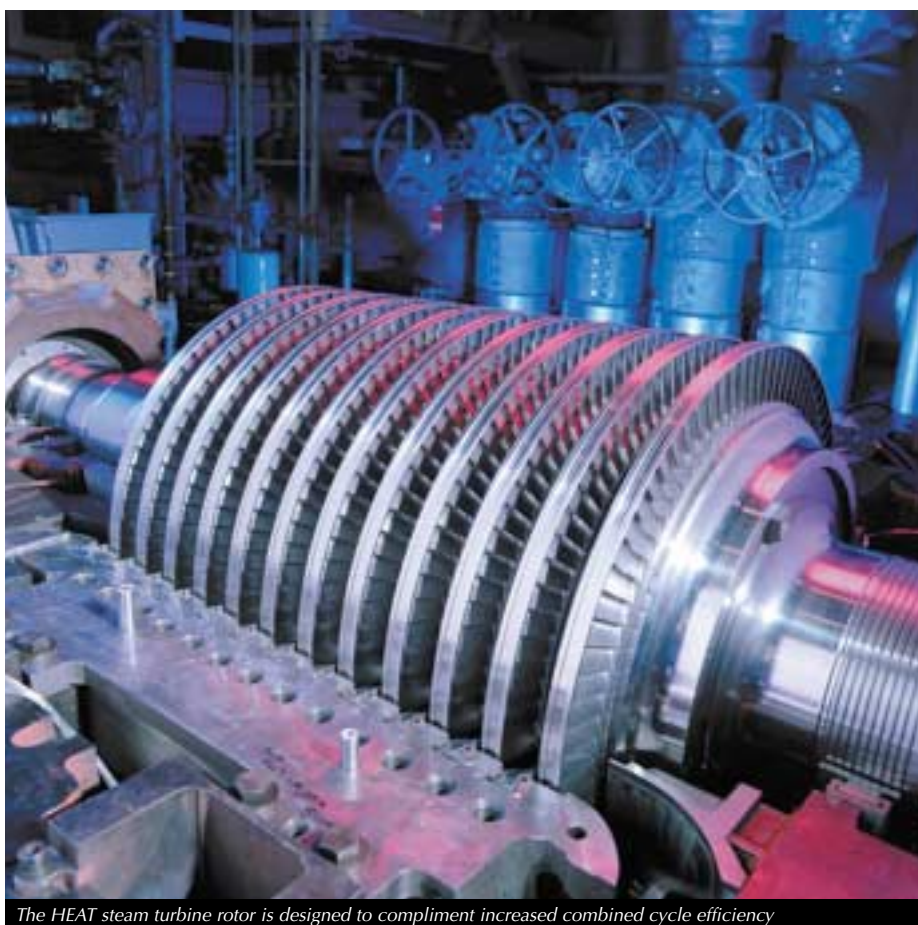


*In today's power market, flexibility and efficiency are key in operating combined cycle plants. This puts new demands on steam turbine technology. GE's new range of HEAT steam turbines are designed to increase steam turbine power output capability and improve combined cycle plant efficiency, leading to lower cost of producing electricity.*

## Steam turbine technology

# HEATs up



The HEAT steam turbine rotor is designed to compliment increased combined cycle efficiency

drum rotor construction, 2400 psia/166 bar pressure capability, optimized seal clearances, lower pressure-drop valve designs, longer and higher efficiency last-stage bucket designs, and advances in material technology. The turbines will increase steam turbine power output capability and improve combined cycle plant efficiency, leading to lower cost of producing electricity.

GE rigorously applied Six Sigma methodology in developing the HEAT line and involved experts from several GE businesses, led by the GE Power Systems steam turbine technology design team and supported by the GE Global Research Center and GE Aircraft Engines.

### HP design advances

Over the past several years, GE has developed 'dense pack' steam turbine technology for new and retrofit units. Dense pack designs increase efficiency by improving basic fundamentals of the steam path, including optimization of blade root diameter, stage count and reaction level.

The application of the dense pack analysis and optimization methods to combined cycle products has revealed that constraints on rotor flexibility limit the minimum steam path diameter for GE STAG 107 and 109 steam turbines. When using a disk and diaphragm construction, the rotor solid diameter is the same as the diaphragm-packing diameter which, due to features of the diaphragm design and construction, must be at least 18 cm less than the steam path diameter. This difference between minimum rotor diameter and steam path diameter – combined with the axial length of a disk and diaphragm stage of 12.7 cm – limits the rotor flexibility. Additional performance gains are possible if this constraint can be relaxed.

To ease the rotor flexibility constraints associated with a disk and diaphragm construction for low-volume flow, combined cycle steam turbines, GE adopted a drum-type construction for the HEAT turbines. This construction reduces the minimum

**A**cross the global electric power generation industry, there is a growing demand for economically viable power plants that enable owners and operators to optimize their return on investment and minimize their life cycle cost of electricity.

As part of this effort, energy producers are configuring combined cycle plants to maximize operational flexibility. In turn, this drives a growing need for power plant, and ultimately steam turbine product, flexibility. Steam turbine suppliers face the challenge of providing machines with the capability to meet a complex range of customer requirements.

