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CURRENT STATUS OF CERAMIC GAS TURBINE (CGT302)

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ABSTRACT

In Japan, from the point of view of energy saving and environmental protection, a 300kW Ceramic Gas Turbine (CGT) Research and Development program started in 1988 and is still continuing as a part of "the New Sunshine Project" promoted by the Ministry of International Trade and Industry (MITI).

The final target of the program is to achieve 42% thermal efficiency at 1350℃ of turbine inlet temperature (TIT) and to keep NOx emissions below present national regulations. Under contract to the New Energy and Industrial Technology Development Organization (NEDO), Kawasaki Heavy Industries, Ltd. (KHI) has been developing the CGT302 with Kyocera Corporation and Sumitomo Precision Products Co., Ltd.

By the end of the fiscal year 1996, the CGT302 achieved 37.0% thermal efficiency at 1280℃ of TIT. In 1997, TIT reached 1350℃ and a durability operation for 20 hours at 1350℃ was conducted successfully. Also fairly low NOx was proved at 1300℃ of TIT. In January 1998, the CGT302 has achieved 37.4% thermal efficiency at 1250℃ TIT.

In this paper, we will describe our approaches to the target performance of the CGT302 and current status.

INTRODUCTION

Features of CGT302

The specifications of the CGT302 are shown in Table 1 and a cross section of it in Fig.1. The CGT302 is a regenerative two-shaft ceramic gas turbine engine. Ceramic materials are applied to high temperature components such as a combustor liner, a scroll, turbine nozzles and turbine rotors. A metal plate-fin recuperator is applied to the heat exchanger.

In order to apply ceramic materials, some unique technologies were developed such as monolithic-fiber reinforced ceramic (FRC) hybrid ceramic components, stress-free supporting structures, joining technologies, etc.

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Table 1 Specification of CGT302

Item	Unit	Pilot CGT Target	Basic CGT Target
Maximum Power	kW(PS)	300 (408)	140 (190)
Thermal Efficiency	%	42	30
Turbine Inlet Temp.	℃	1,350	1,200
Air Flow Rate	kg/s	0.89	0.68
Pressure Rate	—	8	5.9
GGT Speed	rpm	76,000	68,400
PT Speed	rpm	57,000	51,300
Compressor Efficiency	%	82	78
Turbine Efficiency (GGT+PT)	%	85.5	82.2
Heat Exchanger Efficiency	%	80	78

Table 2 Schedule of CGT program

1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998
Ceramic Component Fabrication Technology										
Component Technology (Turbine, Compressor, Heat Exchanger, etc.)										
Basic Design					Intermediate Appraisal					
	900℃ MGT									
		1200℃ Basic CGT								
							1350℃ Pilot CGT			

