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H Gas Turbine Combined Cycle

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H Gas Turbine Combined Cycle

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Abstract

A major step has been taken in the development of the Next Power Generation System - "H" Technology Combined Cycle. This new gas turbine combined-cycle system increases thermal performance to the 60% level by increasing gas turbine operating temperature to 1430 C (2600 F) at a pressure ratio of 23 to 1. Although this represents a significant increase in operating temperature for the gas turbine, the potential for single digit NO_x levels (based upon 15% O₂ in the exhaust) has been retained. The combined effect of performance increase and environmental control is achieved by an innovative closed loop steam cooling system which tightly integrates the gas turbine and steam turbine cycles.

The "H" Gas Turbine Combined Cycle System meets the goals and objectives of the DOE Advanced Turbine System Program. The development and demonstration of this new system is being carried out as part of the Industrial/Government cooperative agreement under the ATS Program. This program will achieve first commercial operation of this new system before the end of the century.

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H Gas Turbine Combined Cycle

Introduction

A key advantage of gas turbine power generation systems is the ability to continue evolving to higher firing temperatures. Each increase in firing temperature yields a dual benefit: *increased efficiency*, that is, lower fuel use, and *increased specific work*, that is, output per unit of air flow, reducing capital cost. In a gas-turbine/steam-turbine combined cycle mode, performance is optimized by selecting a pressure ratio to achieve both high efficiency and high specific work. In order to produce an attractive system, pressure ratio and firing temperature must advance together.

Environmental compatibility continues to be a major concern. For a gas turbine, the main emission issue is nitric oxide (NO_x). To achieve low NO_x in a gas turbine, the maximum temperature in the combustion chamber must be reduced below the levels of conventional diffusion combustion. In order to achieve low combustion temperatures, a new combustion concept called "premix lean" was developed. With premix lean, a large fraction of the compressor discharge air is mixed with the fuel prior to combustion, creating a lean mixture that produces low gaseous emissions when combusted in a fluid-mechanics-stabilized combustion chamber. The dry low NO_x (DLN)

premix combustion system, has moved through the laboratory development stage and has been successfully introduced in commercial service. This combustion system is capable of achieving single-digit NO_x levels.

Rationale for a Next-Generation Power System

The goal of advanced gas turbine development has been to achieve increased performance through increased firing temperature. The increase in performance was obtained by applying advanced airfoil cooling techniques and using new alloys. The additional constraint of emission control for environmental compatibility creates a conflicting set of parameters. Higher performance requires higher firing temperatures, but lower NO_x emissions require lower combustion temperatures.

Both performance and emission targets can be met by changing the gas turbine cooling system. The rationale for the change lies in the

difference between the controlling parameters for performance and emissions—combustion temperature and firing temperature.

The most critical element of an advanced gas turbine is its hot gas path, Figure 1. The compressor discharge air and fuel are mixed and combusted in a chamber at a specific condition, combustion temperature. The flow stream of high-pressure, high-temperature combustion products is accelerated as it passes through the first stationary airfoil (first stage nozzle segment). The firing temperature—the flow stream temperature at the inlet to the first rotational stage (first stage bucket)—establishes the power output (ultimately, the cycle efficiency). The difference between firing temperature and combustion temperature is the temperature drop (nozzle ΔT) required to cool the first stage nozzle, Figure 2.

In the current line of advanced gas turbines, the first stage nozzle is cooled with compressor discharge air flowing through the

