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Present Status and Further Development of Performances of Industrial Gas Turbine Engine Turbogreen 1200

DaiKi Min*, Alexander M. Bograd**

Key Words : Gas Turbine Engine, Engine Test, Instrumentation, DAS, Performance, Efficiency

ABSTRACT

The recent results of the engine development performed in this year on Turbogreen 1200, the first industrial gas turbine engine developed in Korea, are presented. In order to improve the engine performance and structural stability from the first prototype engine, several variants of the engine and major components such as combustor and rotor assembly have been developed and tested. This paper shows these results especially focused on the engine test and performance analysis, in which test system, instrumentation and data processing are discussed as well. The engine performance and its trend give relatively good coincidence with the design ones. At design power of 1.2MW, the thermal efficiency of the engine is estimated over 25% which is below the design target of 27.2%. This gap of efficiency is caused mainly by large tip clearance between turbine blades and casing. Considering high design efficiency superior to those of other competitive engines in this power class, Turbogreen 1200 would have a strong competition in its performance if the design efficiency is achieved by further developments such as tip clearance control, which are very possible and natural in final mass production of the developed gas turbine engine.

1. INTRODUCTION

Turbogreen 1200 is the first industrial gas turbine engine developed in Korea under the development programs initiated in 1992 and supported by Korean government, in which several national research institutes and related industries have participated. Since the first prototype engine was ignited successfully in August 1996, several variants of the engine and components have been developed overcoming a lot of troubleshooting inevitably emerged during the development process. One of them was the thermal problem in high temperature component

* Member, Engine Eng. Center, Samsung Aerospace LTD.
** Engine. Eng. Center, Samsung Aerospace LTD

of so-called scroll, which caused the limit of available maximum power of the engine up to 1.1MW below the design goal of 1.2MW. Two variants of scroll were developed to solve this problem and applied to the engines, and finally made the engine reach the design power without any thermal and structural problem.

This paper presents the recent results of development especially focused on the tests and performances of the prototype engines. The procedure and system for the engine test under development are discussed and the test results are analyzed compared with the design targets of the engine and components. The overall performance of the prototype engine and its tendency show relatively good coincidence with the designed ones, considering the present development status of prototype engine. The design performance of Turbogreen 1200 is summarized as follows :

Shaft Power of Engine	1.2 MW
Rotational Speed of Engine Shaft	27,000 RPM
Thermal Efficiency	27.2 %
Air Mass Flow Rate	6.3 kg/sec
Compressor Pressure Ratio	12.1
Turbine Inlet Temperature	1270 K

Considering the other engines of this power class such as M1A of Kawasaki and Saturn of Solar Turbine, the design performance, especially the thermal efficiency of Turbogreen 1200 is superior to those of competitive engines, which means strong competition of the engine in world wide market if available in real engine performance, of course, together with durability and reliability of the engine.

2. TEST SYSTEM AND DATA PROCESSING

2.1. General Information of Engine Test System

The engine tests of Turbogreen 1200 have been performed at the Research Test Cell of Samsung Aerospace. A hydraulic dynamometer is used to measure and absorb the output power of gas turbine engine during development test, which provides more flexible operation and accurate measurement of torque if compared with a standard electric generator. The test cell is equipped with a computerized test system, which has complete capability of control and data development of all the test facility. The main functions of the system are as follows :

· Real time system
- Þ steady state, transient & dynamic data taking
- Þ initial data reduction to the "physical" format
- Þ engine health monitoring
- Þ real-time graphics and digital format displaying
- Þ testing engine & test facility monitoring and control (auto throttle/auto shutdown/ closed loop control)
- Þ trending
- Þ history/event logging
  automatic self-calibration/verification

· Off-line capabilities
- Þ plotting/logging
- Þ playback
- Þ engine diagnostic program

Data Acquisition System (DAS) for the steady state and transient performance analysis has 600 channels with 10 Hz recording frequency and 100 channels with 100 Hz. Besides, there is an engine control unit (ECU) built-in monitoring system with 20 Hz acquisition frequency. An independent system is also used to monitor and register the dynamic process.

2.2. Instrumentation and Measurements of Performance Data for Turbogreen 1200

The schematic of the instrumentation for the main flow parameters measurement is needed to be designed to make a reasonable compromise between the required number of the sensors and probes for taking detail information, and the influences (disturbances and changes in flow path area) for the performances itself aroused by applying the instrumentation. The list of pressure and temperature instrumentation, used for the performance analysis, is presented in Table 1.

