EVALUATION OF 500W ULTRA-MICRO GAS TURBINE COMPRESSOR

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Abstract: This paper provides the detailed development of 500W ultra-micro gas turbine (UMGT) generator and performance evaluation of the components. The components of UMGT, a radial turbine, a centrifugal compressor, an angular combustor and a shaft are already designed and manufactured in previous researches. The performance evaluation is essential to check the performance of the components and improve the design of UMGT. The purpose of this paper is to present the development process of the performance testing equipments of the UMGT and the result of compressor performance.

The performance evaluation equipment of the compressor consists of an assembled UMGT testing unit, a high temperature air heater, high pressure gas containers, a heater controller and a safety box. The UMGT was designed to rotate at 400,000rpm with the pressure ratio 3.0 and TIT 1200K. However, the evaluation equipment is designed to simulate the design point (400,000rpm) of the UMGT with equivalent experimental conditions, the pressure ratio 5.0 and TIT 420K due to difficulty of maintaining high temperature without the combustor. It is very difficult to make an electrical motor to run at 400,000rpm so that the radial turbine of UMGT is used to drive the radial compressor with high pressure ratio and TIT 420K. The performance evaluations are conducted at 200,000rpm and 240,000rpm with compressed Nitrogen gas and static air bearings. To increase the rotating speed, a high temperature air heater is used together with compressed Nitrogen gas. At early stage of this test, the 50%, 60% speed of design point are fulfilled and the performance map is presented in this paper. The measured pressure ratios are low than the expected values due to tip clearance effect.

Keywords: micro gas turbine, centrifugal compressor, radial turbine

INTRODUCTION

The increase of power consumption in mobile devices requires new mobile power sources. The compactness is essential quality of mobile devices and their energy sources are usually rechargeable battery. Currently lithium ion batteries are the most convenient energy source, but they are not appropriate for the usage of a long period time due to poor specific energy (W-hr/kg). Fuel cell comes out as another energy source. In spite of high specific energy of fuel cell, the poor specific power (W/kg) limits the usage of fuel cell. There is another energy source with high specific energy and power. Internal combustor engines show excellent performance in power intensity and duration which results from the usage of hydrocarbon fuels.

When the internal combustor engines are scaled down, micro gas turbines have higher power density than the other engines. MIT group developed a shirt button size gas turbine manufactured by MEMS technology [1]. Due to thermal loss, they are not enough to produce power for mobile application even though it shows strong technological impact. After their research, micro-machine gas turbine is under development in many different groups [2, 3, 4, 5]. Several researchers present papers about design and optimization of each components [6,7]. So far, none of researchers runs UMGT system standalone up to full performance.

The development of an ultra micro gas turbine is under development by a group in Korea Institute of Machinery and Materials.

Currently centrifugal compressor, radial turbine, angular combustor, shaft, bears are all designed and manufactured. The paper introduces the details of evaluation of each component.

SYSTEM DESCRIPTION OF UMGT

The schematic of the ultra-mico gas turbine is shown in Figure 1. It includes a compressor, a turbine, a combustor, six recuperators, a generator, and a control unit. The system layout consists of a generator, a centrifugal compressor, a radial turbine, an annular combustor, six recuperators in Figure 1. The compressor, turbine and generator are all directly connected in a single shaft.

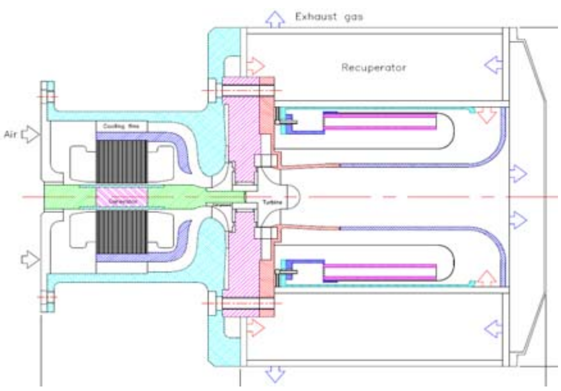

Figure 1 Schematics of the ultra-micro gas turbine

COMPRESSOR TEST EQUIPMENT

In the evaluation of each turbine component, the performance of the compressor is the most critical to succeed in making a self-sustained micro-gas turbine. To check the performance of the designed compressor, the performance evaluation equipment is developed in Korea Institute of Machinery and Materials (KIMM). The components of the evaluation equipment are presented in Figure 2. It consists of static air bearings, a centrifugal compressor, a radial turbine, a housing and a shaft. The shaft and turbine are manufactured in Inconel and other parts are made in Aluminum.

