global
Gas Turbine News
Volume 50, No. 3 • August 2010

ATLANTA, GEORGIA USA /// ASME INTERNATIONAL GAS TURBINE INSTITUTE

In this issue

Register Today for the 2010 ASME Gas Turbine Users Symposium

GTUS GAS TURBINE USERS SYMPOSIUM
Presented by the International Gas Turbine Institute

Co-located with the 39th Turbomachinery Symposium

Join us in Houston October 4-7, for the 2010 ASME Gas Turbine Users Symposium.

The 2010 GTUS program will build on the success of past years with an exciting slate of topics for the gas turbine user, consultant and manufacturer, according to Thom Eldridge, 2010 GTUS Chair.

A new element of the 2010 program is a 2-part tutorial on coatings, their application, uses, materials, processes and serviceability. The program will again include a tremendously popular session featuring selected, application-oriented technical papers from ASME Turbo Expo. A full-day, 3-part tutorial on the Introduction to Gas Turbines will provide a comprehensive overview on the function, performance characteristics, and, in particular the typical operational issues for industrial gas turbines. Additional topics this year include remote monitoring, inlet conditioning and heat recovery steam generators.

With the current uncertainties in this recovering economy, the GTUS forum represents high ROI. It offers a practical and interactive opportunity to share experiences and challenges with other gas turbine users, manufacturers and consultants.

IGTI is also offering pre-symposium workshops on October 4, 2010 at the George R. Brown Convention Center:

- ***Gas Turbine Combined Cycle Primer***
  S. C. (John) Gülen, Principal Engineer, GE
  8:30 a.m. – 5:00 p.m.

- ***Basic Gas Turbine Metallurgy and Repair Technology***
  Lloyd Cooke & Doug Nagy, Liburdi Turbine Services;
  Warren Miglietti, Power Systems Mfg., LLC
  8:30 a.m. – 5:00 p.m.

Visit **www.asmeconferences.org/gtus2010** for more details and to register.

Advance Registration Deadline is September 6, 2010. ASME members qualify for a reduced registration fee. GTUS attendees have the option of upgrading their conference registration to include the Turbomachinery Symposium technical sessions for only $300.00 more. ✻

GTUS Registration Includes:

- Admission to all ASME GTUS sessions
- Free access to the 39th Turbomachinery Symposium (T39) exhibit floor
- Complimentary T39 lunches and evening meals
- GTUS only networking dinner and facility tour
- Invitation to the T39 welcome address
- GTUS proceedings CD
- With upgrade fee, delegates also have admission to all T39 sessions

View From The Chair

By Ron S. Bunker, Ph.D., Chairman of the IGTI Board of Directors

Ron is a Principal Engineer in the Energy & Propulsion Technology Labs of the GE Global Research Center in Niskayuna, New York. bunker@ge.com.

Welcome back to the *Global Gas Turbine News* (GGTN), the quarterly news and events letter of the ASME International Gas Turbine Institute. First, looking back over my own journey of the last five years, I would like to thank our incredible and dedicated IGTI staff, as well as all of the technical community volunteers, for making our premier Turbo Expo event such a success through good times and hard times. We have just completed a record breaking TE2010 in Glasgow despite the slow pace of recent economic recovery (986 technical papers, a 7.5% increase over TE08 Berlin). This speaks volumes to the vitality and necessity of the gas turbine and turbomachinery sector globally, and should emphasize to us all the importance and impact of what we do as a technical group.

I recently viewed a lecture by Prof. Nate Lewis (CalTech), which was part of the "Jet Propulsion Labs von Kármán Lecture Series" of February, 2008 (http://nsl.caltech.edu/energy.html). This lecture summarized our current global energy consumption rates and carbon emissions, and presented several projections with various optimistic or pessimistic assumptions to the year 2050. By Nate's reckoning the next forty years will either make or break humans as a species. It is quite easy to come away from his simple yet logical predictions that we are doomed no matter what we do. The only path to survival that he proposes is one in which the world immediately builds up a solar energy usage capability, starting now (or rather in 2008), at the rate of something like one million homes per day, setting aside issues like energy storage. Well, 'daunting' was the word often used in his lecture to be sure. However, though we are now emitting historically record levels of carbon, we do not actually yet know, nor can we predict, the outcome of these higher ppm levels. This is the one bright spot, if we can call it that, to encourage us to find solutions.

While Nate never mentions gas turbines, one of the big target areas he highlights for immediate action is higher efficiency power / energy production, as well as lower consumer use. Gas turbines, steam turbines, and associated turbomachinery systems are key here, especially as many employ natural gas, the lowest carbon emitter of the current fossil fuels in common use. Nate takes note of wind turbines as the fastest growing and most cost effective means of increasing energy from renewables, at least as a small piece of the overall solution. Solar is by his estimation though the only sustainable resource capable of solving our dilemma.

