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Application of in situ oxidation-resistant coating technology to a home-made 100 kW class gas turbine and its performance analysis

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ABSTRACT

An axial type 100 kW class gas turbine power generation system equipped with an additive supply system was fabricated and tested for the performance evaluation experimentally and analytically, in order to confirm the advantage of in situ oxidation-resistant coatings on gas turbine components toward the performance of a gas turbine power generation system directly. The gas turbine was operated up to the rated speed of 74,000 rpm, and to the turbine inlet temperature (TIT) of ~1200 °C. At the early stage of this test operation, an oxide film precursor (tetraethylorthosilicate/methanol mixture, 10 vol.%) was fed into the combustion chamber by the additive supply system to in situ deposit silica based layers and thus to protect the metallic components from hot combustion gas during operation. After the test operation, in situ deposited silica layers were observed on the surface of the combustion chamber, turbine nozzles and rotor blade. Due to these protective layers the gas turbine could be harmless tested at TIT = 950 °C, much higher than its design temperature of 850 °C. According to the performance analysis, a TIT increase of 100 °C was expected to be accompanied by ~5% increase in the turbine rotation speed by consuming more fuel and air by 22% and 8%, respectively. As a result, the power output increased by 42% and the thermal efficiency from 12% to 14%. This result was well accorded with that of empirically obtained, indicating that no noticeable impacts on the performance due to in situ deposited layers on the components.

1. Introduction

Small gas turbines with output power less than ~300 kW are often referred to as microturbines or micro-gas turbines (MGTs). The TIT of MGTs is typically in the range of 800–1000 °C, the maximum service temperature that the metallic components can tolerate for a long time operation without cooling [1]. The TIT can be further raised by applying sophisticated component design (e.g. cooling holes in the blades [2,3]) and thermal barrier coatings, TBC [4–6], which are adopted by most heavy duty land-based gas turbines these days. For MGTs, however, TBCs cannot easily be applied to the hot gas components due to dimensional problems and to complicated design (to our knowledge, there are no MGTs with TBCs applied on the metallic components, yet). Due to this limitation, the thermal efficiency of MGTs lies in the middle of 20%, though it has been raised above 30% recently by incorporating highly effective recuperation systems [7].

A coating technology applicable to MGTs was proposed and studied recently [8–11]. This technology was characterized by in situ deposition of oxide-base protective layers on the surface of all the components exposed to hot combustion gas by feeding oxide film precursors into the combustion chamber during service. The in situ deposited layers effectively protected the underlying metallic substrates during operation, as demonstrated by metallographic studies on Inconel 713 superalloy blades [9–11]. These results were attributed partly to thermal insulation of the outer highly porous layer and partly to diffusion inhabitation of the inner thin solid layer. Very recently [12], the effect of the periodic deposition of such protective layers on the long term reliability of a very small gas turbine (~10 kW) undergone to a cyclic operation was tested in our group. The test results showed that the in situ deposited hot gas components could tolerate metallographically an increase in the TIT of 100 °C for a long time. In this work, we further took advantage of the thermal and diffusion barrier of in situ deposited oxide coatings further to raise the TIT of a home-made 100 kW class gas

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Nomenclature

CDP	compressor discharge pressure
EGT	exhaust gas temperature
LNG	liquefied natural gas
MFC	mass flow controller
MGT	micro-gas turbine
$N1$	gas generator speed
$N2$	power generator speed
rpm	rotation per minute
TBC	thermal barrier coating
TEOS	tetraethylorthosilicate
TIT	turbine inlet temperature
YSZ	yttria stabilized zirconia

Table 1
Specifications of the home-made gas turbine.

Items	Corresponding values
Overall dimensions	
Gas generator	D250 mm × L500 mm
Power generator	D300 mm × L485 mm
Rotational speeds	
Gas generator	74,000 rpm
Power generator	54,000 rpm
Air flow rate	0.87 kg/s
Fuel consumption	60.4 kg/h (LNG)
Electric power output	100 kW
Thermal efficiency	13.3%

turbine engine, and tested the effect of the TIT increase of 100 °C on the performance of this engine empirically and analytically.

