Journal of Mechanical Engineering *Vol SI 4(3), 64-77, 2017*

K-180 G Micro Gas Turbine Performance Evaluation

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ABSTRACT

The K-180 G jet turbine is categorized as turbojet engine. This paper studied and analyzed the performance of K-180 G micro jet turbine for Unmanned aerial Vehicle (UAV) at static condition. The project was done to study thrust and temperature behavior with respect to rpm for a turbojet engine using standard kerosene fuel. A theoretical thermodynamic model was derived to understand theoretical aspect behind the test and to ensure the validity of performance measured. Various sensors were integrated to the gas turbine and computed to record the performance parameters such as EGT, thrust, engine rpm and pump power. The engine was tested several times in order to obtain average reading. At maximum RPM, the average thrust recorded was 18.57 kg, the maximum temperature recorded was 523˚C and the maximum pump power was 293 W. The relationship between thrust against RPM and the thrust against pump power is third order polynomial and thrust against EGT is parabolic. The mass flow rate of fuel was obtained from the relationship of the RPM against pump power which is third order polynomial. The thermodynamic theoretical model validated the engine's performance measured with the percentage error between 1 to 30%.

Keywords: *micro gas turbine, thrust, RPM, exhaust gas temperature, pump power*

Introduction

Jet propulsion engine is different from a shaft power engine because the thrust is obtained through momentum (jet) thrust of the exhaust. Thus, external propeller or rotor is not involved in generated thrust for turbojet engines. Jet

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ISSN 1823- 5514, eISSN 2550-164X

Received for review: 2017-02-12
Accepted for publication: 2017-05-12
Published: 2017-10-15

propulsion engines can be categorized into two types which are turbojets and turbofan [1]. With turbojet engines, air as the working fluid is used to create thrust which result from the combustion that produces kinetic energy [2, 3]

Turbojet is an air breathing engine that essentially serves as the engine core for all aerospace gas turbine engines. The basic idea for the turbojet engine is simple. First, air is taken in from an opening in the front of the engine and compressed to 3 to 12 times its original pressure by a compressor. Fuel then added to the air and burned in a combustion chamber to raise the temperature of the fluid mixture to 600-700˚C. The resulting hot gas then passes through a turbine, which extracts and transmits work through a shaft to drive the compressor. Finally, the pressurized hot gas is expanded through a nozzle to produce thrust. [1]

In the year between 1950 and 1970, micro gas turbines were introduced in the automotive sector. The first micro turbines were based on gas turbine designed to be used in generators of missile launching stations, aircraft and bus engines, among other commercial means of transport. The use of this equipment in the energy market increased between 1980 and 1990, when the demand for distributed generating technologies increased as well [4]. The operation of hybrid vehicles through a micro turbine connected to an electric motor, have received special attention from some of the major car manufacturers such as Ford, and research centres [5].

The use of micro gas turbine (MGT) engine is increasingly becoming popular technology in the commercial aviation and hobby industries [6]. They are employed in unmanned aerial vehicles (UAVs) applications used in missions such as national security, telecommunications, real-time reconnaissance, remote sensing, crime fighting, disaster management, agriculture and election monitoring [7]. MGTs are also used in hybrid electric vehicles and small electricity generating plant (combined heat and power) applications and as auxiliary power units (APUs) for modern aircraft [8]. They are suitable for such applications due to their high density to weight ratio, multi-fuel capability and simple design, low energy costs and emissions [9]. MGTs can be regarded as a prospective and compact competitor to the other propulsion system power supplies such as battery cells [10]. These engines have interrelated components which have non-linear characteristics. Therefore, the overall engine performance depends on the individual engine element’s performance [6].

This project, aimed to analyze performance of K-180 G jet engine for Unmanned Aerial Vehicle. A theoretical model of calculation was derived to validate the thrust produced by Kingtech turbine. This paper discussed the performance evaluation of the micro gas turbine at static condition.