So, what can IGTI do today and in the critical next 10 to 20 years to help meet this challenge? As many of you saw in Glasgow, we are working to expand our influence and apply our expertise not only to increased energy efficiency from gas and steam turbines, but also wind turbines. The IGTI technical community has vast experience that can be applied in this energy field. It does not stop there. In the TE2011 in Vancouver, technical sessions will begin around the area of combined solar-turbine power cycles and installations. In fact, all aspects of energy exploration, conversion, and delivery that involve rotating turbomachines can benefit from our expertise and accumulated knowledge. As an integral part of ASME, IGTI has a large role to play in ASME's Grand Energy Challenge (http://strategy.asme.org/energy.cfm). The IGTI Board of Directors is seeking to expand our involvement and influence in this challenge, both on the technical and political fronts. This may take the form of joint cooperative efforts with other ASME divisions and other societies / organizations, an expanded Turbo Expo event, or additional IGTI events. Your contributions are absolutely necessary to the success of whatever path(s) we take. I invite your suggestions and commentary at any time, and that includes contributed articles to this GGTN publication. ✻

CALENDAR OF EVENTS

OCTOBER 4, 2010
ASME Gas Turbine Users Symposium (GTUS) Workshops Co-located with 39th Turbomachinery Symposium
George R. Brown Convention Center | Houston, TX USA
- ***NEW* - Gas Turbine Combined Cycle Primer**
  S. C. (John) Gülen, Principal Engineer, GE
- ***Basic Gas Turbine Metallurgy and Repair Technology***
  Lloyd Cooke & Doug Nagy, Liburdi Turbine Services; Warren Miglietti, Power Systems Mfg., LLC

OCTOBER 4-7, 2010
ASME Gas Turbine Users Symposium (GTUS)
Co-located with 39th Turbomachinery Symposium
George R. Brown Convention Center | Houston, TX USA
With its focus on gas turbine drivers, the GTUS program will complement the excellent technical content pertaining to rotating equipment offered at the Turbomachinery Symposium.

OCTOBER 27-28, 2010
IGTC-10
5th International Gas Turbine Conference
Conrad Hotel | Brussels, Belgium
Organized by the European Turbine Network, the program will focus on the future of gas turbine (GT) technology from a users', a research, and a political point of view. It will also explore the market outlook and the role played today by gas turbines in the international energy policy mix as well as for the decades to come.
http://www.etn-gasturbine.eu/page18052315.aspx

NOVEMBER 22-26, 2010
Gas Turbine Technology for Operations & Maintenance Engineers Course
Cranfield University, UK
For more information, visit: http://www.cranfield.ac.uk/soe/shortcourses/gte/page4579.jsp

FEBRUARY 13-16, 2011
The 1st Middle East Turbomachinery Symposium (METS)
Sheraton Resort and Convention Center | Doha, Qatar
Under the primary sponsorship of Qatar Petroleum, METS will be closely modeled after Texas A&M Turbo Lab's Turbomachinery Symposium that has been held in Texas since 1971. For more information, visit: http://middleeastturbo.tamu.edu/

FEBRUARY 21-25, 2011
Southwest Research Institute Training Week
SWRI | San Antonio, TX USA
Offers hands-on training by industry experts.

JUNE 6-10, 2011
ASME Turbo Expo 2011
Vancouver Convention & Exhibition Centre | Vancouver, British Columbia, Canada
IGTI's flagship event comprises a major gas turbine conference and exhibition.
www.turboexpo.org

AUGUST 1-3, 2011
47th AIAA/ASME/SAE/ASEE Joint Propulsion Conference & Exhibit
San Diego Convention Center | San Diego, CA
www.aiaa.org

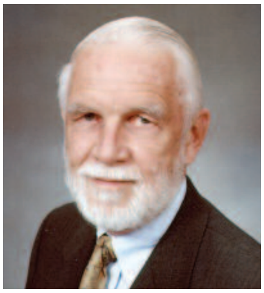
JUNE 11-15, 2012
ASME Turbo Expo 2012
Bella Center | Copenhagen, Denmark
IGTI's flagship event comprises a major gas turbine conference and exhibition.

Featured Column: ***As the Turbine Turns...***

Focus on Fans

By Dr. Lee S. Langston, Professor Emeritus of Engineering, University of Connecticut

Langston is a former editor of the ASME Journal of Engineering for Gas Turbines and Power and has served on the IGTI Board of Directors as both Chair and Treasurer.



When jet-engined commercial flights first started in the 1950's, aircraft were powered by turbojets – jet engines in which all thrust was provided by gases that went through the engine from inlet to exhaust nozzle, exiting in a single high velocity jet.

Nowadays, almost all commercial aircraft are powered by turbofan jet engines, so-named for a ducted front-mounted fan. Air drawn into the fan is divided into that which flows out of the fan into the jet engine itself and the remainder that bypasses the engine. The lower velocity bypassed air and the higher velocity engine air combine downstream to produce thrust with a larger mass flow at an average velocity lower than the high velocity jet flow.

With a large frontal area, the commercial aircraft turbofan is designed to produce peak thrust at takeoff, with most of the thrust produced by air drawn in by the fan that bypasses the jet engine core itself. Bypass ratios, - the mass of fan air bypassed for every unit mass of air through the engine – can be as high as 8.4:1, as in General Electric's 100,000 pound thrust GE90 engine.

The addition of a fan to a jet engine was first proposed by Frank Whittle (one of the inventors of the jet engine) in a 1930 British patent. He called it a thrust augmenter, because its addition does increase thrust and reduce fuel consumption (that is, has a lower thrust specific fuel consumption (TSFC).

For subsonic flight, the propulsive efficiency, η_p, of a turbofan is also higher than that of a turbojet. This efficiency is defined as the useful propulsive power (the product of thrust and flight velocity, V_o) divided by jet power (rate of change of the kinetic energy of gases through the engine). This simplifies to [1]

Fig. 1

$$\eta_p = \frac{2}{V_e/V_o + 1}$$

where V_e is a suitable average of the lower velocity bypass air and the higher velocity jet exhaust. Equation (1) shows that a turbojet engine with a high value of V_e/V_o has low propulsive efficiency, while a turbofan engine with low values has a corresponding high propulsion efficiency.

