

Start-up and Self-sustain Test of 500 W Ultra-Micro Gas Turbine Generator

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Abstract. This paper provides the performance test for start-up and self-sustaining of 500W ultra-micro gas turbine (UMGT) generator. Each component of UMGT, a centrifugal compressor, a radial turbine, an annular combustor and a shaft is already designed, manufactured and tested to meet design requirements in previous researches. However, they are not tested to work in an integrate system. Currently, integrated test unit with a compressor, a combustor and a turbine, is developed to find the proper condition of start-up and self-sustain. Ignition sequence depending on rotating speed is designed. Performance test for start-up and self-sustain is designed based on the ignition possible condition. An air impingement starter and a hot bulb igniter are applied. LPG is used as main fuel.

1. Introduction

The increase of power consumption in mobile devices with motion parts, such as UGV (Unmanned Ground Vehicle) and humanoid robot, requires new mobile power sources with high power density and high energy density. Lithium ion batteries are currently the most convenient energy sources, but their energy densities are usually under 250 Wh/kg. Fuel cell, another energy source for mobile devices, has high energy density but has poor power density. MTG (Micro Turbine Generator) is suggested as a new energy source by many research groups [1-9].

500W class UMGT (Ultra-Micro Gas Turbine) generator is under development by KIMM (Korea Institute of Machinery & Materials). A centrifugal compressor, a radial turbine, an annular combustor and a shaft are developed [10-12]. However, each component is designed and developed based on design point. To increase speed of the integrated gas turbine from stop to design points, start-up procedure and additional auxiliary equipment is required and should be tested. This study presents the test of start-up and self-sustain of integrate gas turbine system for 500 W UMGT generator.

2. Specifications of UMGT

Figure 1 shows the schematic of 500 W class ultra-micro gas turbine generator of KIMM. The target volume of MTG (Micro Turbine Generator) is 1,000 cm³ for mobility. It is composed of a centrifugal compressor, a turbine, a combustor, six recuperators, a motor/generator and a control unit. The compressor, the turbine and the motor/generator are all directly connected in a single shaft. The design speed of the MTG is 400,000 rpm. The pressure ratio of the compressor with 7+7 blades and vaneless diffuser is 3.0. The radial turbine consists of nozzle and rotor. The blade number of the nozzle and rotor is 20 and 8 respectively. The tip clearance of the compressor and the turbine is 0.1mm. The blade of the compressor and the turbine is made by Inconel 718. The combustor is designed in annular type



with 12 nozzles. TIT (turbine inlet temperature) is 1200K. Kerosene is used as main fuel and ignition fuel. The mass flow rate of the main fuel is 0.001945 kg/s at design point. A graphite hot bulb is used as an igniter. Air foil bearings are scheduled to be used for radial and thrust bearings and are under development. Generator is designed to work as a motor at start-up.

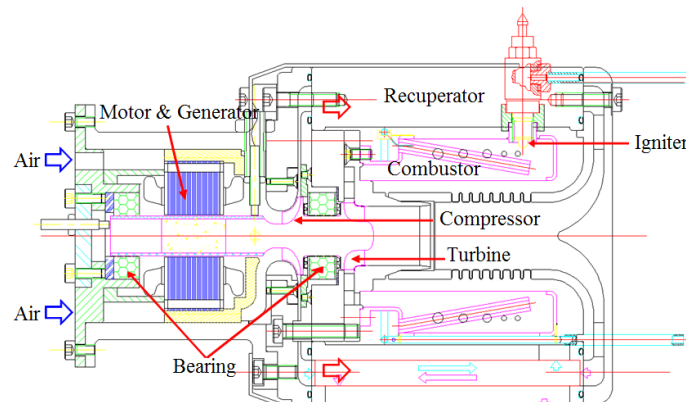


Figure 1 Schematics of 500 W MTG.

3. Test equipment

3.1. Test unit

A test unit is developed to test start-up and self-sustain evaluation as shown in figure 2. It consists of the compressor, the turbine and the combustor developed for 500 W UMGT. Some other parts are designed for this test equipment because they are under development. A radial and thrust all-in-one static air bearing is applied. Compressed Nitrogen gas is supplied for static pressure.

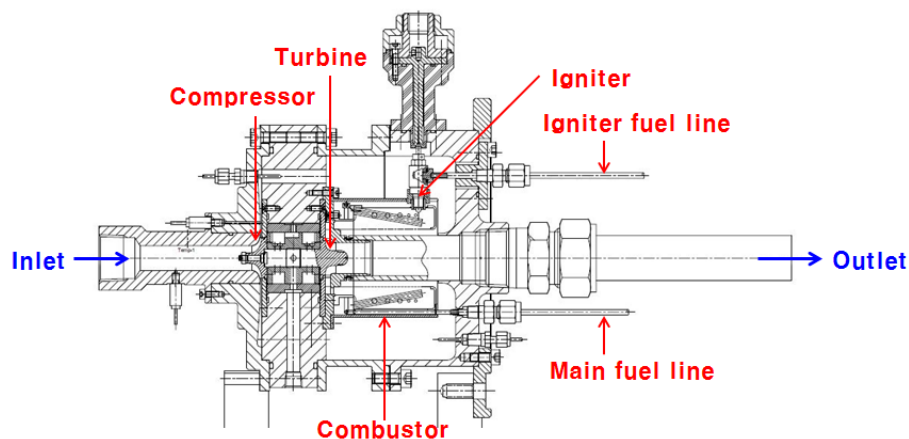


Figure 2 Integrate test unit for start-up and self-sustaining.