K-180G Micro Gas Turbine

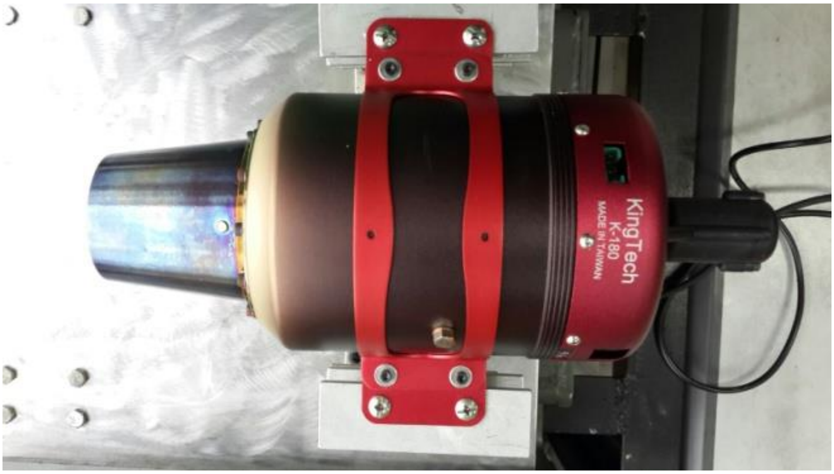

Figure 1: K-180 G micro gas turbine

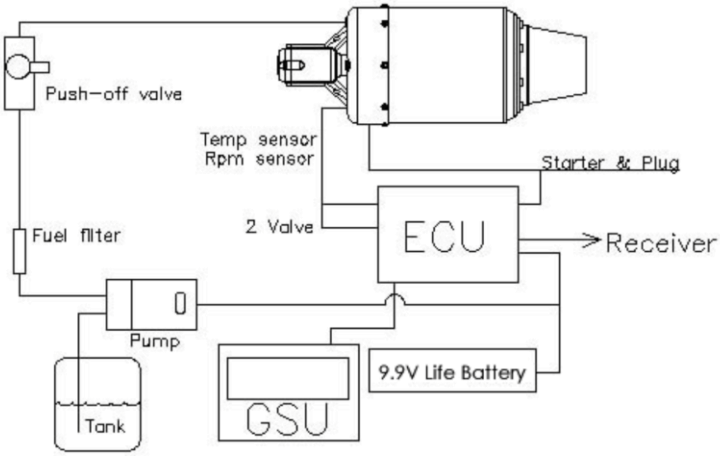

Figure 2: Schematic diagram

The K-180G (Fig. 1) specifications indicate that the diameter of the turbine is 114mm and the weight is 1644g. The RPM are in between 35,000 - 123,000. The thrust produced by the engine is 18 kg at maximum RPM. The NGV temperature is in the range of 520°C to 700°C. Fuel consumption of the turbine is 550g / min. The engine use Diesel, Jet-A or Kerosene as the fuel. [11]. Schematics of K-180G gas turbine operation is shown in Fig. 2. During the process, the engine centrifugal compressor draws in air from its environments into the engine. The air is then compressed to increase its total temperature and pressure. The compressor diffuser increases the static pressure of the air and lowers its velocity as it passes through the diverging passages (vanes). The low velocity air mixes with fuel in the combustion chamber to burn continuously to produce high temperature, high pressure and velocity gas. The turbine expands the high temperature gas from the combustion process to produce mechanical shaft power to drive the compressor. The convergent exhaust propelling nozzle accelerates the exhaust gases from the turbine to create thrust for propulsion.

Thermodynamics Principle

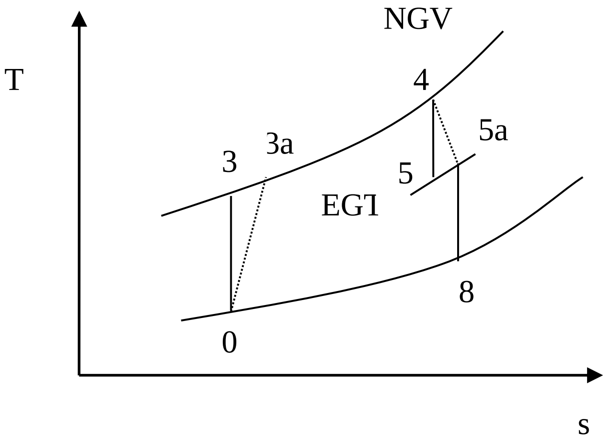

Figure 3: Brayton cycle T-s diagram

For this model, the micro gas turbine follows the principle of Brayton cycle. The cycle is presented by temperature-entropy diagram (T-s) as shown in Fig. 3. The cycle is believed to have isentropic air compression, constant pressure heat addition, isentropic gas expansion and constant pressure heat rejection. However, these processes actually are not isentropic as it has actual value. The actual compressions occur at point 0-3a in the compressor. In the combustion chamber (3-4), the pressure heat addition is constant. The actual expansion happened at position 4-5a in the turbine, isentropic work done at station 5a-8 in the nozzle and finally constant pressure heat rejection from 8-0 into the atmosphere.

