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CURRENT STATUS OF 300 kW CLASS INDUSTRIAL CERAMIC GAS TURBINE R&D IN JAPAN

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Abstract

Advanced technologies in Ceramics Gas Turbine (CGT) are expected to make a great progress in energy conservation, anti-pollution, and fuel-diversification.

In Japan, R&D's in industrial usage 300 kW class CGT have been advanced under a national project entitled "New Sunshine Program", under the subsidy of Agency of Industrial Science and Technology (AIST), Ministry of International Trade and Industry (MITI) through the period of FY1988-1996.

In this project, three different type prototypes of the CGT are under development through New Energy and Industrial Technology Development Organization (NEDO).

Over the last six years, the basic designs have been completed and the ceramic elements such as turbine rotors, scrolls, and combustors were successfully fabricated. To check up the whole progress of the project, an interim evaluation is scheduled by the end of FY1993. Toward this evaluation, each prototype has been programmed to demonstrate 1200°C of Turbine Inlet Temperature (TIT) and prove more than 30% of thermal efficiency. (The ultimate target in the project is 42% of thermal efficiency at 1350°C TIT.) They would also show enough environmental adaptability.

In this paper, overall status of the development in the 300kW CGT project is reviewed and the items in the interim evaluation are explained.

Introduction

Gas turbines consist of very few parts and they have relatively light weight and compact size. Their use is disseminating in recent years in view of their merits regarding compatibility with a wide variety of fuels, low pollution, etc. It must be remembered, however, that gas turbines have a little faults. As things now stand the thermal efficiency is as low as 20%-30%, and the smaller the size the lower the efficiency. Fig.1 shows the thermal efficiencies of small-middle class industrial gas turbines and the final target of Japanese CGT[1].

The efficiency of gas turbines can be improved by simply raising the TIT, but it must be remembered that realizing high temperatures in small size metallic gas turbines of conventional type is quite difficult. Such being the case, CGT using ceramics at the high temperature zone of the gas turbine is being developed for such applications as co-generation, plain power

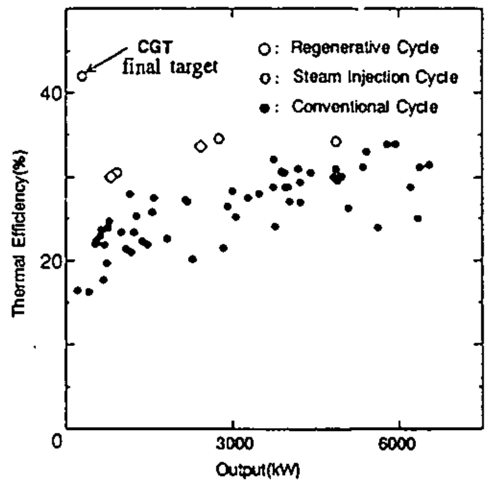

Figure 1 Thermal Efficiency of Gas Turbines

generation, etc., with the object of coping with the requirements of energy saving, low pollution and diversification of fuels.

In a Japanese national energy utilization project titled "300 kW Industrial Ceramic Gas Turbine Research and Development Project", which is established in the "New Sunshine Program", 3 different types of CGT prototype are now under research and construction with support of several public institutes. The whole organization for the project is indicated on Fig.2 and the schedule on Fig.3

The three types of the engines are called CGT301 (siogle shaft for co-generation), CGT302 (two shaft for co-generation) and CGT303 (two shaft for mobile power generation) respectively. Merits of the each type are shown in Table.1.

R&D's have been advanced with 3 stages (1st: Metallic basic stage [TIT=900°C], 2nd: Ceramic basic stage [TIT=1200°C], Final: Ceramic pilot stage [TIT=1350°C]) for each of the 3 types. The ultimate target in the final stage is 42% for thermal efficiency and they would develop full 300kW output.

As of today, the first stage was finished successfully, and the second stage is under way.

The interim evaluation is being undertaken in the 2nd stage at present under the Industrial Technology Council that is organized with impartial members.

