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General Electric ATS Program Technical Review Phase 2 Activities

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Objectives

The Advanced Turbine Systems (ATS) Program Phase 2 objectives are to select a cycle, and to identify and resolve technical issues required to realize the ATS Program goals of 60% net combined cycle efficiency, single digit NOx, and a 10% electric power cost reduction, compared to current technology.

Background

In response to the industrial and utility objectives specified for the ATS, the GE Power Generation ATS Phase 2 Program consisted of a dual approach. These were 1) development of an Industrial ATS (aircraft engine based) led by GE Aircraft Engines, and 2) development of a Utility ATS which was already underway at GEPG. Both programs required the identification and resolution of critical technical issues. Both systems were studied in Tasks 3-7, and both have resulted in designs that meet all ATS goals. The Industrial ATS as defined (130 MW) did not meet projected market power size requirements, and emphasis has remained on the Utility ATS development. The design and testing effort has been focused on the MS7001H combined cycle gas turbine, as the next product evolution in GE Power Generation's product line. Common technology derived from the ATS Program is also being incorporated into the 50 Hz version of the ATS utility machine designated as the MS9001H.

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Program Status

The ATS Phase 2 Program consists of eight tasks, whose status is shown:

Task 1 - Project Plan - completed
Task 2 - NEPA Information - completed
Task 3 - Select Gas Fired ATS
  3A - Industrial GFATS - completed
  3B - Utility GFATS - completed
Task 4 - Conversion to Coal Fueled ATS
  4A Industrial CFATS - completed
  4B - Utility CFATS as part of IGCC analysis
Task 5 - Market Study - Draft Report completed
Task 6 - System Definition and Analysis

6A - Industrial System - completed
6B - Utility System - in progress
Task 7 - Integrated Program Plan
7A - Industrial GFATS - in progress
7B - Utility GFATS - not yet started
Task 8 - Design and Test of Critical Components
8A - Industrial Task 8.5 - completed
8B - Utility - all others in progress

Cycle Selection

Prior to the initiation of the ATS Phase 2 Program, GE Power Generation conducted a study of advanced combined cycles, and concluded that a significant net efficiency gain would be possible with a closed loop steam cooled turbine. This cycle, along with the new technologies required for its implementation, will meet the ATS program goals for net efficiency, emissions, and cost of electricity. Details of the cycle, hot section components, system integration and mechanical cross-section are given in Reference 1.

System Definition and Analysis

General Description

The MS7001H gas turbine has many of the basic heavy duty gas turbine features used on other GE gas turbines. The power output drive shaft is at the cold end. The gas turbine rotor is supported by two journal bearings. Axial thrust is contained by a single thrust bearing located at the compressor end. For ease of maintenance and inspection, the casings are horizontally split. The compressor/turbine rotor is removable as one piece. For each combustor, the liners and transition pieces can be individually replaced. Borescope holes are located in the compressor, combustion and turbine sections to facilitate visual inspections.

Overview

The original plan for the advanced machine product was to have the 7H (60 Hz) gas turbine scaled from the 9H (50 Hz). Based on a thorough analysis of cost, efficiency and market needs, a decision was reached to develop the 7H which was not a true scaled version of the 9H.

The ATS Phase 2 program focus has been on preliminary component design, and performing component detail design in preparation for long lead casting and forging releases. Components addressed include: compressor rotors and stators, combustors, turbine buckets and nozzles, casings, and thrust and journal bearings.

Compressor

The mechanical design of the ATS compressor was derived from GE's proven heavy duty gas turbine experience while the aerodynamics and aeromechanics were scaled from the proven CF6-80C2 aircraft engine. The compressor has 18 stages which provide a 23 to 1 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.

Variable inlet guide vanes and four stages of variable stator vanes are used to control compressor air flow during part power operation and to optimize compressor efficiency and operational characteristics.

Combustor

The ATS machine combustion system is a can-annular lean premix Dry Low NOx (DLN) system. The design builds upon the GE DLN2 combustion technology. GE designed DLN systems are successfully operating in over 100 field installations. The ATS NOx goals are close to being demonstrated with these combustors at combustion temperatures approximating the ATS levels.

The combustor diameter is increased approximately 20% over the current 7FA DLN family in order to pass the higher flow levels. The can-annular combustors are common to both 50 Hz and 60 Hz machines, with a 14-can configuration in 50 Hz, and a 12-can configuration in 60 Hz applications.

Turbine Design

The ATS turbine incorporates high efficiency 3-D aerodynamics in a four stage design, which was selected to maintain optimum work loading and pressure ratio on each stage. With a 1426C (2600F) class firing temperature, the pressure ratio was increased to retain an exhaust temperature of approximately 593C (1100F) for good combined cycle performance.

The turbine employs closed loop steam cooling in the first and second stage nozzles and buckets plus the stage 1 shroud. The first two stages of airfoils are thermal barrier coated (TBC) for life improvement by reducing temperatures and stresses.