Since V_e in Equ. (1) is largely determined by bypass flow in a high bypass engine the fan pressure ratio (which could be 1.6 for a bypass ratio of 8:1) is the key parameter. Lowering it to decrease V_e and increase η_p means increasing the bypass ratio.

New fan technology that has been developed by Pratt and Whitney to increase bypass ratios to 11:l, using a gear box to reduce fan speed and increase fan diameters. The net result is a large reduction in engine noise and as much as a 16 percent improvement in fuel consumption (lower TSFC). Right now P&W geared turbofan engines are being designed, developed and tested in the 18,000 – 30,000 pound thrust range, which represents the biggest and most lucrative part of commercial aviation engine market.[2]

Some have scoffed at the use of a gear box for the fan. At IGTI's TURBO EXPO '05 in Reno, during the keynote session, the president of Pratt & Whitney reported on progress with the geared turbofan. During the keynote discussion period, retired CEOs from GE Aircraft Engines and Rolls-Royce both stated that based on their experience such gear systems were to be avoided.

Recently, I was given a tour of P&W's gear facilities in Middletown Connecticut by Michael McCune, who is the manager of their fan drive gear systems. The company has been developing the fan gear box over a period of twenty years, involving a serious commitment of research, design and gear rig testing. The company has a long history of gear box experience associated with their very popular turboprop gas turbines at Pratt & Whitney Canada.

Field tests have conclusively shown that the geared turbofan has a much lower level of noise. Currently, some airlines have as much as 35-60 percent of their operating costs in jet fuel use. If the geared fan engine does indeed significantly reduce fuel use, this improvement in fan performance will be hard for the competition to beat.

Another way to improve fan performance is to change the pitch of fan blades, during an aircraft flight cycle. For instance, with propeller driven planes, controllable pitch propellers have been in use since the 1920s. During the 1990s jet engine companies tested variable pitch turbofans, but the variable pitch mechanisms used proved to be heavy, bulky and difficult to control.

Recently, Rotating Composite Technologies (RCT), a small firm in Kensington, Conn. has come up with a unique patented design for the variable pitch fan that promises to overcome the deficiencies of those tested in the 1990s[3]. As I write this, two papers on it are scheduled to be presented at our June 14-18, 2010 Turbo Expo in Glasgow. One by John Violette and Eric Loos[4] describes the new RCT variable pitch fan design. The second paper by Robert Mazzawy[5] compares a conventional engine design with one that has the RCT variable pitch fan. Both engines were sized to deliver 30,000 pounds thrust at the operating point. The Mazzawy study shows that an 11 to 16 percent fuel burn improvement for the RCT variable pitch fan design, covering a range of flight profiles.

Stay tuned to see if geared and variable pitch fans will move into the jet engine market, to bring about double digit improvements in airline fuel efficiency! ✻

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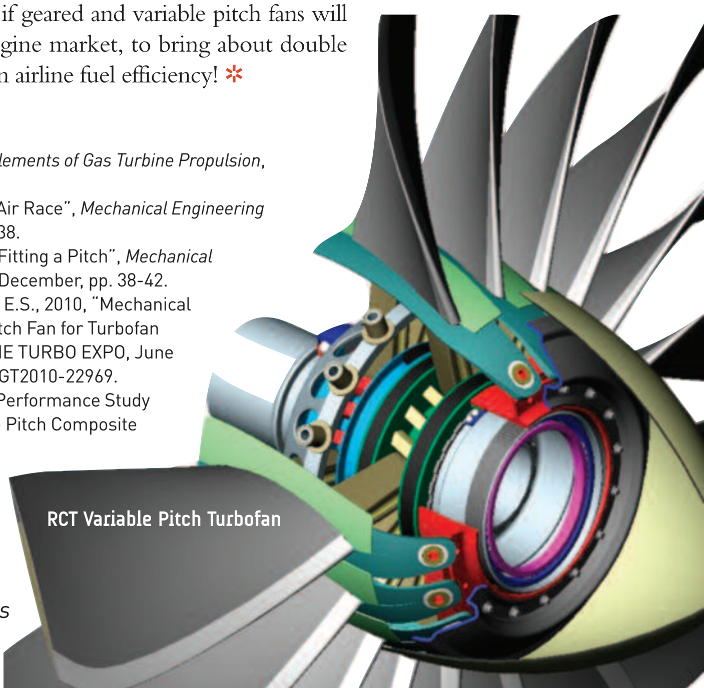
3. Langston, L.S., 2009, "Fitting a Pitch", *Mechanical Engineering Magazine*, December, pp. 38-42.
4. Violette, J.A. and Loos, E.S., 2010, "Mechanical Design of a Variable Pitch Fan for Turbofan Engines", Proc. of ASME TURBO EXPO, June 14-18, 2010, Glasgow, GT2010-22969.
5. Mazzawy, R.S., 2010, "Performance Study for Benefits of Variable Pitch Composite Fan", Proc. of ASME TURBO EXPO, June 14-18, 2010, Glasgow, GT2010-22148.