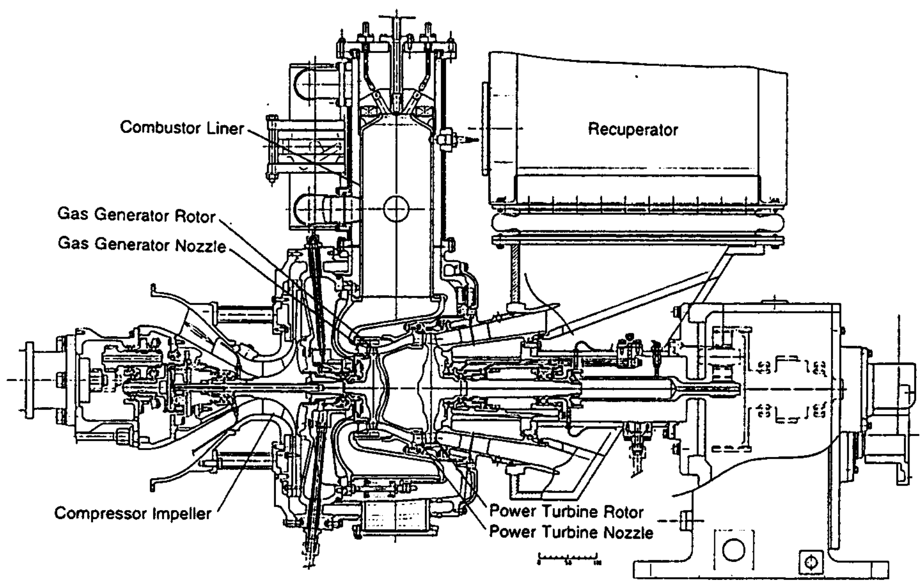

Fig.1 Cross section of CGT302

Developing program

As shown in Table 2, there are three stages in the development program of the CGT302, (1) 900℃ Metal Gas Turbine (MGT), (2) 1200℃ Basic CGT, (3) 1350℃ Pilot CGT. More suitable materials were adopted or developed at each stage and performance of each component has been improved through all stages.

Now the development of CGT302 is in its final stage, and we are developing the 1350℃ Pilot CGT. In the following sections, our approaches to the target performance will be introduced from the point of view of TIT, efficiency and emissions.

For more information and details, refer to ASME97-GT461 and others (see References).

APPROACH TO TARGET TIT

Ceramic materials

More suitable materials were developed at each stage of the program. Kyocera developed SN252 silicon nitride for the Basic CGT and SN281 and SN282 silicon nitrides for the Pilot CGT. SN281 and SN282 had improved characteristics compared to SN252 in strength and oxidation resistance. Fig.2 shows the comparison of the flexure strength of these

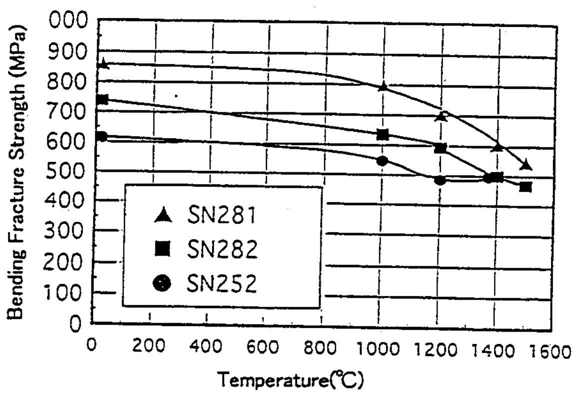

Fig.2 Comparison of flexure strength of ceramic materials

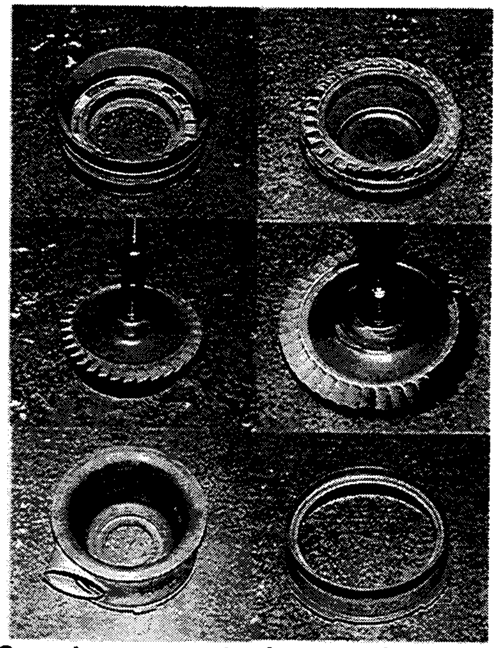

Fig.3 Ceramic components after operation at 1350℃

materials. SN281 was applied to the gas generator turbine (GGT) rotor and SN282 to all the other ceramic components.

In the process of raising TIT, we set some intermediate TIT targets of 1250℃ and 1300℃. Thorough these tests, the reliability of ceramic components and engine stability were confirmed.