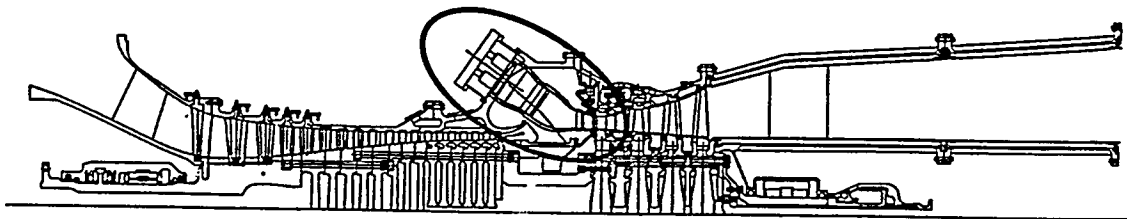


Figure 1. Gas Turbine Hot Gas Flow Path

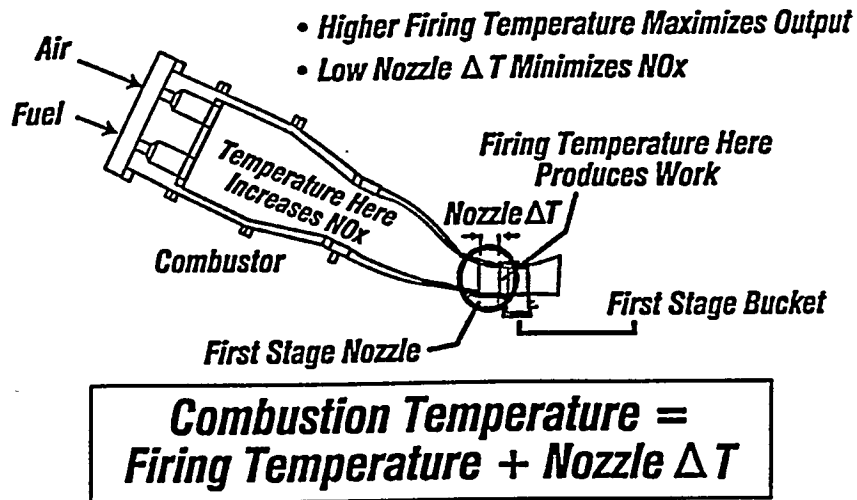


Figure 2. Combustor/1st Stage Nozzle Interaction

airfoil and discharging out into the combustion gas stream as the airfoil is film cooled. This cooling process causes a temperature drop of up to 155 C (280 F) across the first stage nozzle, Figure 3. If the nozzle can be cooled with a closed-loop coolant without film cooling, the temperature drop across the first stage nozzle would be less than 44 C (80 F), which would permit a 110 C (200 F) rise in firing temperature with no increase in combustion temperature.

The key to single-digit NOx capability at increased performance (increased firing temperatures) is closed-loop cooling of the first stage nozzle. The cooling concept has a dual effect: allowing higher firing temperatures to be achieved without combustion temperature increases and permitting more compressor discharge air to flow to the head-end of the combustor for fuel premixing.

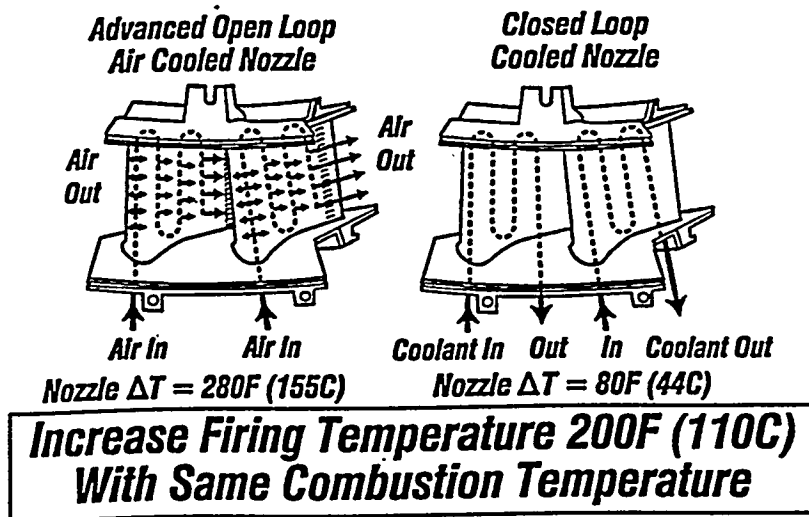


Figure 3. First Stage Nozzle Cooling

A change in cooling strategy for the first stage stationary nozzle will therefore resolve the conflicting requirements for higher performance and lower emissions. However, once a closed-loop cooling system is established, it can do much more to benefit performance. In conventional gas turbines, compressor air is also used to cool the remaining rotational and stationary airfoils. This air also enters the combustion gas flow path and is classified as "chargeable air," reducing cycle performance. If this chargeable air is also replaced with a closed-loop coolant system, a cycle benefit of up to two points can be achieved, a dramatic improvement.