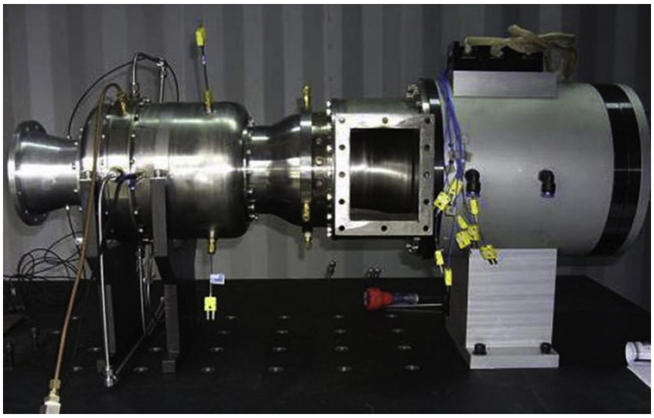

Fig. 2. Photo of the home-made 100 kW class gas turbine installed on the test bed.

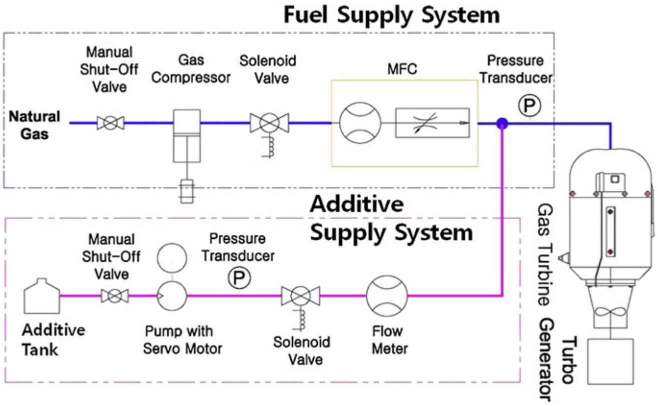

Fig. 3. Schematic of LNG and additive supply systems.

2. Fabrication of the test rig including 100 kW class home-made gas turbine

For the test of this work, an axial flow turbojet engine driven by LNG or kerosene to produce the maximum thrust > 70 kgf was fabricated. Table 1 listed the specifications of this gas turbine. The layout and a photo of the gas turbine installed on the test bed were shown in Fig. 1 and Fig. 2, respectively. By means of replacing its exhaust nozzle with a free power turbine, the turbojet engine could easily be configured into a turboshaft engine [13]. This power generation gas turbine can convert the thrust force of the turbojet engine into the electric power by a turbo-generator (2 in Fig. 1) attached to the exhaust end of the gas generator turbine (1 in Fig. 1). The turbo-generator was composed of a free power turbine (3, 4 in Fig. 1) and a high speed generator directly driven by the power turbine. The power turbine was designed to have the same mass flow characteristics as the exhaust nozzle of the turbojet

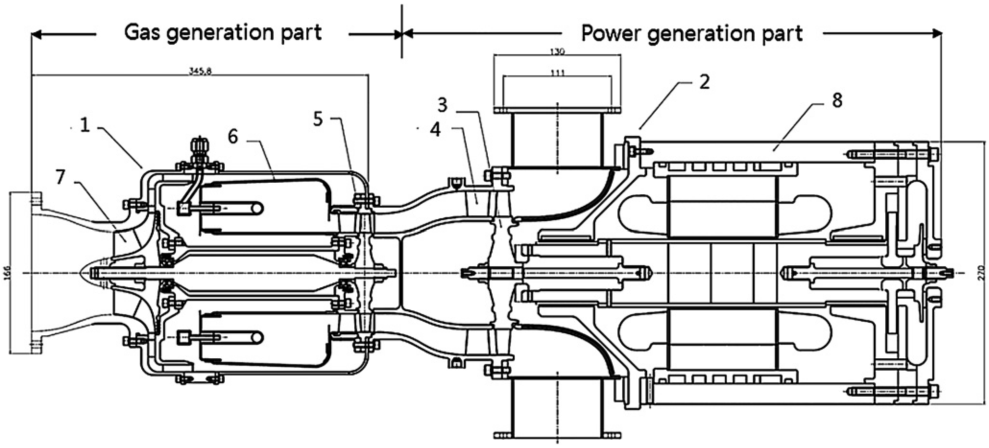

Fig. 1. Layout of the home-made 100 kW class gas turbine: 1. gas generator, 2. power generator, 3. power turbine blade, 4. power turbine nozzle, 5. gas generator turbine blade, 6. combustor liner, 7. compressor impeller, 8. generator frame.