RCT Variable Pitch Turbofan

TURBO EXPO
Turbine Technical Conference & Exposition
Presented by ASME International Gas Turbine Institute

Turbo Expo 2010 Broadens Scope

To a packed house, Executive Conference Chair Graham Hopkins of Rolls-Royce led the opening session featuring an exceptional keynote focused on *"Extending Limited Natural Resources Through Energy Technology Innovations."* Speakers included Peter Christman, Jr., Walter Downing and Colin Smith.

Thank You Turbo Expo 2010 Sponsors

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Solar Turbines
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Dean's Shortbread

ASME Turbo Expo 2010 in Glasgow maintained its reputation as the world's premier gathering of turbomachinery professionals. Throughout the week, the 3,000 delegates from over 50 countries shared practical experiences, knowledge and ideas on the latest gas turbine technology trends and challenges, as well as on related topics in wind and steam turbine technology.

Led by Executive Conference Chair Graham Hopkins of Rolls-Royce, the opening session featured an exceptional keynote focused on *"Extending Limited Natural Resources Through Energy Technology Innovations"*, followed by the annual awards program of prestigious ASME and IGTI gas turbine awards. The Technical Congress offered five days of nearly 1,000 technical presentations, including special honorary lectures by the Industrial Gas Turbine and Aircraft Engine Technology award winners, Dr. Hans-Juergen Kiesow of Siemens and Professor Riti Singh of Cranfield University.

During the three-day Exposition, delegates met with representatives of premier companies supplying quality turbomachinery products and services. Special recognition went to Pratt & Whitney and NASA as exhibition visitors voted their displays the best. A welcome reception hosted by the City of Glasgow and a mixer for early career engineers and students added to the variety of abundant networking opportunities throughout the week. The reception and dinner for women working in the turbomachinery area featured talks from Lynn Gambill of Pratt & Whitney and Antje Lembcke of Siemens, sponsors of the event.

If turbomachinery is part of your professional life, you cannot afford to miss the annual ASME Turbo Expo! To plan for 2011, see page 54 of this issue and keep informed throughout the year by visiting Turbo Expo online at www.turboexpo.org ✲

The city of Glasgow treated Turbo Expo 2010 attendees to an Opening Reception at Kelvingrove Art Gallery and Museum.

Young Engineer Travel Awards Presented at Turbo Expo

IGTI offered several travel awards to students and young engineers employed in industry or government to attend ASME Turbo Expo to present papers on which they were authors. Five individuals were selected for the Glasgow conference. We congratulate them all for their efforts!

Winners included: **Jacqueline O'Connor,** *Georgia Tech;* **Matthew Bloxham,** *Ohio State University;* **Austin Selvig,** *Carleton University;* **Kevin Turner,** *GE Aviation***; Oleksiy Larin,** *National Technical University.*

Best Booth - Large Display - Pratt & Whitney

Best Booth - Small Display - NASA

The Expo showcased cutting edge technologies from major OEMs.

The Reception and Dinner for Women Working in the Turbomachinery Area featured talks from Lynn Gambill of Pratt & Whitney and Antje Lembcke of Siemens.

IGTI Welcomes New Board Member

IGTI is pleased to announce our newest Board member, Dr. Seung Jin Song, Professor of Mechanical and Aerospace Engineering at Seoul National University in South Korea.

Song earned his Sc.D. in Aeronautics & Astronautics at MIT. Prior to his current position, he was a research assistant, assistant professor, and visiting professor at several different universities.

Song specializes in aerodynamics and fluid structure interactions in turbomachinery, power plant system design and performance analysis, and stability of refrigeration systems. He has been involved with ASME Turbo Expo since 1996 and has achieved a variety of honors throughout his career, including the ASME Melville Medal in 2003. He is a member of both ASME and the Korean Society of Mechanical Engineers and has also served as an editor of various technical journals.

Performance Testing of Transonic Rotors

By Anthony J. Gannon and Garth V. Hobson

A driving force behind the improvement found in high-speed compressor fans has been the advent of computer simulations. Of course there is still a need to test these fans and in some cases be able to evaluate the computer codes against accurate experimental data. Here I hope to share some of the challenges and solutions found in the testing these compressor fans.

At the Turbopropulsion laboratory (TPL) at the Naval Postgraduate School (NPS) the research and testing of high-speed compressors also affords students the opportunity to work with these machines. With these types of machines supersonic flows are present and there is no longer the ability to make the assumption of incompressible flow as with most fan test rigs in educational environments. While education is a driving force of NPS the test compressors are used for current research with students completing masters theses using data collected within the laboratory. The TPL test facility focused on here, the transonic compressor rig (TCR) shown in Figure 1 is capable of delivering 337kW (450 hp) at 30 000 rpm. What is remarkable is that this power is absorbed by an 279 mm (11") rotor weighing around 4.5 kg (10 lbs). Of course when involved in testing of such highly stressed machines, on occasion failure does occur; Figure 2.

In an ideal situation experimental work is best done on full scale devices but obviously cost and practical constraints mean this is not usually possible. Instead one needs to isolate the most influential variables and try to design experiments that capture these. In the case of high-speed compressors the Mach number is one of the most important parameters. In order to limit power consumption in a test machine the simplest change is simply to scale down the machine. If the tip speed of the blades is to be kept the same to ensure Mach number matching with operational compressors the rotational speed needs to be increased proportionally. Typically our test compressors run with tip Mach numbers of approximately 1.5.