GE Power Systems has utilized more than 100 years of steam turbine experience and employed Six Sigma design processes to develop advanced, steam turbine designs for increased combined cycle efficiency. The latest example is the High Efficiency Advanced Technology (HEAT) Combined Cycle Steam Turbine product line. The HEAT steam turbines are reheat designs covering an output range of 90 to 300 MW, and are optimized for power plants using GE's F-class gas turbines.

The HEAT turbines incorporate design advances from across GE's steam turbine product line, including: high-reaction

difference between the steam path and rotor solid diameter to 7.6 cm. In addition, the axial length of a drum type stage is reduced by 50 per cent compared to a disk and diaphragm stage. The combination of these factors allows for a smaller steam path diameter and a larger stage count, with an equivalent or improved rotor flexibility. The resulting rotor flexibility limit for the drum represents a significant efficiency gain.

—“The HEAT steam turbines are reheat designs covering an output range of 90 to 300 MW, and are optimized for power plants using GE’s F-class gas turbines” —

With the introduction of higher reaction aerodynamic designs, the mechanical structure that supports both rotating and stationary steam path components has changed. In addition to a drum rotor, the higher reaction high-pressure (HP) section includes dual symmetric inlets, a double shell with inner carriers, revised front/mid standards, and centreline support of all structures.

With more than double the number of stages compared to a traditional impulse steam path design, the span between bearings becomes a critical design choice. Increasing the span allows more stages at the expense of rotor dynamics, end packing sealing, and cost. A balance must be achieved to optimize these parameters. Since stages are very close together, retention of the stator blades (nozzles) is a design consideration. In addition, stator structure thermal response must match rotor thermal response to maintain clearances and thus performance levels. To help achieve these objectives, GE has employed a double shell construction for the stator structure of HEAT steam turbines.

The outer shell retains dual inner shells or carriers. The inner carriers, in turn, retain the individual nozzles that form the stationary steam path. Benefits of this arrangement include:

- Increased pressure capability
- Thermal stability
- Alignment flexibility
- Improved inlet and exhaust flow

**Inlet/exhaust improvements**

In the past, steam path inlet and exhaust systems have been designed to pass the necessary flow by using inlet and exhaust pipes in the lower half shells. While this arrangement is conducive to power plant design and ease of maintenance, it drives

non-symmetric heating and cooling of the turbine shells. Field data, analysis and operating experience have shown that during transient operation, the steam supply and exhaust arrangement can drive significant shell deflections and asymmetry. In designing its HEAT turbines, GE made a number of design enhancements to address this problem.

First, dual HP inlets have been introduced to the HEAT product line. Steam is introduced at the bottom and top vertical centerlines. The symmetric flow of steam drives uniform heating and cooling of the shell and inner carriers.

Secondly, the carrier outer surfaces are bathed in steam from a mid-stage extraction between carriers, to help equalize the outer and inner surface thermal response.

Finally, to further enhance uniform thermal behaviour, the carrier designs include false flanges at top and bottom centerlines where required. The size, shape and thermal mass of the false flanges have been optimized to match the horizontal joint thermal response. This ensures symmetric deflection and growth during operating conditions.

GE also utilized modern computational fluid dynamics (CFD) tools to verify the

—“With more than double the number of stages compared to a traditional impulse steam path design, the span between bearings becomes a critical design choice” —

improvement in efficiency of the inlet and exhaust geometries. Significant improvements have been achieved in pressure drop and velocity profiles entering the first stage nozzle. Steam flow within the inlet volute is one aspect of the inlet loss that has been improved, while the entrance loss to the first stage nozzle vane also has been significantly reduced.

The HEAT design with improved distribution reduces the amount of incidence flow entering the turbine first stage nozzle. The incidence angle flow variation has been reduced by 50 per cent in the HEAT inlets.



The new last stage buckets come in two sizes — 85 cm and 1.21 m

Similar gains have been achieved in the HP exhaust designs. A critical feature is the axial length of the exhaust diffuser which, along with surface finish and exit volume, drives the majority of the exhaust losses associated with HP shell designs. GE employed a CFD analysis to study these effects and redesign the exhaust geometry to minimize losses.

As a result of this effort to understand

the inlet and exhaust designs for the HEAT product line, significant gains in overall section efficiency were realized. By using state-of-the-art analysis techniques and Six Sigma tools, GE created a robust and optimal design that helps to meet the overall section performance goals.

**Valve design**

Valves for both main and reheat sections of GE combined cycle steam turbines utilize a unique configuration that allows a single valve seat and casing to provide both control and stop valve functions. The control valve is contained in the upper

chamber of the valve casing, and the stop valve is in the lower chamber. Each is spring-closed and positioned by a separate hydraulic actuator. The vertical configuration of this valve design allows easy access for maintenance, since all of the steam parts in the valve assembly can be removed through the top of the valve by using either a station or portable crane. No special fixtures are required for disassembly or reassembly.

Use of a single casing and seat minimizes loss in the valves. Employing Six Sigma design methodology, GE has achieved improvements in the inlet valve design being applied to the HEAT turbines. The optimum flow configuration has been determined by breaking down the valve into critical sections and using CFD to analyze each section.