For the measurement of fuel flow rate three independent flow meters are used. Two of them are instruments of test facility itself,

Table 1. Pressure and Temperature Measurements along Flow Path of Turbogreen 1200

No.	Parameter	Probe Number	Remark
INTAKE (BELL MOUTH)			
1	Inlet total pressure	4x5 = 20	
2	Inlet static pressure	6	
3	Inlet temperature	6	
LOW PRESSURE COMPRESSOR			
4a	LP compressor inlet temperature	4x5 = 20	Combined four rakes with five probes per each rake
4b	LP compressor inlet total pressure	4x5 = 20	
5	LP compressor inlet static pressure	3	
6a	LP compressor outlet temperature	3	Combined rakes
6b	LP compressor outlet total pressure	3	
7	LP compressor outlet static pressure	3	
HIGH PRESSURE COMPRESSOR			
8a	HP compressor inlet temperature	3x4 = 12	Combined three rakes with four probes per each rake
8b	HP compressor inlet total pressure	3x4 = 12	
9	HP compressor inlet static pressure	3	
10	HP compressor outlet temperature	3	
11a	HP compressor outlet total pressure	3	Combined rakes
11b	HP compressor outlet static pressure	3	
TURBINE and EXHAUST			
12a	Turbine outlet temperature	3x5 = 15	Combined rakes
12b	Turbine outlet total pressure	3x5 = 15	
13	Exhaust outlet temperature	3x5 = 15	
14	Exhaust frame outer wall static pressure	5	
15	Exhaust gas temperature	3	

which are not appropriate for the transient and starting measurements. For this purpose there is a special flow meter, installed just at the inlet of engine fuel control system. DAS also considers monitoring and registration of all engine and facility systems. Besides those special instrumentation, used for the development purposes, there is engine monitoring system having it's own registration capability including some measurements of the flow parameters.

2.3. Development Process of Performance Data

The development process of test data is staged and conventionally divided into three levels as presented in Fig. 1. At Level 1, the data of the main engine and facility are converted in real time to the physical images, recorded and/or displayed in order to monitor the process of engine test. Only relatively simple reduction calculations of additional test data could be performed in real time, which depends on computer capability. In the case of Turbogreen 1200 calculations of the inlet air mass flow rate and corrections of parameters to the standard day condition are available during Level 1 data processing. The most typical calculation is done by analog to digital conversion, applying calibration results to the electric signal of frequency or voltage to transform into a physical format.

At Level 2, the complete performances of the engine and its components are analyzed by applying specially developed software. The basic principles of the software are identical to those of design procedures in order to have the absolute correlation of test and design data.

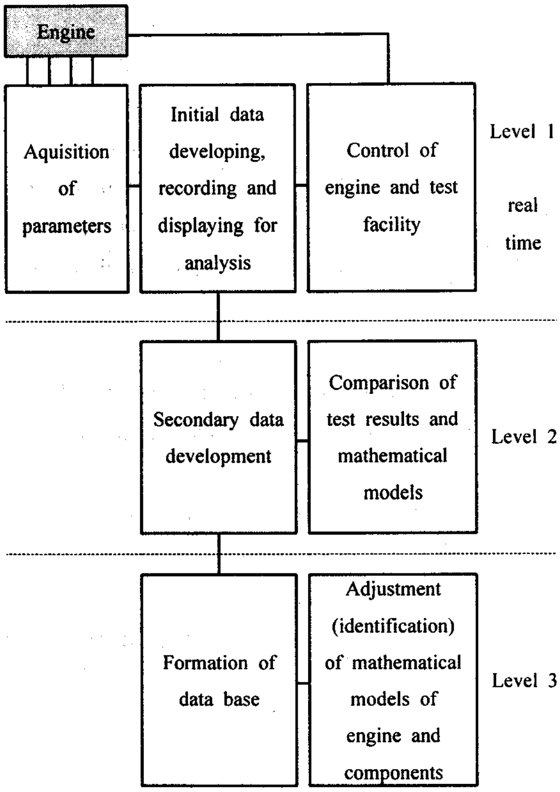

Fig. 1. Schematic of Reduction Process of Test Data

The present test hardware profile can provide the possible integration of both of Level 1 and Level 2 into the one developing system of real time parameters. In order to simplify the software and make it perfectly reliable it was decided to keep staged data development at the initial phase of the engine and facility testing.

Data analysis at Level 3 should include evaluation of measurement quality, analysis of possible reasons for discrepancy between test and design data, adjustment of measured data and mathematical model, and analysis of possible reasons for measured data inferiors. A strict evaluation on the performance of the engine and components is one of the specific features of Level 3, which is also very important to verify reliability of design methods and make proper corrections to improve them.