Power Plant Design

The ATS gas turbine is part of a combined cycle power plant. Exhaust steam from the high pressure steam turbine is split and a portion used to cool the ATS gas turbine hot section. After cooling, the hot gas path hardware, 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 for energy recovery.

Phase 2 Component Development Tasks

The definition of the cycle that meets ATS Program goals requires advancements in several areas of gas turbine technology. An extensive experimental program was initiated to develop these technologies. The results of these tasks are being utilized in the design of the ATS machine.

Coolant Fluid Contaminants. It is necessary to characterize any particles present in the steam flow path of a combined cycle steam loop in order to verify that the cooling steam quality is acceptable. Development programs were initiated to sample an existing combined cycle steam loop, to evaluate the use of filtration for particulate control, and to determine deposition characteristics of particulates in static and rotating coolant paths.

Thermal Barrier Coatings. Development of thermal barrier coatings (TBCs) with improved life and reliability will require a comprehensive understanding of the mechanisms of degradation that occur in a gas turbine. There are several ongoing TBC program elements.

The first is development and confirmation of methods to measure and predict TBC stress states as a function of thermal stress and mechanical strains to facilitate TBC design and life prediction methodologies. An additional objective is development of a practical, versatile laboratory-scale thermal gradient exposure facility capable of simulating the extreme thermal conditions anticipated for TBCs in the ATS machine. An atmospheric E-beam facility has been developed and is being used to evaluate TBC coated specimens in thermal and stress states expected in service.

Test specimens were designed to properly model the thermal and strain field present in critical regions (such as fillets) of a first-stage nozzle in the ATS gas turbine.

Improved instrumentation is being developed to measure the temperatures, fluxes and strains present in the E-beam specimens. Instrumentation types include: thin-film thermocouples, thin-film strain gages, IR pyrometers, surface profile monitors and laser fluoresence of the thermally grown alumina layer.

Advanced Seals Technology. The ATS gas turbine will require improved seals in order to withstand the increased pressures and temperatures, while reducing leakage compared to current seal designs. A static seal test rig was designed and built, and a variety of seal configurations were tested. Several seal designs were chosen that significantly reduce leakage in the turbine nozzle and shroud components.

An experimental facility is being fabricated to test the new seals at temperatures and pressures that simulate ATS conditions.

Rotational Heat Transfer - Bucket Cooling. Prediction of gas turbine bucket life requires accuracy in the prediction of both the local hot gas side and coolant side heat transfer coefficients present at the relevant bucket surfaces. A considerable database exists for the hot gas side coefficients, but the database for the rotating bucket coolant passages is very limited.

Experiments were performed in the Rotating Test Rig to determine the effects of rotation on local heat transfer coefficients in rotating cooling ducts. The results of these tests have been incorporated into the ATS bucket cooling passage design procedures.

Nozzle/Bucket Heat Transfer. It is necessary to determine the internal heat transfer coefficient distributions for critical regions of the ATS stage 1 nozzle and bucket. The closed-circuit cooling requires enhanced channel heat transfer to meet performance goals and part life.

Model fabrication of the nozzle and bucket airfoil cooling passages have been completed and some testing has been initiated.

High Mach Number Diffuser. The higher pressure ratio and flow of the ATS gas turbine result in higher compressor exit Mach numbers than have been previously experienced. The compressor exit diffuser must provide good pressure recovery and an even flow distribution to the combustors.

Flow visualization tests are being performed to evaluate the impact of higher compressor exit velocities and split diffuser designs. CFD will also be used to model the flow field within the compressor/diffuser wrapper volume to evaluate potential problems. Testing of an optimized exit diffuser is in progress.

Market Study

A market study was performed to assess the potential market in the U.S. for a gas fired ATS (GFATS). The study focused on the 1995-2004 time frame, and explored the competitive economics of GFATS, current technology gas-fired systems, and coal-fired utility power plants.

The study used NERC (North American Electric Reliability Council) supply and demand projections to establish future production requirements for all nine NERC regions. These regions vary in projected load growth, load profile, generation mix, reserve margin and fuel prices.

GE Power Generation's FASTPLAN utility generation resource planning program was used to model the electricity demand by region over the next decade, and the projected mix of capacity additions to be added. Additions are based on the least cost to provide the generating addition required.

The FASTPLAN analysis predicts a market penetration of 56% for capacity additions over the next decade, with a 10% reduction in the cost of electricity compared to current gas fueled turbine systems.

Conclusion

The ATS Program Phase 2 efforts have shown that the ATS Program goals are achievable. The GE Power Generation advanced gas turbine will utilize closed-loop steam cooling in the first two turbine stages and advanced coatings, seals and cooling designs to meet the ATS performance and cost of electricity goals.

Acknowledgment

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References

1. J.C. Corman, 1995, "H Gas Turbine Combined Cycle", presented at DOE 1995 ATS Program Review and included in the proceedings.