The move to a higher level of gas turbine power generation performance while meeting emission control targets can be achieved by a change from open-loop air cooling to closed-loop cooling of the gas turbine hot gas path parts. However, in order to achieve effective cooling thus maintaining hot gas path part integrity, an improved coolant medium is required.

In a power generation application, the high levels of performance for gas turbine systems are achieved by means of a combined cycle. The

high temperature exhaust from the gas turbine is used to generate steam in a heat recovery steam generator (HRSG). This steam is then expanded through a steam turbine. For the gas turbine combined cycle power generation application, there is another coolant alternative—steam.

The airfoil cooling requirements of the gas turbine are met by using steam—a cooling fluid that is much more effective than air—to cool the hot gas path parts without relying on film cooling. This coolant is provided in a closed-loop system integrated with the steam bottoming cycle.

Advanced H Combined Cycle System

The integration features of the H Combined Cycle System include the flow of coolant steam from the steam cycle to the gas turbine, as shown in Figure 4. The high-pressure steam from the HRSG is expanded through the high-pressure section of the steam turbine. The exhaust steam from this turbine section is then split. One part is returned to the HRSG for reheating; the other is used for cooling in the gas turbine.

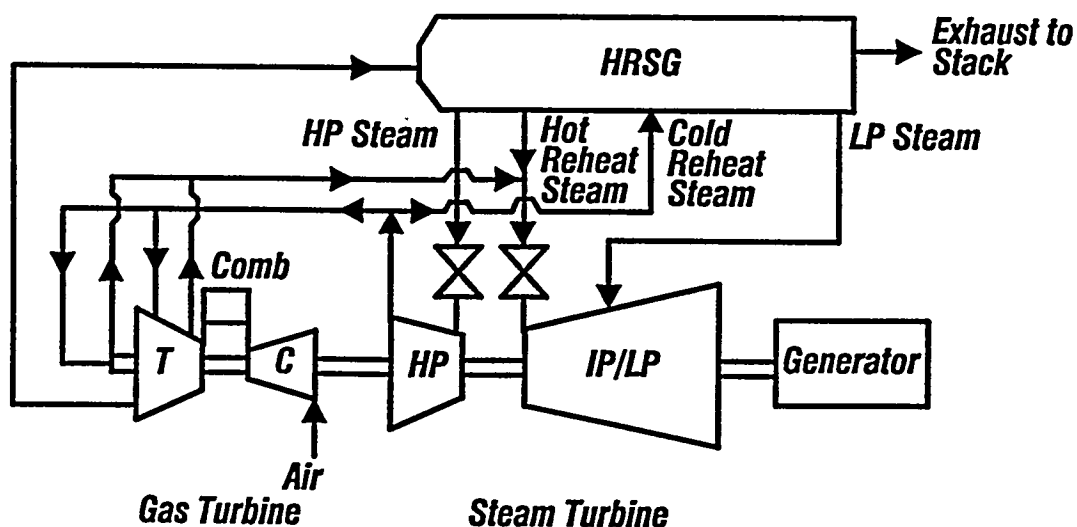


Figure 4. Stag 109H and 107H Combined Cycle System Description

Steam is used to cool both the stationary and rotational parts of the gas turbine. After cooling the hot gas path parts, the steam temperature is increased to approximately reheat temperature. The gas turbine cooling steam is collected and returned to the steam cycle, where it is mixed with the reheated steam and introduced to the intermediate-pressure steam turbine section for energy recovery.

The H Combined Cycle is composed of the H gas turbine, at increased operating conditions; the three-pressure-level HRSG, and a reheat steam turbine. These three components can be configured in a single-shaft or multi-shaft arrangement for an efficient, low emission power generation system.