A detailed analysis of pressure

and thermal stresses, using finite element methods,

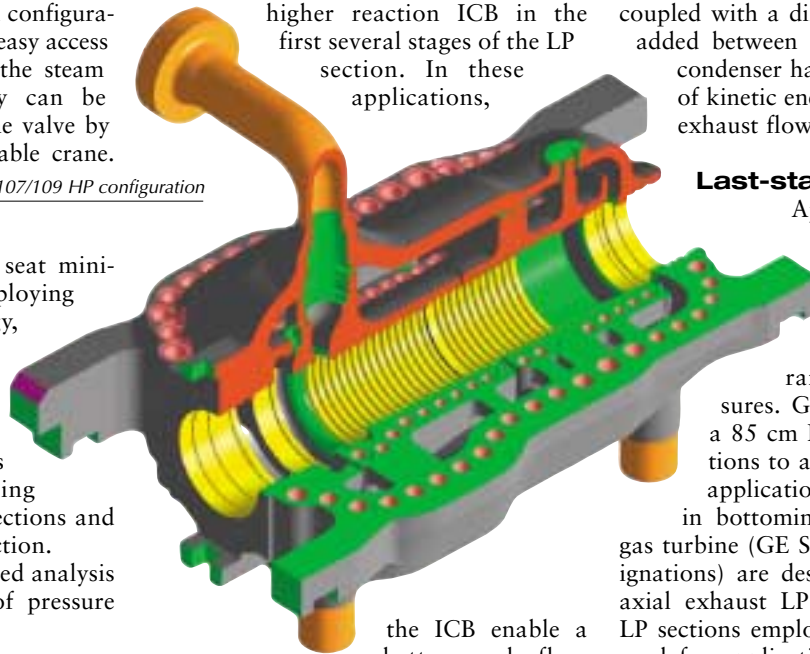
HEAT 107/109 steam turbine configuration

has shown that changes made for flow optimization will not reduce valve structural robustness. Further reviews have assured that cost and manufacturability will not be jeopardized by these changes. The resulting valve design has been integrated with two actuators that utilize fire-resistant hydraulic fluid at 2400 psig to provide reliable actuation without the need for a lever system. The final result is a valve design that is significantly smaller in size while offering pressure loss improvement over prior designs.

**IP and LP sections**

The HEAT turbine intermediate pressure (IP) and low-pressure (LP) sections have been designed with numerous features to enhance section efficiencies and reduce aerodynamic losses, while maintaining the machine reliability and availability. With the IP and LP flow path, bucket tip and diaphragm packing seals have been optimized to reduce leakage and enhance performance.

These improvements include the application of integrally covered buckets (ICB) in the IP section, and higher reaction ICB in the first several stages of the LP section. In these applications,



the ICB enable a better seal flow coefficient than a

peened-on cover.

GE has optimized the transition between the IP and LP flow paths by using extensive CFD analysis to verify design calculations and performance. This transition region must guide the flow between the IP and LP sections while allowing

bearing stiffness with associated benefits in rotor dynamics. From a performance viewpoint, the redesigned exhaust frame coupled with a diffuser extension section added between the exhaust frame and condenser have doubled the amount of kinetic energy recovered from the exhaust flow.

**Last-stage buckets**

Application of multiple last-stage bucket (LSB) designs can lead to optimized combined cycle performance over a wide range of exhaust pressures. GE offerings range from a 85 cm LSB for 60 Hz applications to a 1.21 m LSB for 50 Hz applications. Steam turbines used in bottoming cycles with a single gas turbine (GE STAG 107 and 109 designations) are designed with single-flow axial exhaust LP sections. Double-flow LP sections employing the same LSB are used for applications with two gas turbines (GE STAG 207 and 209).

*The final result is a valve design that is significantly smaller in size while offering pressure loss improvement over prior designs*

an efficient mixing of the LP admission flow. In addition to the steady state flow enhancement, consideration has been given to the non-uniform heating of this region during transient operation – resulting in a design that maintains high performance over the entire operating envelope. A diffuser added at the transition between the IP and LP turbines creates a more controlled flow management in the transition zone and increases the section efficiency.

Significant advances also have been made in the exhaust frame and axial diffuser. By using a smaller number of optimized struts compared to previous designs, the exhaust frame has been redesigned to provide enhanced pressure recovery and greater stiffness. Structurally, this results in an increased

The latest LSB added to the GE combined cycle product line is the 1.21 m steel LSB applied in an axial flow configuration to the STAG 109 HEAT turbine. This bucket is part of a three-stage LP end group that was designed as a system. The design point for the 1.21 m LSB was selected to reflect the operating conditions typical of modern combined cycle plants, where turbine design points are chosen to minimize the exhaust loss.

**Focus**

To successfully develop power generation systems and products, multiple market requirements must be satisfied simultaneously, in an effort to minimize the overall life cycle cost of producing electricity. The development of steam turbine technology is embodied in the addition of the GE STAG 107/109 HEAT systems to the GE product line. The development focus for these products has been to improve overall bottom cycling efficiency while providing cost effective, flexible steam product solutions.