A second concept to reduce the power consumption of the machine once you have scaled it down is to throttle the flow before the rotor rather than after it. As a high-speed rotor compresses the incoming air by around 1.4-1.6 times the air leaving it is appreciably denser than that coming in. If one throttles upstream of the rotor the exhaust air leaves the machine at atmospheric pressure which means that the incoming air is below atmospheric pressure. Throttling after the machine means one is sucking in atmospheric air and the mass-flow through the machine is approximately 30% higher with a near proportional increase in the power consumption. In the case of aviation engines this reduction in density is similar to flying at high altitude. For sea level based gas-turbines such as in ships or power stations the flow change from laminar to turbulent over the blade will occurs sooner than at altitude, however these effects can be accounted for empirically. With upstream throttling care has to be taken to provide long enough ducting ahead of the test compressor to present as uniform as possible flow after the flow rate measuring nozzle.

Another challenge is bearing choice and the proper functioning of the associated lubrication systems. Rotating test rigs are by there nature unique devices and so operation of them is a continuous learning process. In the last decade the emergence on affordable ceramic ball bearings has been a major advantage. They allow operation at much higher rotating speeds and operating temperatures. Bearing cooling and lubrication is still needed and this is performed using an oil mist cooling system. In the TPL rig there are four bearing sets and four oil mist coolers with redundancy built in by allowing each oil mist cooler to service two bearing sets (Figure 3). In this way if one oil mister fails no bearing are left without lubrication. A bearing arrangement similar to a milling machine spindle is used with the rear bearing pair held in place by flexure arms that are instrumented to measure the net force forward or rearwards on the shaft while the front bearing pair is allowed to float. The reason for this is that the shaft lengthens during operation due to temperature increase and load and thus one bearing pair needs to float. The axial forward pull of the test rotor is counteracted by a pneumatic balance piston at the rear of the shaft and the force adjusted until the net axial force on the shaft is close to zero. The most amazing aspect of this rig is that it was designed on the late 60's by the late Professor Mike Vavra and the rig is still state-of-the-art today.

There was some concern about the ability of ceramic ball bearings to handle the shock loads of compressor stall and surge. Here the compressor applies large cyclic forces to the rig via the rig as it stall and un-stalls during a surge cycle. During an experiment it is routine to drive the compressor into surge and observe when surge occurs and what is required to recover from a surge. Our experience has shown that the bearings can withstand about a dozen surge cycles.

A further operational consideration is the need to operate with very small tip clearances. A scaled down compressor operating at high-speed tends to grow radially and rubbing between the casing and blade tips is normal. Figure 4 shows the abradable material which allows operation at very small tip gaps without damaging the rotor. This material is baked into a trench above the rotor and needs to abrade without sanding the tips of the rotor. We have settled with a machinable rubberized material and grooved the bottom of the trench to improve the adhesion to the casing.

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Figure 1.
Test Fan and Stator.

Figure 2.
Compressor Rotor Failure.

Figure 3.
Drive Turbine Housing and Oil-Mist Cooling System.

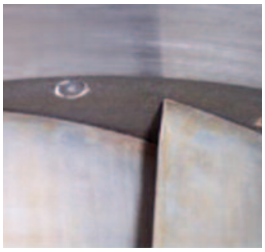


Figure 4.
High-speed Pressure Probes and Abradable Strip.

Figure 5.
Instrumentation setup.

IGTI Training Events Attract Early Career Engineers!

By Shirley Barton, IGTI Professional Development Manager

Engineers in the early stage of their careers have constituted 62.5% of the registrants at IGTI training programs over the last year! This is one indicator of the professional development value of the programs offered. Basic as well as intermediate training programs have been delivered on a variety of platforms, including computer-based distance learning, CD-ROM, classroom, webinars and training weeks. Through these platforms, every program has focused on salient industry topics presented by top experts.

Workforce development is a primary strategic goal throughout ASME and a high priority at IGTI. Under the direction of Professional & Member Development Manager, Shirley Barton, IGTI's objectives include expanding opportunities for education and training in those areas most important to members. This also includes partnering with organizations with complementary objectives to provide training opportunities. **If you have a topic you think will be of value to the turbine industry and would like to present it in a webinar or training week format, please contact Shirley at bartons@asme.org.** Webinars are typically one-hour, live sessions, highly customizable and affordably priced for group participation. Training weeks are on site, hands-on events and customizable.

Here are some recent training highlights:

- As IGTI partners once again with the Turbomachinery Symposium in Houston, TX, October 4 – 7, 2010, two pre-conference workshops will be held on Monday, October 4: ***Gas Turbine Combined Cycle Primer and Basic Gas Turbine Metallurgy and Repair Technology.***
- IGTI has partnered with Southwest Research Institute the last two years to offer hands-on training to gas turbine industry professionals. The 2010 "Training Week", comprised of four separate courses, was held February 22-26 at their facility in San Antonio. Registrants came from throughout the US, Canada, Germany, Kuwait, Trinidad, Finland, and Mexico. IGTI extends its gratitude and thanks to the Southwest Research Institute and their engineers for opening up their campus and providing their industry experts to train this group. **Mark your calendar now for the next offering of the IGTI/SwRI Training Week scheduled for February 21-25, 2011.**
- IGTI partnered with ASM International to do a one day workshop entitled ***Gas Turbine Metallurgy Coatings & Repair Technology*** on May 2nd in Singapore in conjunction with ITSC 2010 Conference. **Due to its success, discussions are taking place to offer this workshop as a two day course at ITSC 2011 in Hamburg.**
- IGTI and VKI (von Karman Institute) partnered to conduct the ***Film Cooling Science & Technology for Gas Turbines Workshop*** at the 2010 Turbo Expo in Scotland, June 13th. **Discussions are underway to expand this relationship in order to offer condensed versions of VKI-Lecture Series to North American audiences.**
- Webinar's continue to be well attended and are meeting the needs of those who typically do not travel to face-to-face events.