In 1997, the engine tests in which all SN281 and SN282 ceramic components were installed have been conducted and the TIT reached 1350℃. In the operation at 1350℃ TIT, oxidation, fracture or any other problems were not detected. Furthermore, a durability testing for 20 hours at 1350 ℃ was carried out successfully. The representative ceramic components after 20 hours of operation at 1350℃ are shown in Fig.3.

Heat resistant metallic materials

It was predicted that the exhaust gas temperature would be more than about 850℃ at 1350℃ TIT. So, for the pilot CGT, better heat resistant alloys such as Hastelloy alloys, instead of Stainless steels, were adopted to metallic parts like exhaust collector and bellows.

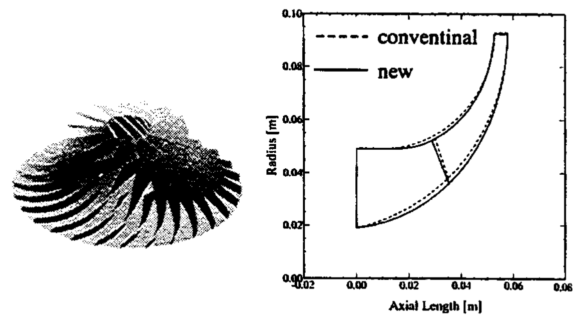

Fig.4 Newly designed impeller

APPROACH TO TARGET THERMAL EFFICIENCY

From the tests results up to now, we can predict that the pilot CGT will achieve about 40% thermal efficiency at the pilot condition as mentioned later. But the target efficiency is 42%, a little higher than the presumed efficiency, and further improvement of each component performance is required.

Compressor

Compressor efficiency has been improved by adjustment of the engine matching point. In order to improve compressor performance still more, a new type impeller was designed with three-dimensional viscous flow analysis as shown in Fig.4.

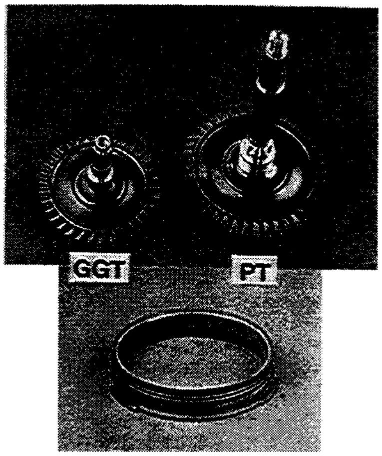

Fig.5 Integrated ceramic PT rotor and ceramic PT shroud

Turbine

Adoption of integrated ceramic PT rotor and ceramic PT shroud

In the Basic CGT, a metallic PT rotor and a metallic PT shroud were installed. In the Pilot CGT, a hybrid PT rotor (metallic disk - ceramic blade) and a ceramic PT shroud were intended to be installed at first. However, it is difficult for the hybrid PT rotor to keep small tip clearance and also difficult to control gas passing between the ceramic blade dovetail and the metallic disk. And these affect turbine efficiency considerably. As fabrication technology of ceramic components has advanced, it became possible to manufacture an integrated ceramic PT rotor at about 200mm in diameter. So, the integrated ceramic PT rotor were adopted for the Pilot CGT to obtain high turbine efficiency by resolving those problems (Fig.5).

Optimization of turbine nozzle throat area

It was revealed that the difference of turbine nozzle throat area of each assembly was greater than we assumed. Therefore, after investigating the correlation between throat area and the efficiency, better nozzles were selected.

Table 3 Rotational speed (tip speed) of engine

Item	Original speed	New speed
GGT	76,000 rpm (573 m/s)	64,000 rpm (483 m/s)
PT	57,000 rpm (573 m/s)	47,800 rpm (480 m/s)

Fig.6 New(left) and original(right) GGT blade airfoils

Redesign of GGT and PT rotor blade airfoils

During the development of the Basic CGT, we sometimes experienced blade chippings which were presumably caused by FOD. For the countermeasure against FOD, the engine rotational speed were reduced as shown Table 3. And the GGT and PT rotor airfoils were re-designed to maintain performance at the lower engine speed. They were designed twice thicker against FOD as shown Fig.6, so there is a suspicion of a drop in efficiency.