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Table. 1 Comparison of 3 types of CGT (in final target)

	CGT301	CGT302	CGT303
Usage	Co-generation for Stable Power Condition and Large Scale Power Request	Co-generation for Floating Load Condition and Non-Large Scale Power Request	Mobile Type Power Generation (for Machine Driving)
Comparison with Other Engine Systems	• Low Pollution (Environmentally Friendly) • Adaptable for Various Types of Fuel • Light-Weight and Compact • High Thermal Efficiency from High TIT with Ceramic Materials • Low Vibration and Limited High-Frequency Noise which is Squelchable • No Need for Warm-Up and Easy to Get Emergency Power • Easy to Adapt to Highland and Cold Climate • Low Maintenance and Running Cost		
	• High Quality Electric Energy and Thermal Energy from Single Heat Source • Easily Adaptable to Larger Power Request with Combining Plural Engines • High Temp. & High Pressure Steam from High Exaust Gas Temp. Able to be Used for High Efficiency Cooling System		• High Efficiency and Low Emission even at Partial Load • Portable and Vibration-Free when Mounted on Cars, and This Leads to Compact and Light-Weight Car Structure, and Further Conservation and Lower Pollution
Spool	Single Shaft • High System Performance near Full Load • Simple, Compact and Light-Weight • Large Inertial Moment and Low Fructuation • Easy Maintenance	Double Shaft (GGT, PT) • Stable Operation and Small Drop in Efficiency even at Partial Load • Flexible Operation in Wide Thermal/Electrical Power Ratio Control (CGT302) • No Restriction in Optimizing Engine System with Freely Setting RPMs of GGT and PT	
Cycle Pressure	P/R=7.3 [7.3 in Interim Evaluation Stage] • High Efficiency on Cycle Performance	P/R=8.0 [5.9 in Interim Evaluation Stage] • High Efficiency on Cycle Performance	P/R=4.5 [4.4 in Interim Evaluation Stage] • Low Air Leakage • High Efficiency on Heat Regenaration
Compressor Type	1 Axial-Flow Stage and 1 Centrifugal Stage (Metal) • Easy to Extend in the future to Multi-Stage, High Pressure, and Large Mass Flow • Avoiding Stall by Adopting 2 Stages. • Easy to Apply Abradable Sealing	1 Centrifugal Stage (Metal) • Simple Structure, Small Load to Bearing • Large Margin for Stall and High Pressure Ratio in 1 stage. • Durable against FOD	1 Centrifugal Stage (Metal) • Simple Structure, Small Load to Bearing • Large Margin for Stall and High Pressure Ratio in 1 stage. • Durable against FOD
Combustor Type (Mid Duct)	Pre-Mixed Lean-Burning (Ceramic) (Mounted on Co-Axial Position) • Limited Liner Cooling Air by Using Ceramics even in High COT. The Saved Air can be Induced to Premixed Combustion Region for Low NOx Production • Reliable and Low Cost with No Scroll	Pre-Mixed Lean-Burning (Ceramic) (with Scroll) • Limited Liner Cooling Air by Using Ceramics even in High COT. The Saved Air can be Induced to Premixed Combustion Region for Low NOx Production • Optimizable of the Position of Combustor and Compact Size in Axial Direction	Pre-Mixed Lean-Burning (Ceramic) (with Scroll) • Limited Liner Cooling Air by Using Ceramics even in High COT. The Saved Air can be Induced to Premixed Combustion Region for Low NOx Production • Optimizable of the Position of Combustor and Compact Size in Axial Direction
Turbine Type (Nozzle)	Fixed Stator (Ceramic) • Simple Structure • No Moving Parts = Limited Gas Leakage	Fixed Stator (Ceramic) • Simple Structure • No Moving Parts = Limited Gas Leakage	Variable Stator (Power Turbine) (Ceramic) • Easy to Optimize TIT at Partial Load and to Diminish Efficiency Loss
Turbine Type ():Rotor Each Model has Ceramic Segment Type Stator	2 Axial Flow Stage (Ceramic Blades inserted in Metal Rotor) • Easy to Extend in the future to Multi-Stage, High Pressure, and Large Mass Flow • Relatively Durable against FOD • Easy to Apply Abradable Sealing	1 Axial Flow Stage for GGT (Ceramic Blades inserted in Metal Rotor) + 1 Axial Flow Stage for PT (Ceramic Blades inserted in Metal Rotor) • Easy to Extend in the future to Multi-Stage, High Pressure, and Large Mass Flow • Relatively Durable against FOD • Easy to Apply Abradable Sealing	1 Radial Inflow Stage for GGT (Ceramic) + 1 Axial Flow Stage for PT (Ceramic Blades inserted in Metal Rotor) • High Performance with Compact Structure • High Durability in Hot TIT. • Easy to Apply Abradable Sealing for Axial Flow Stage
Heat Exchanger Type	Cross-Flow type Shell and Tubes (1 Ceramic Stage and 2 Metal Stages) • Reliable in High Temp. Heat Regeneration • No Need for Driving Power • Limited Air Leak	Counter-Flow type Plate-Fin (Metal) • Reliable Metal Structure which can be used for Relatively Low Temp. Exaust Gas • Limited Air Leak	Rotary type (Ceramic) • Able to Exchange Heat against High Temp. Exaust Gas • High Efficiency in Heat Exchange • Compact Size
Note	Balance Piston for Diminishing Thurust Load	Bound Structure for Large Scale Members with Ceramic Fibre Winding	