For more information on up-coming workshops, courses and webinars for the gas turbine industry, please visit the IGTI web site at http://igti.asme.org/ or contact Shirley Barton at bartons@asme.org

Performance Testing of Transonic Rotors . . . CONTINUED FROM PAGE 50

Of course simply having an operating rig is only half the challenge, once in place useful data has to be taken from the test article. The scaling down of the test article does reduce power but makes the positioning of probes more difficult. Steady-state performance measurement such as pressure ratio and efficiency testing is fairly standard and requires the measuring of the pressure and temperatures upstream and downstream of the compressor. Care has to be taken to distribute the probes evenly around the compressor as clustering them all in one place can results in local flow blockage and cause premature stall. We calculate efficiency from probe measurements since an on the shaft torque transducer is both too costly and complicated at these speeds. To make accurate measurement we use a conservative mass averaged approach using 20 pressure probes and 10 temperature probes (Figure 5).

The valuable data is in trying to see what the flow structure within the flow passages is like. The high-speed data acquisition capability was first pioneered by Emeritus Professor Ray Shreeve and researchers to develop their DPDS (Dual-probe dual-sampling) procedure to measure the instantaneous velocity vector field downstream of the rotor in the 1970's. The current TPL high-speed pressure transducers are embedded in the wall of the compressor and are each continuously sampled at 196 kHz. At 100 % speed this results in nearly 20 measurements from blade-to-blade and the continuous nature of our sampling allows stalls to be captured. This is important as the change from un-stalled to stalled operation can be as little as 5-10 revolutions or about 1/100th of a second. Understanding the flow just before stall occurs will hopefully allow for designs that are more resistant to stall and surge while maintaining high efficiency.

Our latest rig improvements aim at making the installation of new rotors simpler with a more modular rig layout. Here the use of computer aided design makes design decisions much simpler as it is possible to 'assemble' the entire rig virtually before cutting material. Future rig modifications will include a closed loop system for testing process gas compressors and the potential to operate the entire rig at lower pressures to be able to test two-stage compressors while still remaining within our power limitations and of course better simulating high altitude operation.

U.S. Navy Experience with SSS (Synchro-Self-Shifting) Clutches

By Morgan Hendry, President Of SSS Clutch Company Inc., Director Of SSS Gears Limited, UK, www.sssclutch.com
& B. Michael Zekas, Propulsion and Power Systems Division Head,
Naval Surface Warfare Center Ships Systems Engineering Station, Philadelphia, PA

In the late 1940's and early 1950's, various navies began to consider the use of aero-derivative gas turbines for marine propulsion because the gas turbine was seen as a compact, high-power-to-weight ratio engine that would reduce engine room space, reduce ship size or increase space for armaments, etc., reduce the time required to get a ship underway, and potentially reduce manpower requirements. As the gas turbine, unlike the steam turbine, was not particularly efficient at part load, it was seen that multiple engines would be needed per propeller shaft and a reliable means to connect each engine to a propulsion system/shaft line at rest and at speed would be needed.

Both the British Royal Navy and U.S. Navy explored the addition of cruising steam and later cruising gas turbines for steam turbine main propulsion plants in the late 1950's and early 1960's; and the first SSS (Synchro-Self-Shifting) clutches were supplied for the Y-100 marine main propulsion plant for the British Royal Navy in 1958. The successful operation of this SSS clutch paved the way for future consideration for naval gas turbine applications.

Recognizing that a combined propulsion machinery unit with gas turbines for boost power would require reliable propulsion clutches to disconnect the engines when not in use, the U. S. Navy initiated an evaluation of various means of disconnecting a gas turbine engine and ultimately selected and tested 7500 hp capacity clutch designs including a forced synchronizing friction/tooth clutch and overrunning clutches. After considerable testing and evaluation, the clutch designs were considered acceptable for high-power propulsion with reasonable requirements for differential speed at engagement.

In 1968, the U. S. Navy decided to proceed with its first, combined all gas turbine powered (COGAG) naval ship class, the Spruance Class Destroyers, and the main reduction gearbox manufacturer supplied forced synchronizing/dental tooth clutches. In the late 1960's, the U. S. Navy initiated the construction of a large number of single-shaft ships, the Admiral Perry Class (FFG) Frigates, and SSS clutches were recommended and supplied by the main reduction gearbox manufacturer who had gained valuable experience with SSS clutches on U. S. Coast Guard High Endurance Cutters.

In 1980, SSS clutches were chosen for the U. S. Navy Ticonderoga Class Cruisers (CG-47 Class), and the main reduction gearboxes were the same as the Spruance Class Destroyers except SSS clutches were chosen by the U. S. Navy instead of forced synchronizing/dental tooth clutches because of operating experience problems on Spruance Class Destroyer clutches. Within ten years most of the Spruance Class clutches were retrofitted with SSS clutches. From the mid-1980's all future U.S. Navy gas turbine propelled ships utilized SSS main propulsion clutches. SSS clutches were also being adopted for auxiliary drives as well.