3.2. Starter

In start-up, the generator is used as a starter motor in 500 W MTG and is under development. Therefore, a substitute of a starter is needed. An air impingement starter is used to the test unit. Compressed air is supplied and air flow rate is controlled by a throttle valve. A pipe from compressed air is connected directly to the inlet of the test unit. By the compressed air, the compressor can be driven from zero to 240,000 rpm, 60% of design speed. In the test, if the rotor reaches to a certain target speed for ignition by the starter, the pipe can be disconnected from the inlet of the test unit and an ambient air can be inhaled through the inlet of the test unit.

3.3. Igniter

Electric sparks are generally used in gas turbines as igniters, but graphite hot bulb igniter is applied in the test unit. It can reduce the weight for mobility because of absence of a voltage step-up transformer. Another reason is flash temperature. Total pressure ratio of the compressor at design point is 3.0 and the ratio at the start of ignition is about 1.3. The increase of temperature by air compression is about 10~20 °C and the flash point of kerosene is between 37 ~ 65 °C. So, the compressor outlet temperature may be insufficient for ignition depending on ambient temperature conditions. Therefore, a hot bulb type igniter is used. Kerosene is used for igniter fuel.

3.4. Combustor

An annular type combustor with 12 nozzles is developed. Mass flow rate of main fuel and igniter fuel is controlled by MFC (Mass Flow Controller). 500 W MTG is designed to use kerosene for igniter fuel and main fuel, but in the test unit, LPG is used for main fuel. The tilt angle and length of flame holder are optimized and the diameter and type of air admission hole are modified to increase the stability of flame by enhancement of air flow and swirl effect. The performance test of combustor is conducted to find the ignition possible condition. Depending on the speed, air mass flow rate and total pressure ratio are generally determined and a proper amount of fuel mass flow rate is obtained.

3.5. Test bench

Test bench is established as shown in figure 3. Temperatures at compressor outlet, turbine inlet and exhaust out are measured. Compressor outlet pressure is measured. Rotating speed and mass flow rate of main fuel and igniter fuel are also monitored. Moving pipe line for air impingement is installed at inlet of test unit.

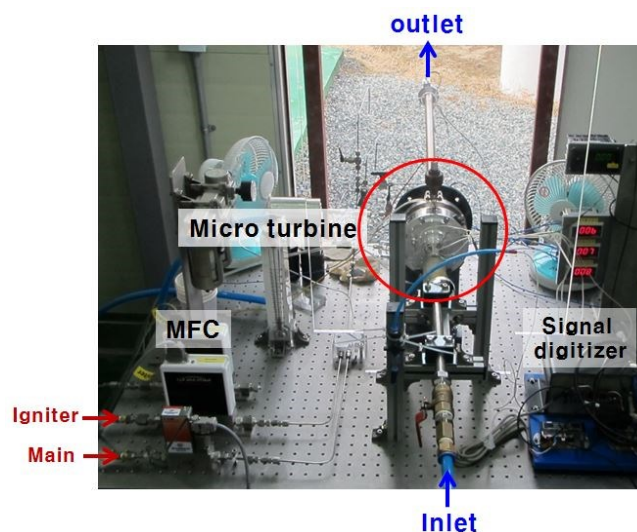


Figure 3 Test bench for start-up and self-sustaining test.

4. Experimental results

4.1. Starting sequence

Figure 4 shows the starting sequence of the MTG. Rotor speed is accelerated to target speed 100,000 rpm, 25% of design speed, for ignition by air impinging starter and the speed is held by throttle valve. The graphite hot bulb igniter is heated and then, igniter fuel is injected. After some time passes, main fuel is injected and compressed air supply is disconnected simultaneously. Rotating speed decreases by free run down, but the speed is recovered by combustion. If the main fuel is sure to be ignited, the igniter is turned off.

In case of electric motor type start, the starter can provide sufficient acceleration to spin the rotor up to a light up speed, and then continue to provide useful torque to enable the engine to accelerate to self-sustain speed smoothly by controller. But in case of air impingement type starter, it is hard to control the speed smoothly. Therefore, free run down is needed. In 500 W UMTG, an electric motor and generator will be used instead of air impingement starter and the starting sequence should be modified and retested.