This new PT airfoil was adopted for the integrated ceramic PT rotor, which has been tested in the engine. We have seldom experienced blade chipping, so another new PT rotor blade with thinner airfoil is designed to obtain higher turbine efficiency,.

Adoption of abradable ceramic turbine shroud

In order to further increase turbine efficiency, the turbine tip clearance will be reduced by using an abradable ceramic turbine shroud.

Heat exchanger

The target efficiency of the heat exchanger of the Basic CGT has been achieved. However, it is predicted that the efficiency will decrease at the pilot condition. The reason is that the heat transfer rate decreases with increase of the amount of heat exchange on the definite heat transfer area. To solve this problem, the number of heat transfer fins was increased from 8 to 10 per inch. For higher heat resistance, HA230 super alloy was applied to the fin. The new heat exchanger is shown in Fig.7.

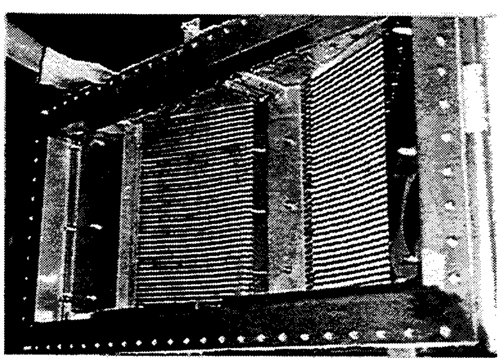

Fig.7 New heat exchanger

APPROACH TO TARGET EMISSIONS

The CGT302 adopted the premixed lean combustor to keep low NOx emissions. Fig.8 shows a schematic drawing of the premixed lean combustor. This combustor has one air bypass line with one valve. By controlling this valve, the premixed lean combustion operations are conducted.

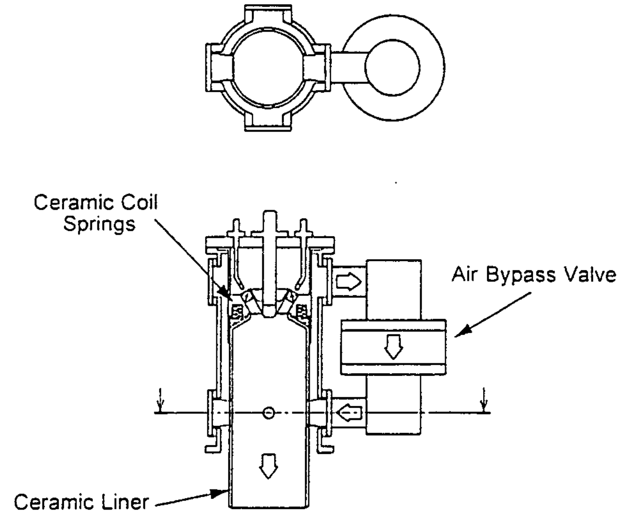

Fig.8 Schematic drawing of premixed lean combustor

CURRENT STATUS OF CGT302

Engine tests have been conducted since 1993. In 1997, TIT reached the target temperature of 1350℃ and 20 hours durability operation was achieved at 1350℃ with all ceramic components for the Pilot CGT. Total cumulative operation time reached 223 hours as shown in Table 4.

Table 4 Total operation time of engine

Turbine Inlet temp.	Operating Hour			
	Step 4	Step 5 (Full Ceramic)		Total Hour
	Metal PT	Hybrid PT	Integrated PT	
1350℃~	0m	0m	20h 32m	20h 32m
1300~1350℃	8m	0m	16h 07m	16h 15m
1250~1300℃	19h 37m	0m	2h 52m	22h 29m
1200~1250℃	42h 18m	12m	3h 31m	46h 01m
1150~1200℃	4h 52m	1m	2h 41m	7h 34m
1100~1150℃	8h 07m	21m	3h 03m	11h 31m
1000~1100℃	22h 42m	58m	3h 42m	27h 22m
800~1000℃	56h 27m	2h 26m	12h 23m	71h 16m
Sub Total by Step	154h 11m	3h 58m	64h 51m	223h 00m
No. of Start	371	19	57	447