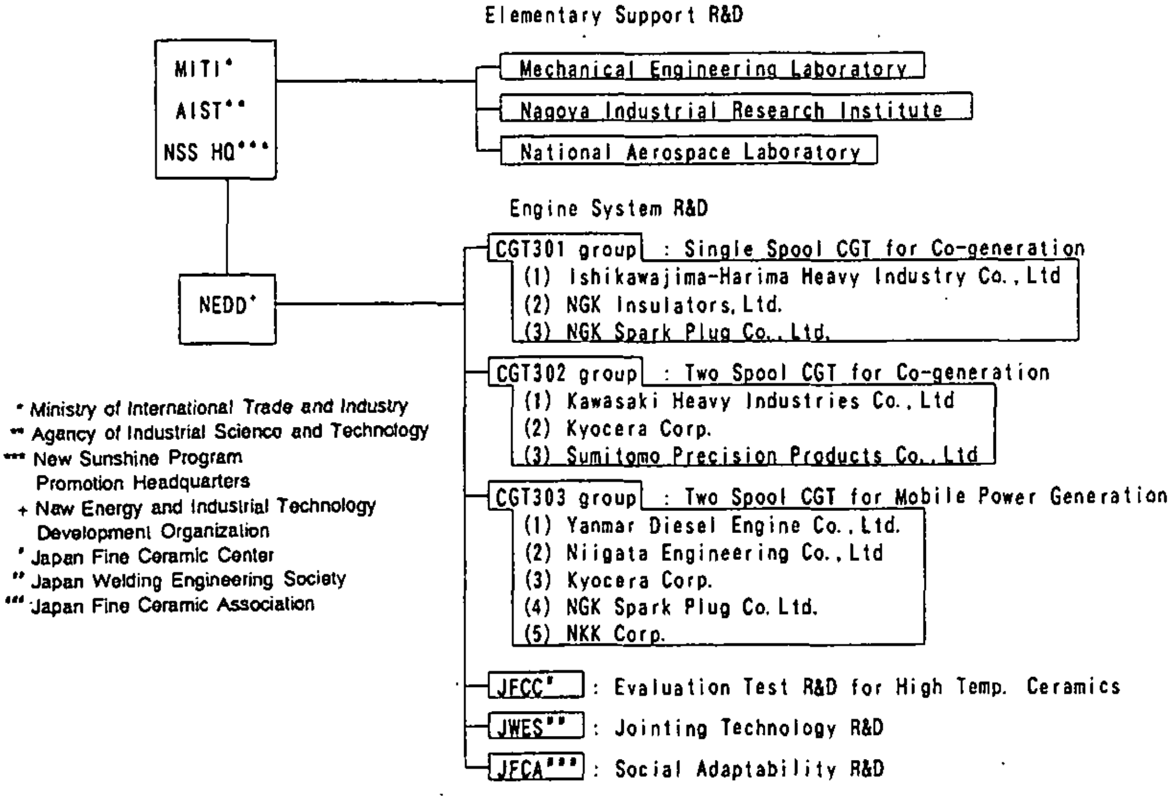


Figure 2 Organization of Japanese 300kW CGT Project

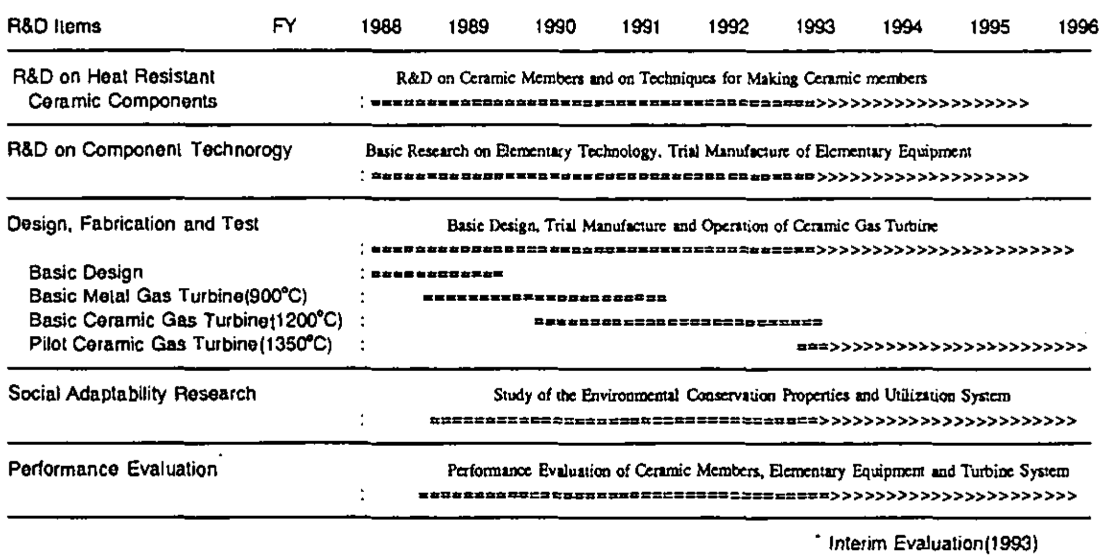


Figure 3 Schedule of the 300kW CGT Project

Profiles of each type of the 300kW class CGT

Since the interim evaluation on the CGT project is being conducted at present (the 2nd stage of the project), the following is about the 2nd stage. The ultimate targets in the final stage of this project are also shown in brackets.

(1) CGT301: Single Spool CGT with Regenerator for Co-generation [Fig. 4]

Having one spool, targeting for high efficiency in full load running, this type adopted co-axial axisymmetrical simple design for almost all elements except the heat exchangers. Introducing this structure, it is relatively easy to extend to cope with larger power request in the future.

By controlling the amount of exhaust gas flown through the regenerator, wide range of thermal/electric output ratio is achieved.

A combination of one axial-flow and one centrifugal compressor is designed to produce P/R 7.3[7.3] and 79.0%[81.5%] of adiabatic efficiency.

The heat exchanger is constructed with 6 array modules. In the basic CGT stage, though all metallic parts are used for this heat exchanger for the actual engine, elementary R&D's using ceramics are proceeding toward the final stage. In the final stage (pilot CGT), each module would have 1 ceramic stage and 2 metallic stages. The cold air passage is 3 step serpentined.

All 3 stages are designed as "cross-flow shell and tube" structure. The ceramic stage are further divided into two blocks, each has 163 ceramic pipes with inner fins. Each ceramic pipe, which has about 600mm length and 8mm diameter, is bonded to the wall plates by applying double step sintering. The target efficiency is 84%[84.5%].