H Gas Turbine

The attractive operational characteristics of the H Combined Cycle system are a direct result of the gas turbine performance level. This new gas turbine, Figure 5, features closed-loop steam cooling for the first and second stages of its four-stage turbine. In order to optimize the efficiency and specific work with the 1426 C

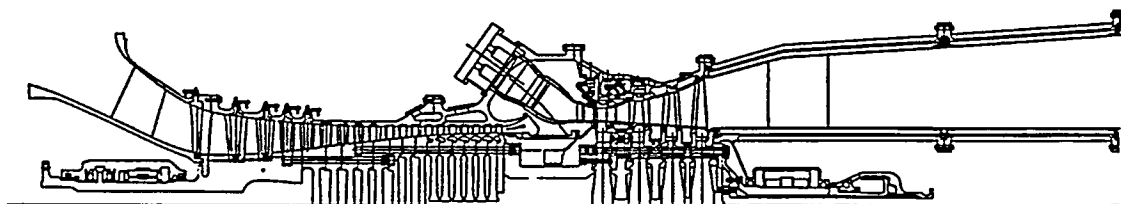
(2600 F) class of firing temperatures, a higher pressure ratio compressor derived from the GE Aircraft Engine CF6 80C2 has been used. The DLN combustion system now in service across the commercial product line has been adapted to the H gas turbine. These are the three key components for the H technology.

Compressor

The H compressor uses a proven aircraft engine design that is scaled to appropriate utility application size. The CF6 design geometry was scaled by a factor of approximately three to match the H requirements. The result is an eighteen-stage compressor with a 23.2 to 1.0 pressure ratio and an air flow of 558 kg/sec (1230 lb/sec) at 60 Hz and 685 kg/sec (1510 lb/sec) at 50 Hz.

Combustor

The H combustion system is a lean premix DLN system. In order to meet the increased flow requirements, the combustor diameter has been increased by approximately 20% from the FA



Features

- ***Closed Loop Steam Cooling***
- ***4-Stage Turbine***
- ***Compressor Scaled From Proven Design***
- ***Dry Low NO_x Combustor***

Figure 5. Cross Section H Gas Turbine

family of designs. This proven can/annular design permits a 14-can configuration at 50 Hz and a 12-can configuration at 60 Hz. The combustion system has been staged for significant turndown capability while retaining low emission characteristics.

The DLN development has been carried out in a parallel program to the ATS activity. This combustion system is now operational in close to 100 GE gas turbines in commercial service. The DLN system has demonstrated an ability to achieve single digit NO_x and CO at combustion temperature close to that required for the ATS gas turbine. This major component availability supports the ATS Development.

Turbine

The innovative part of the H gas turbine is the turbine section. The pressure ratio was increased to match the 1426C (2600F) firing temperature while retaining a turbine exhaust temperature of approximately 593C (1100F) for good combined cycle performance. To achieve high turbine efficiency, a four-stage turbine design was selected to maintain optimum work loadings on each stage.

The flow path of the turbine employs optimized 3D geometry with closed-loop steam cooling for the first and second stage rotational and stationary airfoils. This effective cooling medium will allow the firing temperature of the H gas turbine to increase to 1426C (2600F) while retaining the same design life specifications as the current gas turbine products. In fact, the bulk airfoil metal temperatures will be lower than those of conventional air-cooled gas turbines.

(Although the conventional machines operate at lower firing temperature).

The first stage of the H gas turbine uses an aircraft-engine-proven, single crystal alloy and thermal barrier coatings (TBCs). The second, third, and fourth stages use directionally solidified materials. The third stage is air-cooled; the fourth stage is uncooled.