As several parameters cannot be obtained through experiment, some equation are needed to derive the theoretical model calculation. The actual temperature and pressure at phase 3a can be determined by using the relationship of work done at compressor and turbine:

$$\dot{W}_T = \dot{m}_{fuel+air} C_{p,hot}(T_4 - T_{5a}) \tag{1}$$

$$\dot{W}_C = \dot{m}_{air} C_{p,cold}(T_{3a} - T_0) \tag{2}$$

Knowing that the parameters at phase 3a, temperature and pressure at phase 3can be obtained by using relations of efficiency of compressor and isentropic relation:

$$\eta_c = \frac{T_3 - T_0}{T_{3a} - T_0} \tag{3}$$

$$\frac{P_3}{P_0} = \left(\frac{T_3}{T_0}\right)^{\frac{k}{k-1}} \tag{4}$$

The value of temperature at point 4 is the nozzle guide vane temperature which is 700˚C and the temperature at 5a is the exhaust gas temperature which determined from the experiment. Temperature and pressure at phase 5 and 8 can be acquired by efficiency of turbine and isentropic equation:

$$\eta_T = \frac{T_4 - T_{5a}}{T_4 - T_5} \tag{5}$$

$$\frac{T_{5a}}{T_8} = \left(\frac{P_{5a}}{P_8}\right)^{\frac{k-1}{k}} \tag{6}$$

As all the parameters at each phases are determined, the thrust of the jet engine can be obtained by this equation:

$$T = \dot{m}_{out}\, v_{out} - \dot{m}_{in}\, v_{in} + A_{out}(P_{out} - P_{in}) \tag{7}$$

The intake mass flow rate and velocity can be cancelled out due to the static K-180 G jet turbine performances and the micro jet engine is in full expansion. The equation to calculate K-180 G jet engine are as follow:

$$T = \dot{m}_{fuel+air} v_{out} \tag{8}$$

Experiment Set Up

KingTech engines use Diesel, 1-K kerosene or Jet-A1 for fuel. Fuel must be mixed with 5% KingTech Special Blend or synthetic turbine oil (Aeroshell 500 and all 2-stroke oil are prohibited), or 1 quart of oil in every 5 gallons of fuel. Among the above 3 types of fuel KingTech highly recommends using regular pump Diesel as it is readily available and inexpensive as well as has higher energy density and up to 10 to 12% better fuel efficiency.

In order to run satisfactorily in jet engines, fuels must assure certain minimum performance criteria embracing not only the clear one of combustion, but also such aspects as thermal stability, flow at low temperatures, corrosives, cleanliness, etc. To this end, internationally agreed specifications have been developed to ensure satisfactory fuel performance in all aviation gas turbines. [12]

The gas turbine was mounted by using two pieces of aluminum bracket as shown in Fig. 4. The bracket was placed around the turbine, with the glow plug situated within the slot of the smaller bracket piece. This will help stabilize the engine along the thrust axis.

Then the components of fuel system are connected and they consist of electrically-powered pump, filters, safety petcock, main tank and hopper tank (Fig. 5). Next, a NiMH battery is connected to the pump to pump in the fuel into the main tank through the Hopper tank (Fig. 6). The hopper tank is needed to prevent the air bubbles flow inside the turbine. Then, the turbine is connected with ECU (Fig. 7), which is a Full-Authority Digital Electronic Control type (Fig. 8), and the fuel systems.

The engine performance data is transfered from FADEC ECU to the computer via telemetry wirings with USB connector. Raw signal is then processed by a proprietery KingTech FADEC software in which virtual engine performance instruments will be displayed in real time on computer screen (Fig. 9) while recording data throughout the experiment on a format that can be read by MS Excel spreadsheet.

The engine idle speed is at 35,000-36,000 rpm while its maximum speed is around 120,000 rpm. The performance parameters such as EGT, thrust, and pump power were recorded at every 10,000 rpm increment until it reaches its maximum rpm at 120,000 rpm. The experiment was repeated several times in order to get the average values and to ensure consistency of performance.