SSS CLUTCH DESIGN & OPERATING PRINCIPLES

The SSS clutch is a freewheel-type, overrunning clutch which transmits torque through concentric surface-hardened gear teeth. Unlike a servo-actuated tooth coupling which is difficult to shift into mesh at rest or at speed, phasing and engagement of the SSS clutch teeth at synchronous speed is accomplished automatically without any external controls and without possibility of error. Also, unlike a tooth coupling, disengagement of the clutch will occur whenever the input slows down relative to the output without the need to maintain an unloaded turbine condition for disengagement.

The principle of operation of the SSS clutch can be seen in Figure 1. When the speeds of the clutch input and output reach synchronism, the pawls on one clutch element engage with ratchet teeth on the other to phase the teeth precisely for engagement. A few degrees of relative rotation causes the pawls to provide the small force to move the sliding component axially along helical splines, thereby engaging the driving and driven teeth smoothly and positively.

The pawls do not transmit any driving torque because they move axially out of contact with the ratchet teeth as the clutch teeth shift into full engagement.The clutch completes its engagement when the sliding component moves axially against an end stop, and then full torque passes through the helical splines and the fully engaged clutch teeth.

Figure 1. SSS Clutch Principle of Operation

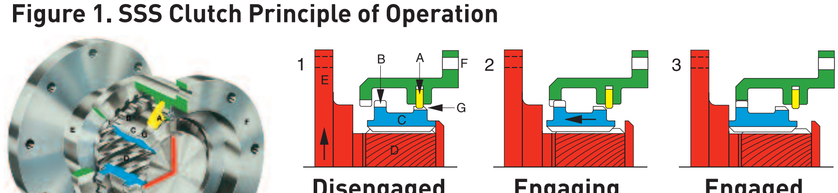
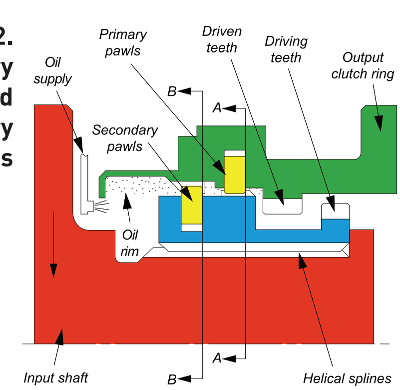


Figure 2. Primary and Secondary Pawls



As soon as the clutch input speed reduces relative to the clutch output speed, the clutch automatically disengages due to the reversal of torque on the helical splines. To enable the clutch to engage at low and high speeds, but also to prevent sustained ratcheting action of the pawls with the clutch output at high speed and the clutch input stopped or at low speed, primary and secondary pawls are used, as can be seen in Figure 2.

The primary pawls are mounted on the clutch output and are spring-loaded into engagement with ratchet teeth on the clutch sliding component. Unbalance relative to the pawl central pivot pin causes the primary pawls to retract from the ratchet teeth due to centrifugal force when the output exceeds a predetermined speed; typically about 500 rpm.

The secondary pawls, which are mounted on the clutch input, usually the clutch sliding component, are used to engage the clutch in the high-speed range, which is to say when the clutch input accelerates to the same speed as the output. When the input rotates, unbalance relative to the pawl central pivot pin engages the pawl with the ratchet teeth in the clutch output. However, when there is high differential speed between the pawls and ratchet teeth, the pawls skim on the oil within the clutch output. Therefore, both sets of pawls are inert when the clutch output is rotating at high speed and the clutch input is at rest or at low speed, and both sets of pawls are separated axially from their ratchet teeth when the clutch is engaged. Hence the pawls have a very long life; in many cases they last the life of the ship.

ADDITIONAL SSS CLUTCH FEATURES

In addition to the basic SSS clutch design and operation, additional features are available for high-power and/or high-speed applications. These features include an oil dashpot inside the clutch, continuously supplied with oil from the lubrication system, to "cushion" clutch engagement under high relative acceleration conditions and to prevent disengagement under transient negative torque conditions. An additional feature is a relay clutch built within the main SSS clutch to enable SSS clutches to transmit high power yet keep the synchronizing mechanism (pawls and ratchets) within the clutch small and reliable. To suit various arrangement and operating requirements, optional features such as Manual Lock-Out, Servo Lock-Out, Servo Lock-In, and a Lock-Out/Lock-In feature can also be provided.

MOUNTING ARRANGEMENTS

SSS clutches are typically an in-line, flange mounted drive arrangement, or mounted on the end of the gearbox input shaft that extends through the center of the high speed pinion (quill shaft mounting). For Combined Gas Turbine or Diesel (CODOG) or combined gas turbine and diesel (CODAG) gearboxes, the clutches are sometimes mounted in the intermediate shaft position as often one gas turbine and two diesel engines are used per reduction gear. The U.S. Navy and other navies have also designed main reduction gears with electric motors for auxiliary or cruise propulsion and gas turbines for boost power (CODELAG), and again the clutches are mounted in either configuration.

U.S. NAVAL MARINE EXPERIENCE

The U.S. Navy has nearly forty years of experience using SSS clutches in main reduction gears of gas-turbine-driven ships and propulsion systems with combinations of gas turbines and diesel engines or electric motors, and in steam-turbine propulsion plants for use with electric motor drives. Over 900 SSS clutches have been installed in fourteen different classes of U.S. Navy ships, with some having been in service for over thirty years. SSS clutches have accumulated approximately 15,278,000 hours of operation.