H Technology Product Performance

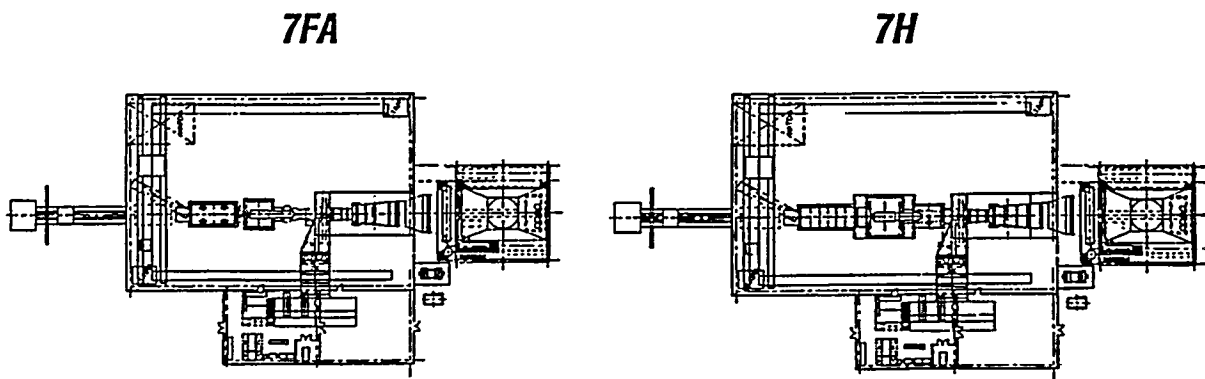
The H combined cycle power generation systems are designed to achieve 60% net plant efficiency. The operational and performance characteristics for the H technology gas turbine/combined cycle products are summarized in Table 1. The significant efficiency increases over the FA technology product line are achieved by advancing the operating conditions—pressure ratio and firing temperature. These advantages are achieved while maintaining single-digit NO_x and CO capability.

Power Plant Configuration

The output of the H family of products is 400 MW at 60 Hz and 480 MW at 50 Hz in a single-shaft combined cycle. One extremely attractive feature of the H family of combined cycle power plants is the high specific output, which permits compact plant designs resulting in reduced "footprint" and the potential for low plant capital costs. In a 60 Hz configuration, Figure 6, the result is a 58% increase in output over the FA plants with an increase of just 8% in plant size.

Table 1. 60 Hz Characteristics & Performance

<u>Characteristics</u>	<u>7FA</u>	<u>7H</u>
<i>Firing Temperature Class, F (C)</i>	2350 (1300)	2600 (1430)
<i>Air Flow, Lbs/sec (Kg/sec)</i>	974 (442)	1230 (558)
<i>Pressure Ratio</i>	15	23
<u>Emissions</u>		
<i>NO_x, ppm</i>	9	9
<u>Combined Cycle Performance</u>	<u>STAG 107FA</u>	<u>STAG 107H</u>
<i>Net Output, MW</i>	253	400
<i>Net Efficiency, %</i>	55	60
<i>Specific Output, MW/Lb/sec (MW/Kg/sec)</i>	.26 (.57)	.33 (.72)



7FA vs. 7H
58% Increase in Output
With Only
8% Increase Footprint

Figure 6. Advanced Machine Plant Layout

DOE/GE Advanced Turbine System Program & Schedule

In response to the market opportunity, the initial H technology design effort has been focused on the MS9001H (50 Hz) gas turbine, with a full speed no load (FSNL) test, and subsequent shipment, of the first unit scheduled for the second half of 1997. The MS7001H (60 Hz) follows directly thereafter, and benefit from the significant design commonality with the MS9001H. The ATS government/industrial partnership has provided support for the establishment of the technology base for this Advanced Turbine System. The information developed under this program has been integrated into the Design Methods used to configure the machine. The component tests, now underway, are providing validation of the design.

The ATS Phase 4 Cooperative Agreement will provide an opportunity to work with a user at a host site to install and test the first ATS combined cycle unit. It is expected that this "first commercial" unit will be completed before 2000.

Conclusion

The H technology gas turbine/steam turbine systems provides an opportunity to move up to the next plateau for power generation systems. The innovative cooling system for the H gas turbine permits a step change in firing temperature, reaching record levels of efficiency and specific work, while retaining low emission compatibility.

The design for this next generation system has proceeded through the development stage and has achieved a design freeze status. This will permit both 50 Hz and 60 Hz gas turbine combined cycle systems to enter commercial service before the end of the decade. The H family of advanced power generation systems will set the performance, emission control, and operational standards well into the 21st century.

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Ms. Abbie Layne

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Phase 2 - 8/25/93 to 3/31/96

Phase 3 - 9/29/95 to 12/31/97