Figure 4: Turbine mounted at the bracket

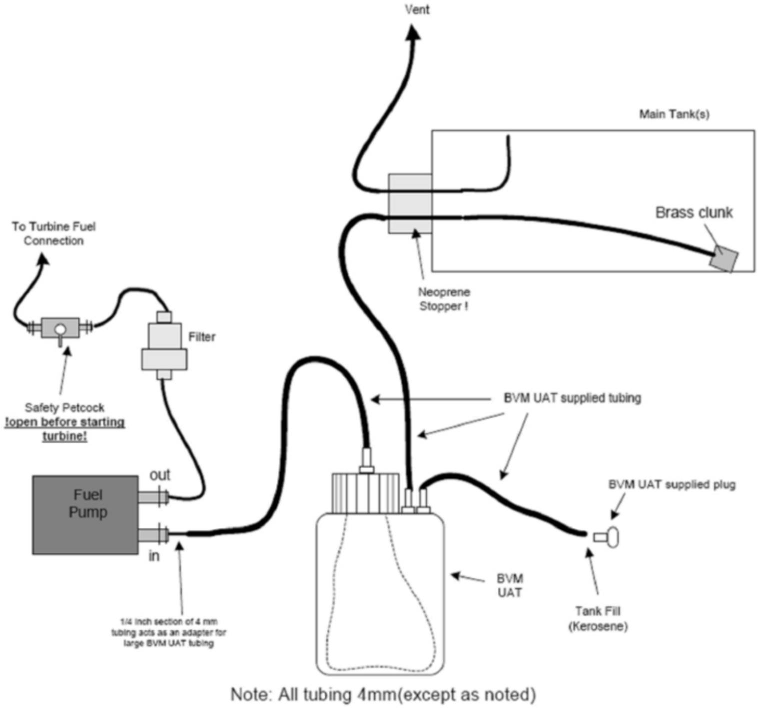

Figure 5: Fuel system schematic diagram

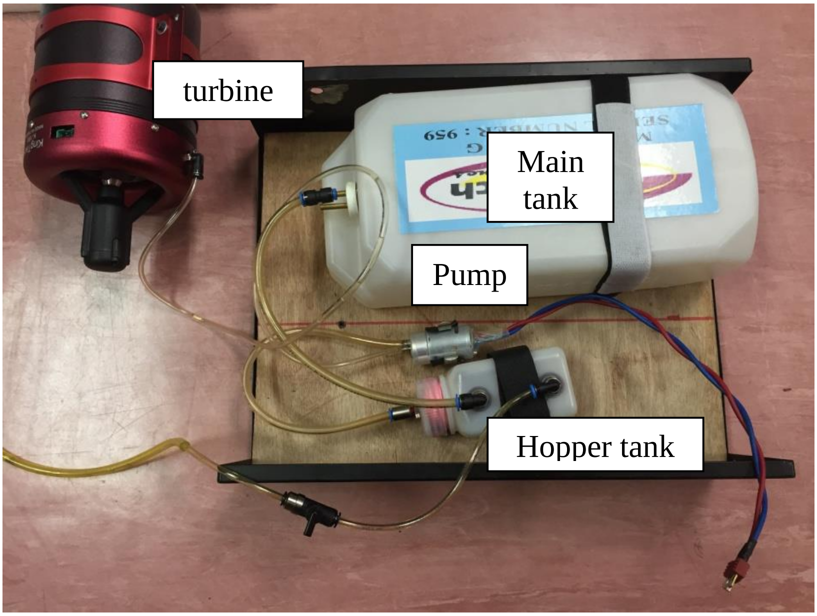

Figure 6: Fuel system connection

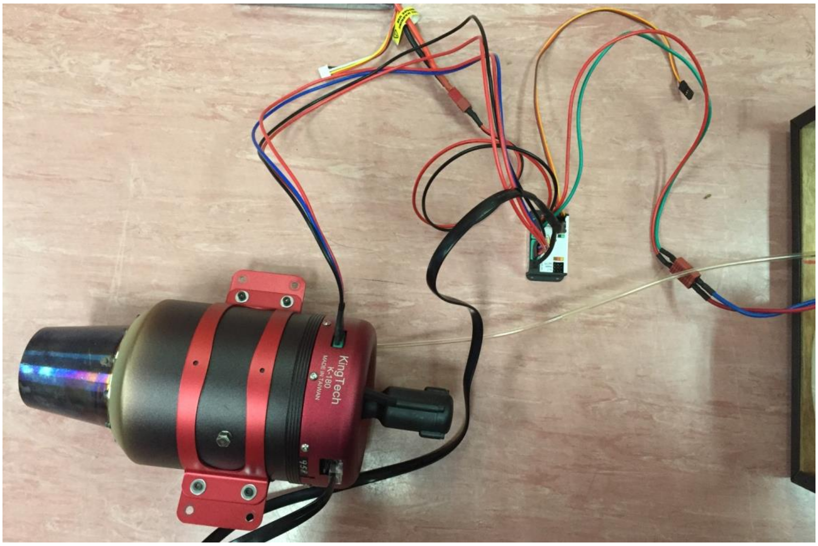

Figure 7: Engine-FADEC ECU connection

Figure 8: Ports on FADEC ECU

Figure 9: Data collected by FADEC

Results and discussion

The parameters that were involved and looked into were thrust produced, the RPM, and pump power. From this information, the data were then plotted and theoretical calculations were made to verify the outcome of the experiment.

Table 1: Experiment Data
Average Results

RPM	EGT, ˚C	Power, W	Battery amperage, A	Battery voltage, V	Pump power, %	Thrust, kg
35100	404	52	0.4	9.9	17	0.80
65400	363	83	0.7	9.9	28	3.61
80833	369	106	0.9	9.8	35	6.20
93333	400	138	1.2	9.8	46	8.80
102733	443	165	1.5	9.8	56	11.59
113400	473	214	2.2	9.7	72	15.09
121833	523	292	3.2	9.6	98	18.57

The K-180 G micro gas turbine was tested several times in order to obtain the average data. The idle rpm of the turbine was 35100 and the maximum rpm was 121833. It is important to test the turbine to see the efficiency of the turbine. From all of these data, a theoretical calculation model was made to validate the parameters recorded.

Based on Fig. 10, as the rpm increased, the thrust produced by the turbine also increased. The trend line of the graph is polynomial to the power of two. It increased gradually from the idle rpm which was at 35000 and reach its peak at 120000 rpm. Fig. 11 shows that at idle rpm, the exhaust gas temperature, EGT was initially found at 404˚C before it dropped to 363˚C. Then, it started to rise again to the maximum rpm at 523 ˚C. This happened due to the fact that the turbine needed to reach it idle rpm at the beginning of the experiment. It heated the turbine until the rpm was stabilized. The trend line of the graph is polynomial to the power of three. From Fig. 12, the mass flow rate of fuel can be generated through the relationship between the pump power and RPM of the micro gas turbine. As the pump power increased, the RPM also increased. The trend line that can be accepted for the data is polynomial with the power of two. The mass flow rate of fuel increased with the increase of the pump power of the micro gas turbine.

