDUSTRY.
NOW WE'RE REINVENTING IT.
As part of Air Products, the world leader in industrial gas, Rotoflow is transforming the turbomachinery industry with unprecedented performance, reliability, and value.
This powerful new partnership combines technological innovation, unique operational data, and world-class service, ensuring that you experience more.
24/7/365 Global Support
+1-610-481-7234 • connect@rotoflow.com • www.rotoflow.com
TPS
TURBOMACHINERY & PUMP SYMPOSIA
VISIT US AT BOOTH #3216!
ROTOFLOW
An Air Products Business
Experience more. *Together.*


Atlas Copco
Meeting Your Total Turbomachinery Needs
We know you're no stranger to pressure. At Atlas Copco Gas and Process, we transform industrial ideas into solutions that help you thrive under extreme conditions. Backed by more than seven decades of extensive experience and technical expertise, our full spectrum of compressors and expanders provides the reliability and efficiency you need.
Handle the Pressure
Whether you need turboexpanders, turbocompressors or gas screw compressors, Atlas Copco Gas and Process is the total provider for your process gas operation, helping you handle today's pressures while creating a sustainable future.
Learn more at www.atlascopco-gap.com