A single can ceramic combustor, which is located in the rear co-axial position toward the turbine section, will achieve less than 70ppm NOx emission by premixed lean burning. This combustor is at present divided into 4 pieces. However it is planned to integrate it into one piece as the reliability of the ceramics progresses.

A two stage axial flow turbine is employed, which would achieve 83%[87.5%] of adiabatic efficiency. Each stage has inserted type ceramic blades with a metal disk for the rotor (hybrid), and segment type ceramic nozzle for the stator. In hybrid type rotors, insulating foil between ceramic blades and metallic disk is a key technology for CGTs. Casings of the turbine section are made of metal, each of which is formed into conical shape to reduce thermal stresses.

As to the material, several types of silicone nitride (monolithic) are being tried for the combustor, the turbine stators and the turbine rotors.

(2) CGT302: Two Spool CGT with Regenerator for Co-generation [Fig. 5]

The CGT302 has been designed to fit floating-load power requirement. From the standpoint of thermal efficiency at partial output, 2-shaft design has been adopted. The concept of the CGT302 is based on the structure of conventional small gas turbines, which is much experienced and reliable. Replacement into ceramics would be the main objective in the CGT302.

Also in the CGT302, by controlling the amount of exhaust gas flown through the regenerator, a wide range of thermal/electric output ratio is accomplished.

A single stage centrifugal compressor generates P/R 5.9 [8.0] and adiabatic efficiency 79%[82%].

"Counter-flow plate-fin" type recuperators, which is constructed with corrugated superalloy plates by using brazing technique, are introduced. The target efficiency is 78%[82%] based on temperature.

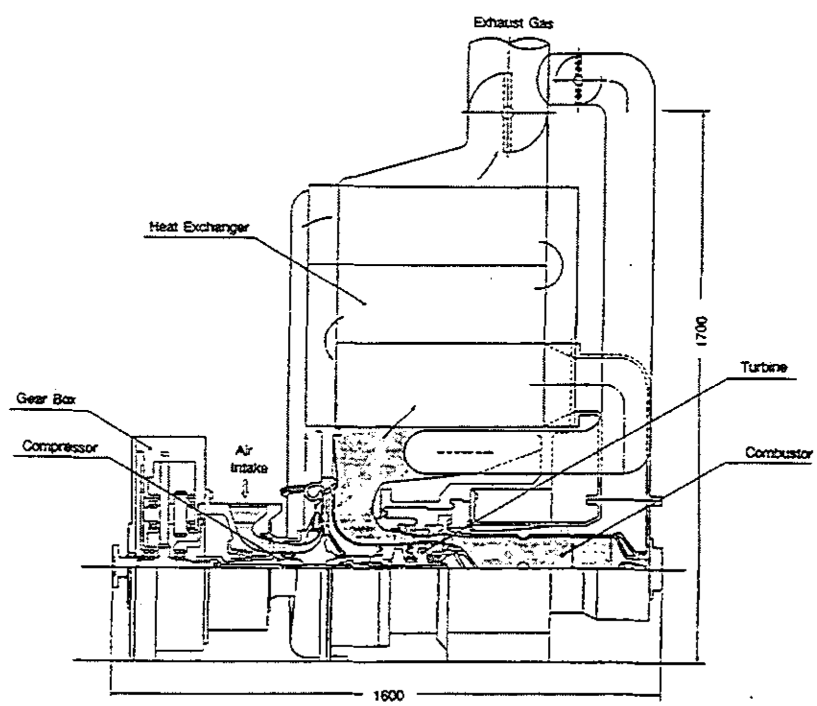
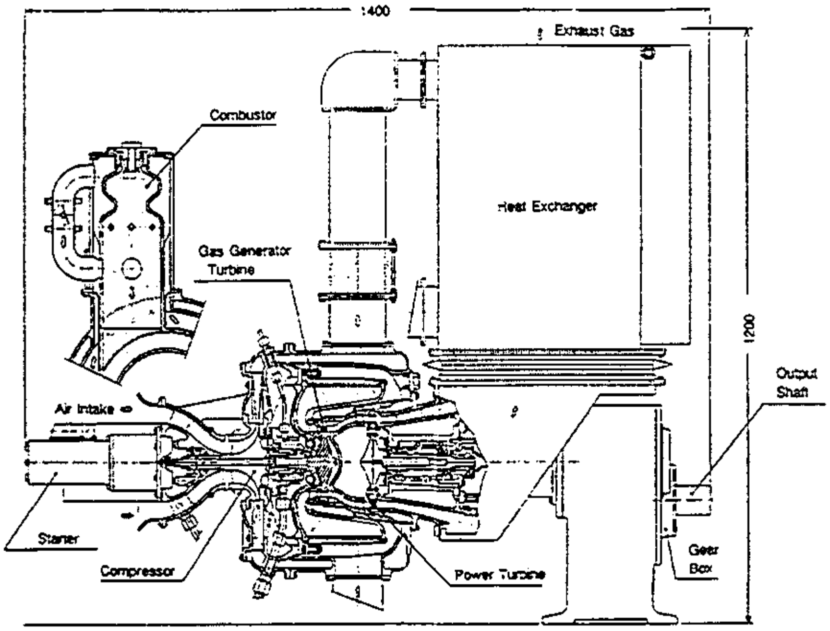