Engine performance tests

In January 1998, The CGT302 has achieved 37.4% thermal efficiency at 1250℃ TIT with 240kW. The engine

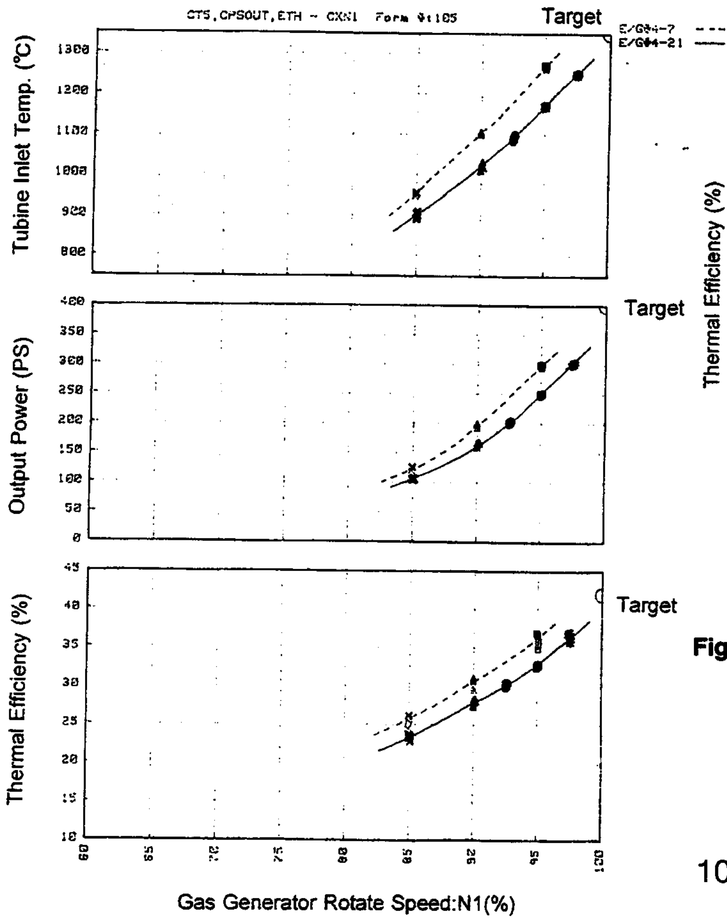

Fig.9 Performance curves of CGT302

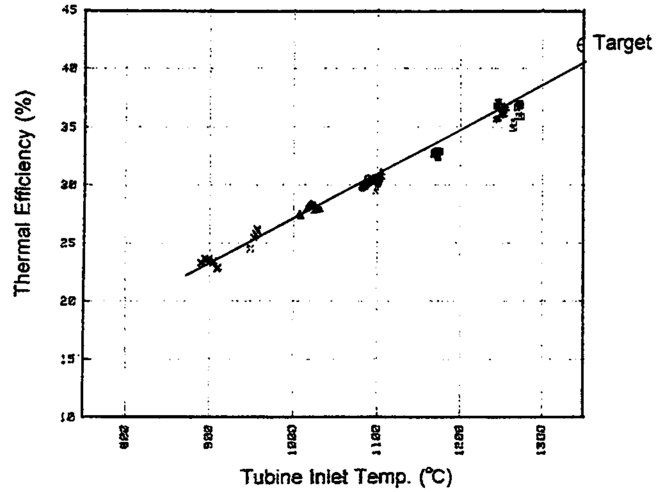

Fig.10 Performance curve of CGT302 (η_{th} vs. TIT)