Clutch duty on U.S Navy ship Classes, each nominally rated at a 50,000 SHP, is considered to be more strenuous than the original design requirement due to the increased operating time (and cycles) at high torque. The highest percentage of ship operations is performed in a single engine driving / trail shaft mode (on twin shaft ships) in order to minimize fuel usage and to maximize range. The end result is operating at a higher torque (that exceeds full power torque) on the driving shaft. Fleet data indicates that ships operate in this mode 68% of the time. Full power operation is performed 10% of the time, and the remaining 22% is at the less than 50% power level. As the SSS clutches are "operating" whenever they are engaged or whenever they are disengaged or overrunning (as would be the case with the off-line clutch when the ship is in single engine propulsion mode) the average total number of clutch operating hours could be up to 68% greater than total engine operating hours on any given ship.

Operational Availability (Ao) is the Navy's primary measure of system material readiness and is a function of a system's inherent reliability and maintainability attributes as well as the support network sustaining the system. Ao is defined as the probability that the system is ready to perform its specified functions, in its specified operational environment, when called for at a random point in time.

Ao is defined as:

$$Ao = \frac{\text{Uptime}}{\text{Uptime} + \text{Downtime}} = \frac{\text{MTBF}}{\text{MTBF} + \text{MTTR} + \text{MLDT}}$$

MTBF = Mean Time Between Failures in Hours
MTTR = Mean Time To Repair in Hours
MLDT = Mean Logistics Delay Time in Hours

MTBF is a function of reliability, and MTTR is a function of maintainability that only accounts for time associated with active repair (including failure isolation, repair, part replacement, and restoration checkout times). MLDT is a function of the onboard spares depth and breadth (sparing policy) as well as the time it takes to obtain parts not available at the shipboard level.

MTBF for U.S. Navy clutch applications, is relatively high (271,550 hours) based on the operational hours accumulated and the total number of failures that have occurred. The maintenance and repair strategy used for U.S. Navy SSS clutches is similar to a Performance Based Logistics (PBL) arrangement where the Navy maintains a rotatable pool of ready for issue clutches, and in the event of a problem or failure, the clutch is changed out with an available spare. The removed clutch is returned to SSS for repair, refurbishment, and returned to the rotatable pool. This type of approach minimizes MTTR and MLDT and yields a substantially high Ao of .998, indicating that the SSS clutch is available for operation 99.8% of the time.

The basic design of the size 140T clutch, designed for the FFG-7 Class ships and adopted for DDG-51, CG-47, DD-963 and Sealift ships, is now being utilized for additional U.S. Navy applications including the LHD-8, LHA-6, and LCS-1 and LCS-2. 140T SSS clutches have also been supplied for the U.S. Navy's experimental ship X-Craft, and reduced scale clutches (120T), are being used for the electric motors on the LHD-8 and LHA-6 ships. SSS clutches have been used in the propulsion plants of hovercraft by other navies, and are a candidate for use aboard the U.S. Navy's new Ship To Shore Connector (LCAC) replacement program.

A SOLUTION FOR THE FUTURE

SSS clutches are currently used by more than forth navies for gas turbine driven, diesel driven, and electric motor driven main propulsion systems. With an increasing requirement for reliability and flexibility, together with high performance ships with high power-to-weight ratios, higher efficiency and lower emissions, innovative propulsion systems utilizing proven components such as the SSS clutch are being adopted by many navies of the world. SSS clutches used in other marine and industrial applications have operating and design limits that exceed those of the clutches currently used for naval applications. SSS clutches capable of operation at speeds up to 17,000 rpm, combined acceleration rates of up to 1,600 rpm/sec, and powers up to 300 MW at 3000 rpm demonstrate that the basic clutch design is suitable for future higher power, high speed requirements. ✲

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Turbo Expo attendees celebrated the launch of ASME Turbo Expo 2011 during the closing ceremony of the 2010 exposition in Glasgow. Join us at the Vancouver Convention & Exhibition Centre, June 6-10, 2011, in Vancouver, Canada for ASME Turbo Expo 2011!

Conference Chair Thomas Sattelmayer spotlighted other members of the 2011 leadership team, including Executive Conference Chair Ibrahim A. Yimer of National Research Council Canada's Institute for Aerospace Research, Technical Program Chair Timothy Snyder of Pratt & Whitney, Local Liaison Committee Chair Dale Hunt of ADHoc Services, and Karen Thole, Review Chair.

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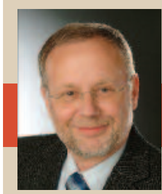

Dr. Thomas Sattelmeyer

Dr. Ibrahim Yimer

Timothy Snyder

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Karen Thole

Call for Papers ASME Turbo Expo 2011

Abstracts are due by September 6, 2010, and must be submitted online (plain text, 400 word limit) via the IGTI Conference Web site at www.turboexpo.org.

The 2011 Publication Schedule:

- Abstract Submission - **September 6, 2010**
- Draft Paper Due Date - **November 8, 2010**
- Paper Reviews Complete – **December 20, 2010**
- Author Notification of Paper Acceptance - **January 10, 2011**
- Submission of Final Paper – **February 21, 2011**
- Final Paper Approval by Review Chair - **March 21, 2011**

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We are pleased to announce the new technical committee officers for July 2010 through June 2012.