Figure 4 Concept Figure of CGT301



For the combustor, a single can ceramic type has been made use of. Premixed lean burning combustor is now under component tests and is expected to achieve low NOx emission (less than 70ppm) in the actual engine.

A scroll is constructed with 3 parts (outer scroll, inner scroll, and deflector). The outer scroll is divided into 4 pieces to maintain reliability by avoiding too large parts. Those are bound together into a kind of composite material with silicone carbide fiber. Chemical Vapor Deposition (CVD) treatment is applied to bond the fiber to each other.

A single stage axial flow gas generator turbine would achieve adiabatic efficiency 79% [84%]. The nozzle stage is a segment type and all segments are also bound together with ceramic fiber. The rotor is one piece ceramic brisk (144mm for the diameter), which is jointed to a metallic shaft by using brazing and shrinkage-fitting.

For power output, single stage axial flow power turbine has been used, which would achieve 82% [88%] as adiabatic efficiency. The stator is a segment type and the rotor is a ceramic blade hybrid type.

As to the material, for all the ceramic elements except for the fiber bound structure (silicone carbide), several kinds of silicone nitride are tried.

(3) CGT303: Two Spool CGT with Regenerator for Mobile Power Generation [Fig.6]

The main purpose of the CGT303 is mobile power generation, in which the merits of the ceramic gas turbine (portable size and light weight) are effective.

A two spool design is adopted to fit varying power requirements.

A rotating type heat recovery system is used for its compactness. In the CGT303, the heat recovery system plays important roles because of the design concept, in which the high thermal efficiency relies upon the heat recovery performance.

Single radial type compressor, which is also made of titanium alloy, generates P/R 4.4[4.5] and adiabatic efficiency 82.0%[82.4%].

A pair of rotary type heat exchangers (610mm for the diameter and 20 rpm for the rotating speed) are placed on both sides of the engine. The heat accumulator core is made of a number of low expansion ceramic (cordierite) cell blocks. Several types of diaphragm seals with plasma-sprayed ceramic lubricant have been devised to minimize the thermal deformation. The target heat exchange efficiency is 88%[92%].

A single can combustor is employed. Premixed lean burning has been studied to attain low NOx emission. Based on the component tests, satisfactory values (less than 70ppm NOx) are expected in the actual engine.

A scroll, which is the largest part in this CGT project, is constructed with three pieces (440mm for the outer diameter) to avoid introduction of defects.

A radial in-flow type gas generator turbine is utilized to achieve adiabatic efficiency of 85.0%[88.3%]. The radial rotor has a diameter of 163mm and made in one body. Shrinkage-fitting with brazing is applied to connect the rotor to a metallic shaft. Segmented cascade type nozzles are introduced. While these nozzles had been made of SiAlON at the beginning of this project, application of rather tougher silicone nitride is considered at present.