Figure 2. Photo of UMGT compressor performance evaluation equipment

In addition to the performance evaluation equipment in Figure 2, a high temperature air heater, high pressure gas containers, a heater controller and a safety box are used together to supply high temperature air (Figure 3). For safety, the whole rotating system is contained in the bullet proof glass container.

The UMGT was designed to rotate at 400,000rpm with the pressure ratio 3.0 and TIT 1200K. However, the evaluation equipment is designed to simulate the design point (400,000rpm) of the UMGT with equivalent experimental conditions, the pressure ratio 5.0 and TIT 420K due to difficulty of maintaining high temperature without the combustor. It is very difficult to make an electrical motor to run at 400,000rpm so that the radial turbine of UMGT is used to drive the radial compressor with high pressure ratio and TIT 420K.

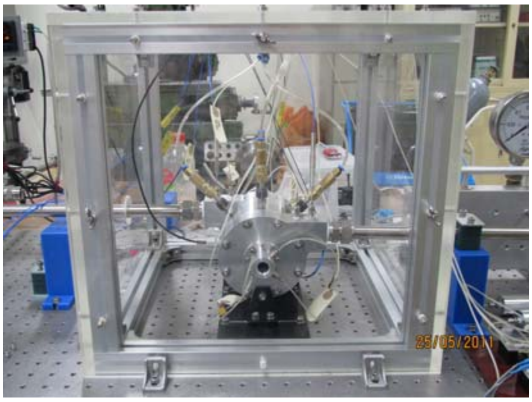

Figure 3. Assembled UMGT compressor performance evaluation equipment on the test bed.

CENTRIFUGAL COMPRESSOR

Due to small mass flow rate and relatively large pressure ratio, a centrifugal type compressor is selected for UMGT. To get higher efficiency in the small size compressor impeller, specific speed, 0.65 is chosen and the rotating speed is computed to 400,000rpm. The development is fulfilled using commercial 1-D program and 3-D CFD code. The design parameters are listed in Table 1. The vainless diffuser is selected for the lower performance and manufacture problems of a vain diffuser.

Table 1 Compressor design parameters

	Item	unit	value
Flow	Speed	rpm	400,000
	Mass Flow Rate	kg/s	0.02
	Inlet Volume Flow Rate	m3/s	0.0163
Impeller	Blade Number	-	7+7
	Reference Radius	mm	11.4
	Tip Clearance	mm	0.1
	Exit Angle	deg	-43
Performance	Total Pressure Ratio		3.055
	Total Isentropic Efficiency	%	74.61
	Input Power	W	2910

RADIAL TURBINE

For compressor performance evaluation, the radial turbine in UMGT is used to drive the centrifugal compressor. At early stage, it is designed to drive the compressor with an electrical motor. Since it is difficult to get a motor rotating at 400,000rpm, the radial turbine is employed instead. Although the turbine is designed at TIT=1200K and expansion ratio 3. It confirmed that the turbine could generate 400,000rpm and enough power with TIT=420K and expansion ratio 5. Therefore, the radial turbine is used with change of nozzle inlet angle. The design parameters are listed in Table 2.

Table 2 Turbine design parameters

	Item	unit	value
Flow	Speed	rpm	400,000
	Mass Flow Rate	kg/s	0.02
	Inlet Volume Flow Rate	m3/s	0.0241
Nozzle	Blade Number	-	20
	Reference Radius	mm	16
	Exit Angle	deg	73.9
Rotor	Blade Number	-	8
	Reference Radius	mm	10
	Tip Clearance	mm	0.1
	Exit Angle	deg	-43
Performance	Total Pressure Ratio(TT)		2.52
	Total Pressure Ratio(TS)		2.98
	Total to Static Isentropic Efficiency	%	70
	Out Power	W	4521

COMPRESSOR EVALUATION

For compressor performance evaluation, the simulated equivalent conditions are applied instead of real conditions in UMGT. As mentioned before, TIT=1200K is too high temperature to run evaluation test without a combustor. Therefore, lower temperature (420K), higher expansion ratio (5) and increased mass flow are used to obtain 400,000rpm and 4.5kW in the turbine at the design point.