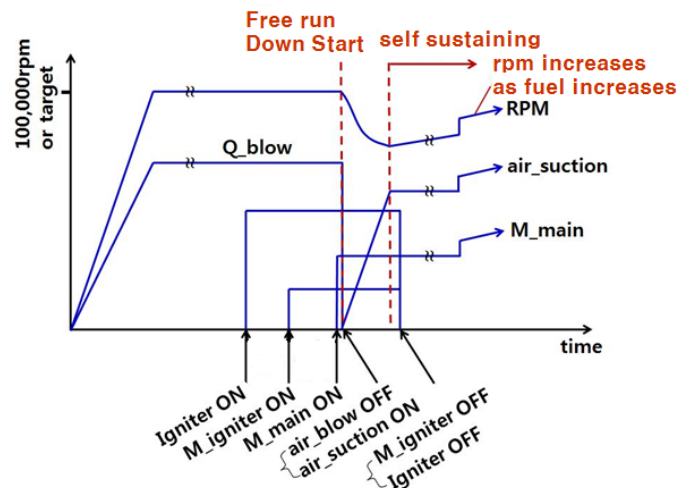


Figure 4 Starting sequence logic.

4.2. Self-sustaining test

Many self-sustaining tests are conducted. One of the test results is shown in figure 5. Free run down and ignition starts at 100,000 rpm and dramatic drop of speed by free run down does not happen. But sudden increase of speed happens by combustion. Self-sustaining successfully continues for 160 second around 200,000 rpm.

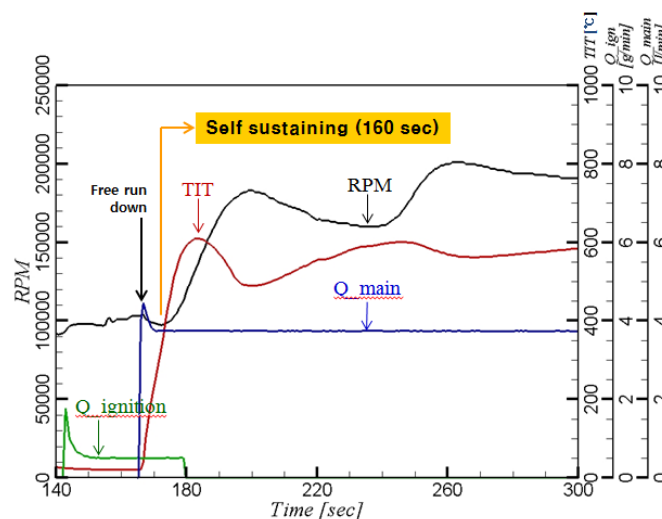


Figure 5 Duration graph for self-sustaining test.

4.3. Boosting test

Boosting test is conducted to examine the smooth speed acceleration from self-sustaining speed to the design speed by increase of main fuel. Figure 6 shows the results of boosting test. Slight increase of

main fuel produces slight increase of rotating speed. But, the boosting test is conducted till 230,000 rpm. The test unit uses a radial and thrust all-in-one static air bearing and its durable temperature is about 800 K and its maximum rotating speed is about 250,000 rpm. Therefore the boosting test cannot be carried out in higher speed range. However, the result shows the successful increase of speed by increase of main fuel.

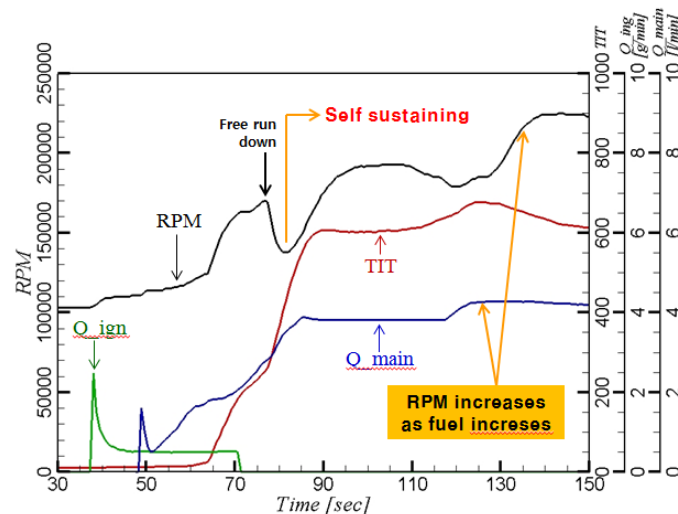


Figure 6 Duration graph for boosting test.

5. Conclusion and perspectives

An integrate test equipment with a centrifugal compressor, a radial turbine and an annular combustor is developed to conduct a performance test for start-up and self-sustain of 500W ultra-micro gas turbine (UMGT) generator. Air impingement starting is used as a starting method and a hot bulb igniter is employed. LPG is used as fuel. Starting sequence is designed based on ignition possible condition and the test results show that the start-up and self-sustain procedure works properly. New integrate test unit with a motor/generator and a new bearing system will be developed and tested in the near future.

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