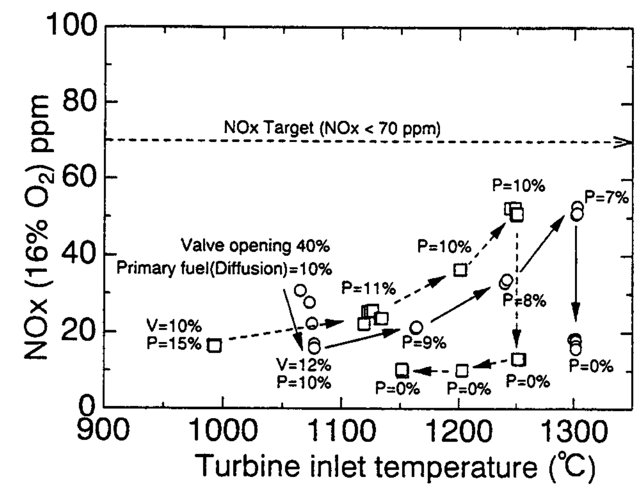

Fig.11 Engine tests results of premixed lean combustor

performance curves obtained in the tests are shown in Fig.9 and 10. From the results, we can predict that the CGT302 will achieve about 40% thermal efficiency at the final 1350℃ TIT.

Premixed lean combustion tests

The premixed lean combustion test was carried out on the CGT302 engine at 1300℃ TIT. The results are shown in Fig.11. At the pilot fuel ratio of 7%, NOx emissions were 50.8 ppm (16% O_2) at 1300℃ TIT, and by cutting off the pilot fuel (P=0%), 15.8 ppm (16% O_2) of NOx emissions were demonstrated.

It is considered that the reason why such low NOx emissions were observed is because a ceramic liner can keep the maximum combustion temperature lower than conventional metallic liners, for no cooling of the surface is necessary for a ceramic liner.

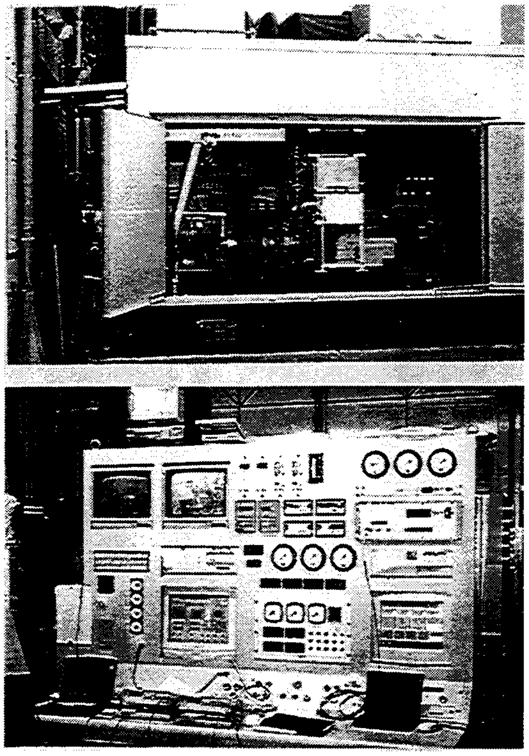

Fig.12 Test bench of long-term operation

Long-term operation

Long-term operation for 1000 hours at 1200℃ TIT started in 1997 to confirm the reliability of the ceramic materials. All ceramic components for the Pilot CGT were installed in the engine. For the long-term operation, a test bench was newly constructed. Fig.12 shows the test bench.

SUMMARY

The R&D program of the CGT302 is in its final stage.

- Turbine inlet temperature of the CGT302 reached the target temperature of 1350℃ and 20 hours durability operation at 1350℃ succeeded with all ceramic components for the Pilot CGT. The total operation time has cumulated to 223 hours.
- The CGT302 has achieved 37.4% thermal efficiency at 1250℃ TIT with 240kW. .
- The CGT302 demonstrated 15.8 ppm (16%O_2) NOx emissions at the 1300℃ TIT condition in the premixed lean combustion tests.
- Long-term operation for 1000 hours at 1200℃ TIT started to confirm the reliability of the ceramic materials.

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