In lab test, the evaluation equipment achieves 60% of design speed with compressed Nitrogen gas and static air bearings. Due to vibration and clearance loss, more than 240,000rpm is not tested yet.

The compressor map is present in Figure 4 for 200,000rpm (50% of design speed) and 240,000rpm (60% of design speed). For comparison, numerical simulation results are presented together for each rotating speed. The numerical simulations are conducted with ANSYS CFX. They show very good agreement in Figure 4.

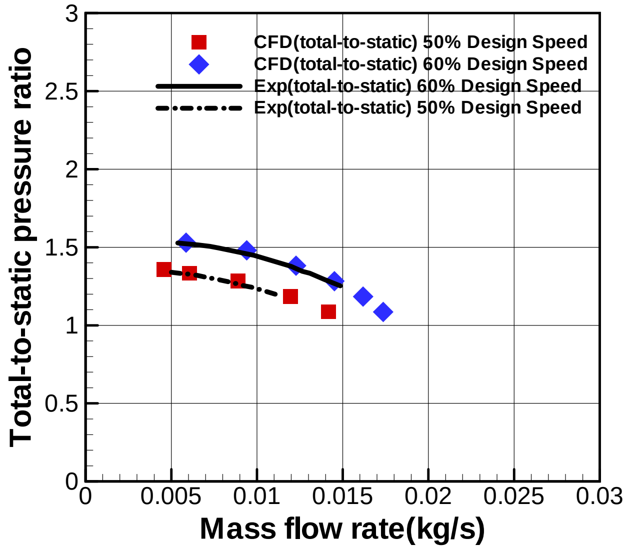

Figure 4. UMGT compressor performance map.

Higher rotating speed is tried, but it is not successful yet. To overcome this, additional balance and better clearance control are required. From Figure 4, it is believed that the compressor of UMGT is designed properly so far. Before the prototype of UMGT is assembled, full compressor map should be presented for confidence. It will be conducted in the next project.

CONCLUSION

To evaluate the performance of UMGT compressor, an evaluation unit is built and get test results at different rotating speed. The test equipment is designed to reach the design point, but the vibration and clearance loss limit the lab test. So far, 200,000rpm (50%) and 240,000rpm(60%) are obtained and shows good agreement with numerical simulation. Based on the test results, it is concluded that the compressor is designed properly.

ACKNOWLEDGEMENT

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REFERENCES

[1] Epstein A H 2004 Millimeter-scale, micro-electro-mechanical systems gas turbine engines *ASME J. Eng. Gas Turbines Power* **126** 25-26

[2] Isomura K et al 2003 Development of micro-turbo charger and micro-combustor as feasibility studies of three-dimensional gas turbines at micro-scale *ASME Paper GT2003-38151*

[3] Lee Y B, Kwak Y S, Kim C H, Oh J, Chung J T 2007 Feasibility Study of 100Watts Class Micro Turbocharger for Micro Gas Turbine Engine *PowerMEMS 2007*, pp 221-224

[4] Stevens T., Rogiers F., Baelmans M. 2007 Integrated Design of A Micro Recuperator in A Gas Turbine Cycle *PowerMEMS 2007*, pp 253-256

[5] Peirs J., Waumans T., Liu K., Reynaers D. 2008 Measurement of Compressor and Turbine Maps for An Ultra-Miniature Gas Turbine *PowerMEMS 2008*, pp 413-146

[6] Feffaris E et al 2007 Production of a miniature Si3Ni4-TiN ceramic turbine impeller by die-sinking EDM *PowerMEMS 2007*, pp 229-232

[7] Waumans T et al 2007 Design and testing of aerodynamic thrust bearings for micro turbomachinery applications *PowerMEMS 2007*, pp 257-260

[8] S. Han, J. Seo, J. Park, B. Choi, K. H. Do, Proc. PowerMEMS 2010, pp. 247-250.

[9] T. Stevens, F. Rogiers, M. Baelmans, Proc. PowerMEMS 2007, pp. 253-256.

[10] D. Krahenbuhl, C. Zwyssig, H. Weser and J. W. Kolar, Proc. PowerMEMS 2007, pp. 289-292.