3. PERFORMANCE ANALYSIS

The typical example of engine test for the steady state performance is shown in Fig. 2. The initial data for performance analysis of steady state are recorded after stabilizing parameters for the operational mode. Setting mode is specified by engine shaft speed and output shaft power. For Turbogreen 1200 having relatively heavy casings and turbine disks, it takes about 30 minutes to get complete thermal stabilizing of hardware. Most of performance parameters, however, become stable within 350 second after cold start of the engine and require much shorter time to be stabilized to another operational point once the engine is settled down at any point.

The main performance test results of steady state of Turbogreen 1200 are presented in Fig. 3 and 4, in which plots of parameters vs. power are shown for 100 % of engine shaft speed. All parameters are corrected to standard day conditions. In current stage of the development the engine efficiency is less than design one so that a higher level of turbine inlet temperature (TIT) is required for the specified output power by about 50 K. This discrepancy is mainly due to lower turbine efficiency than the design value. It happens mostly because of large tip clearances between turbine blades and casings. For the initial development stage it was decided as a reasonable meter in order to have safe operation without rubbing by contact of rotating and stationary parts at any operation conditions.

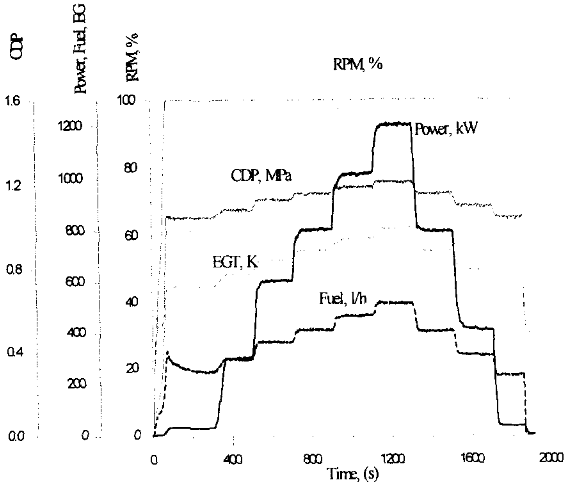

Fig. 2. Performance Test of Turbogreen 1200 (5 November 1998, Start No. 9)

This is very usual when rotor dynamic characteristics is not stabilized yet and it is not clear for flexible bending of rotor to happen during engine running.

Further development of the engine makes it possible to return back the turbine tip clearances to specified design values. Fig. 5 demonstrates the expected results of that improvement. For the analysis the experimental and design mathematical models of the engine are compared. Besides effects of turbine tip clearances, it will be necessary to optimize the performance matching of components by adjusting the effective area of flow path. It will provide optimum operational point as well as stall margin of compressor approaching to design position.

Beside engine performance data at the 100% of rotor speed, the steady state characteristics are investigated at the range from 35 to 102% of rotor speed. These steady state results are very important to determine reasonable fuel control schedule for starting and acceleration of the engine, and to get information of compressor stall margin. At the same time it is confirmed that the design rotor speed of the engine is close to optimal values in terms of engine efficiency, which means the maximum efficiency of the engine for the same specified power within limits of turbine inlet temperature.

Starting time is one of the important engine characteristics, especially for the engines of emergency duty application. The starting characteristics of Turbogreen 1200 were preliminary examined in March this year with the prototype engine to which the second variant of scroll was applied. The test was performed with dynamometer instead of electric generator. In this case the total inertia moment is less by about 30 %. At the same time, the combustion system configuration with the second variant of scroll resulted in a slightly higher pressure drop, which made the operation line above the normal position and reduced acceleration rate of the engine. During the test No. 34 it was demonstrated that engine acceleration time up to 100-2 % of rotor speed is 37.3 seconds as shown in Fig. 6. Further slight reduction in starting time could be achieved by fuel schedule adjustment, but the main source for the starting characteristic improvement is the increase in power of starting motor. The present engine configuration, however, satisfies the specified requirement of starting time, that is, 40 seconds.