Radial turbines are generally susceptible to FOD, because the centrifugal force on the "foreign object" balances the pressure gradient and the object is liable to be caught at the rotor outer diameter. Some improved designs have been applied to the rotor.

For the power turbine, hybrid type has been used to perform the efficiency of 83.8%[86.8%].

In the CGT303, several kinds of silicon nitride are introduced to accomplish the targets.

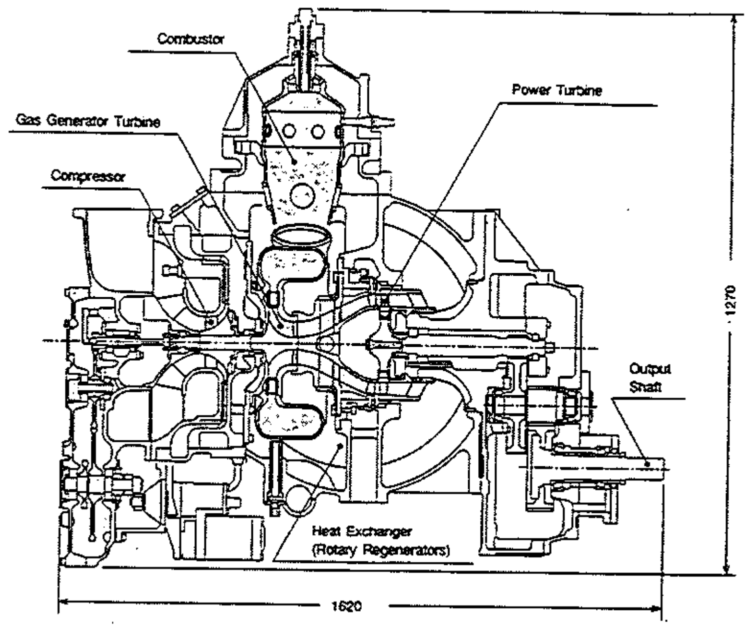


Figure 6 Concept Figure of CGT 303

Interim Evaluation

The interim evaluation for the CGT project is now under way. The objective of the evaluation is to check up not only the technical possibility of realization of the engine system but also the adaptability into our society from the viewpoint of environmental friendliness and economic effectiveness. Some of the target technical items of each type of the CGT in the evaluation are mentioned in each part above. In addition, of course, strict accuracy for the shape/size of critical members and system/component reliability throughout running in 1200°C TIT are required. (In the final stage, durability at 1350°C TIT is eventually required. Tests for final stage material have been also proceeded with in the interim evaluation.)

All the elements are required to continue R&D for the accuracy of fabrication to obtain further good performance. However, the process technology have reached to the level that the preciseness and durability required in the design can be achieved.

Also as a standard of environmental friendliness in the evaluation, with natural gas as fuel, the CGT's should achieve less than 70ppm NOx emission (16%O_2 condition), which meets Japanese national regulation. (The ultimate target in the final stage is 35ppm NOx which follows Japanese urban regional regulation.)

As to thermal efficiency, which is most essential index of energy conservation, the target in the interim evaluation is 30% compared to the value of 42% at the final stage. Even in 1200°C TIT, this is extremely high value in this class of gas turbines.

Economic effects when the CGT's are put to practical use are under research by JFCA. Since the demand of co-generation systems in Japan has not been fully explored yet, this class of CGTs are much expected to prevail.

Conclusion

The overview of current status of Japanese 300kW CGT program was reported. Especially the differences in the design concepts of three types of the CGT engines are discussed.

The key items in this CGT project, which spread into many fields, are the heat exchangers, the turbine rotors, the assembling technology and of course the durability and manufacturability of heat resistant ceramic components.

Policy in the interim evaluation in FY1993 was also commented on to clarify the purpose of the Japanese 300kW CGT project.

Acknowledgement

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