Performance Test and Component Characteristics Evaluation of a Micro Gas Turbine

Jong Joon Lee, Jae Eun Yoon
Graduate School, Inha University,
253 Yonghyun-Dong, Nam-Gu, Incheon 402–751, Korea

Tong Seop Kim*
Department of Mechanical Engineering, Inha University,
253 Yonghyun-Dong, Nam-Gu, Incheon 402–751, Korea

Jeong L. Sohn
School of Mechanical and Aerospace Engineering, Seoul National University,
Seoul 151–742, Korea

This study aims to analyze engine performance and component characteristics of a micro gas turbine based on detailed measurement of various parameters. A test facility to measure performance of a micro gas turbine was set up and performance parameters such as turbine exit temperature, exhaust gas temperature, engine inlet temperature, compressor discharge pressure and temperature, and fuel and air flow rates were measured. The net gas turbine performance (power and efficiency based on the gas turbine shaft end) was isolated and analyzed. With the aid of measurement based simulation, component characteristic parameters such as turbine inlet temperature, compressor efficiency, turbine efficiency and recuperator effectiveness were estimated. Behaviors of the estimated characteristic parameters with operating condition change were examined and sensitivities of estimated parameters to the measured parameters were analyzed.

Key Words: Micro Gas Turbine, Performance Test, Performance Parameters, Characteristic Parameters, Optimal Solution, Sensitivity

Nomenclature

CDT : Compressor discharge temperature [K]
EGT : Exhaust gas temperature [K]
\( h \) : Specific enthalpy [kJ/kg]
LHV : Lower heating value [kJ/kg]
MGT : Micro gas turbine
\( \dot{m} \) : Mass flow rate [kg/s]
N : Shaft speed [rpm]
\( P \) : Pressure [kPa]
PR : Pressure ratio

RMS : Root mean square deviation
\( T \) : Temperature [K]
TET : Turbine exit temperature [K]
TIT : Turbine inlet temperature [K]
\( \dot{W} \) : Power [kW]
\( \delta \) : Deviation
\( \eta \) : Efficiency, effectiveness
\( \eta_{th} \) : Thermal efficiency at shaft end

Subscripts
0–8 : Location
a : Air
c : Compressor
f : Fuel
gen : Generator
in : Inlet
m : Measurement

---

* Corresponding Author,
E-mail: kts@inha.ac.kr
TEL: +82-32-860-7307, FAX: +82-32-868-1716
Department of Mechanical Engineering, Inha University,
253 Yonghyun-Dong, Nam-Gu, Incheon 402–751, Korea. (Manuscript Received May 16, 2006; Revised November 4, 2006)
max : Maximum
out : Outlet
rec : Recuperator
ref : Reference
s : Isentropic
sh : Shaft
sim : Simulation
t : Turbine

1. Introduction

Recent attention for the distributed power generation systems has promoted development effort for various small power sources including conventional heat engines and renewable power generators. Among others, the micro gas turbine (MGT) is considered to be one of the prospective candidates considering technical maturity and environment friendliness. Micro gas turbines are defined as small gas turbines, usually less than 200 kW (Rodgers et al., 2001). The maximum temperature (turbine inlet temperature, TIT) of micro gas turbines is limited to far less than those of large gas turbines because using hot section cooling is not feasible. In addition, their pressure ratios are also sufficiently low. Thus, adopting a recuperator is inevitable to overcome efficiency limitation. Currently available MGTs are designed with TIT of 800 to 900°C and pressure ratio of 3 to 5, and their efficiencies are 25 to 30 percent. Endeavors are still being made to develop more efficient and power upgraded versions. Thermal efficiency of 40 percent is the current goal of micro gas turbine developers (US Department of Energy, 2000). There exist many important factors in the development of micro gas turbines, such as designing both efficient and cost-effective compressor and turbine, low emission combustor and robust engine control system, and so on. Technical issues are well summarized in the literature (Simon and Jiang, 2003). In particular, designing a compact and efficient recuperator is deemed to be the most critical considering its critical role in engine performance (McDonal, 2000; McDonald and Rodgers, 2005). Near 40% efficiency, based on currently available micro gas turbines, is also possible by a combined cycle (Lee and Kim, 2006). The recuperated cycle gas turbine exhibits unique part load performance characteristics in comparison with the simple cycle gas turbine due to the existence of the recuperation process. It needs a unique operating strategy such as variable speed control to have good partial load performance (Kim and Hwang, 2006).

Performance diagnostics of micro gas turbines has not been as popular as that of conventional gas turbines. However, as the working hours accumulate, performance of the micro gas turbine also degrades. Therefore, prediction and prevention of the performance degradation of micro gas turbines through appropriate diagnosis will be as important as in conventional gas turbines. The unique features of the micro gas turbine, such as using the recuperator and adopting the digital power control covering a wide operating range in terms of shaft speed, make the performance diagnostics challenging. Recently, a few studies have been reported on the subject of performance test and basic diagnostics. Small jet engines are mostly used in fundamental studies (Yin and Huang, 2003; Davison and Birk, 2004). Reports on performance test of an industrial micro gas turbine for commercial development (Shibata et al., 2003) and prediction of the operating behavior of a commercial micro gas turbine (Chiag et al., 2004) are also available.

For a successful engine diagnosis, information of exact reference data (characteristic parameters) of all major components must be present at first. This study aimed to obtain component characteristic parameters of a micro gas turbine using detailed measurement. A test facility for a commercial micro gas turbine generator has been set up, with various measurements embedded. First, performance of the entire engine was evaluated for a wide operation range. Then, an analysis method, based on optimal matching between measured performance data and simulation results, was used to estimate component characteristic parameters such as compressor and turbine efficiencies, recuperator effectiveness as well as the unmeasured turbine inlet temperature. Sensitivities of estimated parameters to the measured parameters were also analyzed.