Temperature of the engine casing has also a great influence on the starting performances. Fig. 7 represents that for the same fuel schedule the starting time is different for about 20 seconds if comparing "cold" and "warm" starting conditions. The turbine exhaust temperature shows also large difference for these two cases. it is noted that for the emergency duty engine having a short starting time the fuel schedule for starting should be made with a correction

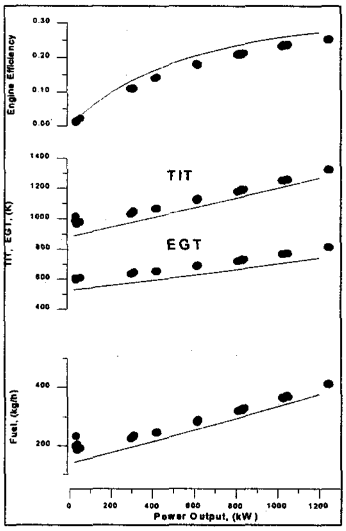

Fig. 3. Engine Characteristics of Turbogreen 1200

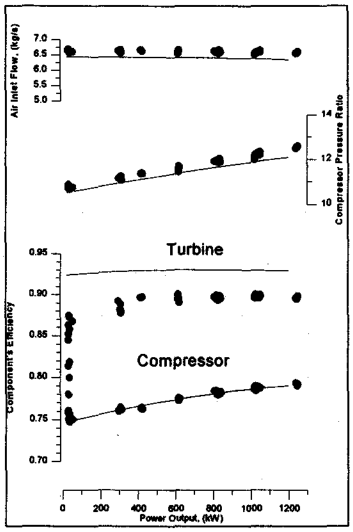

Fig. 4. Component Characteristics of Turbogreen 1200

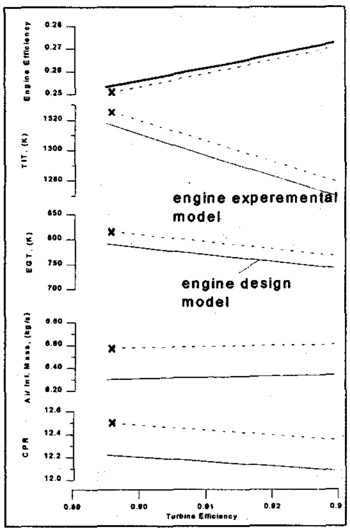

Fig. 5. Influence of Turbine Efficiency

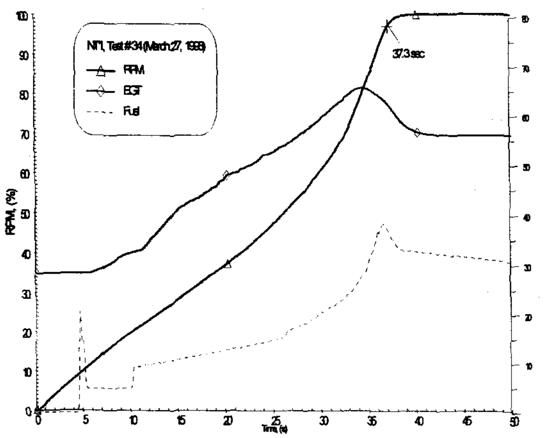

Fig. 6. Starting Characteristics of Turbogreen 1200

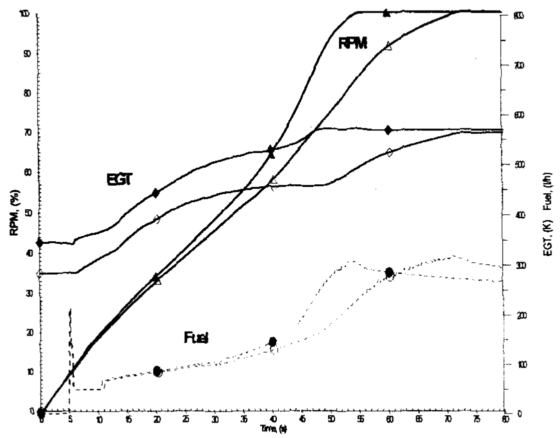

Fig. 7. Influence of Casing Temperature on the Starting Characteristics

depending upon the temperature condition of the engine casing

4. CONCLUSIONS

Development tests and their analysis of industrial gas turbine engine Turbogreen 1200 have been performed to investigate the performance of the developing engine compared with the design goal. Engine test system, test facility, instrumentation and data processing scheme have been developed specially and applied to tests and performance analysis of the engine under development. From the analysis on the test results the engine efficiency and its trend coincide with the design ones to a resonable extent. The analyzed efficiency is lower than the design value by around 2% at full power of 1.2MW, attributed mainly to lower efficiency of turbine component, which is caused by large tip clearances of turbine blades in order to make a safe running of the developing engine. On the other hand, the preliminary engine test and its analysis on the starting characteristics show that the starting performance is satisfied with the design limit of 40 seconds for the emergency application and it is necessary to increase the power of starting motor in order to reduce starting time, and the temperature condition of the engine casing has a big influence on the starting characteristics of the engine.

ACKNOWLEDEMENTS

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