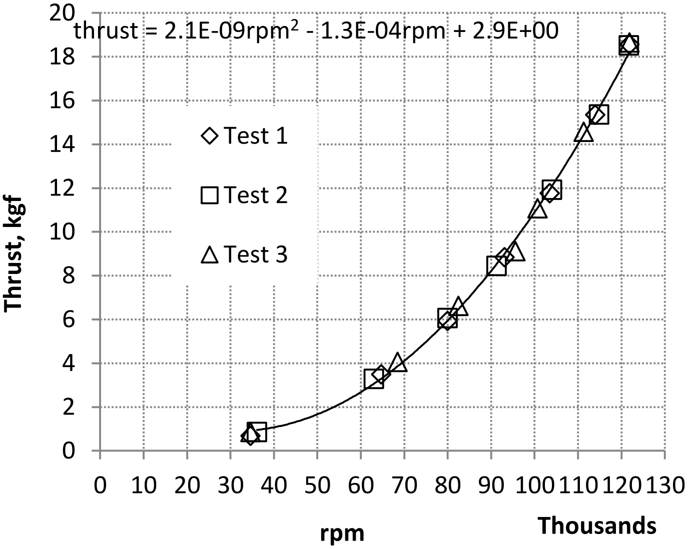

Figure 10: Thrust against RPM

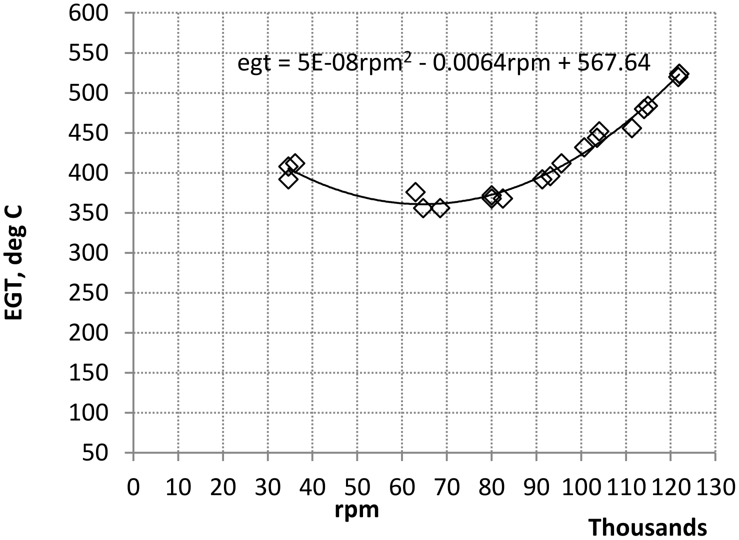

Figure 11: EGT against RPM

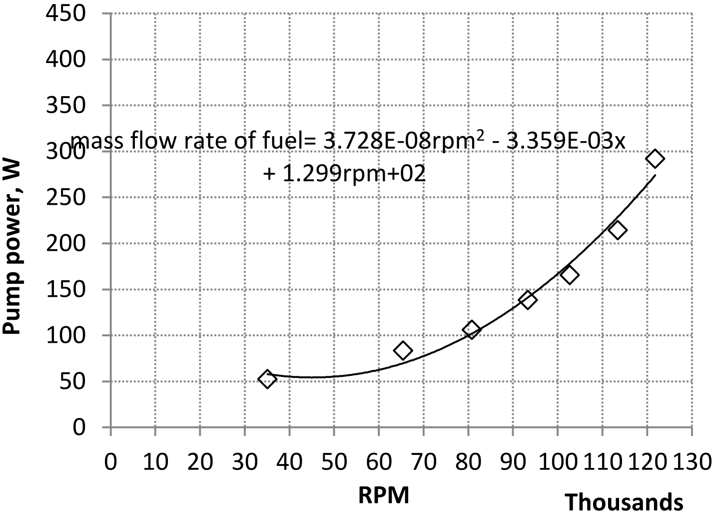

Figure 12: Pump power against RPM

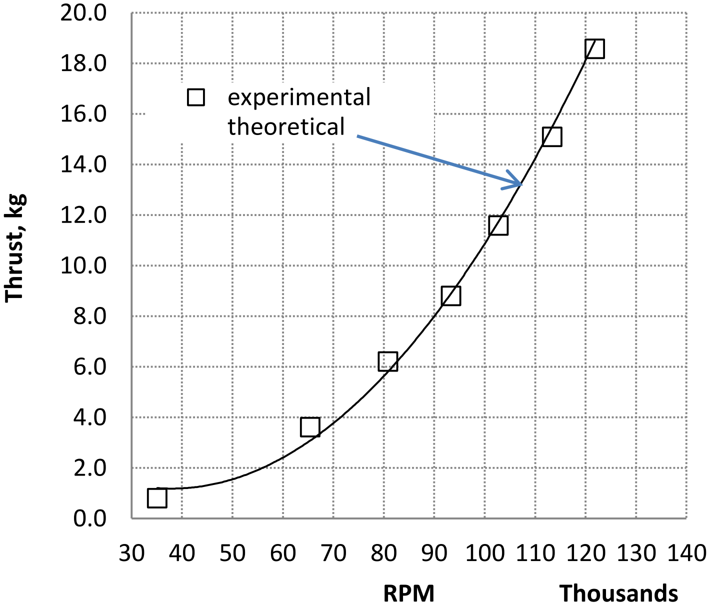

Figure 13: Thrust versus RPM - Theoretical prediction curve and experimental plot

Based on Fig. 13, the experimental values and theoretical calculations showed a slight difference for the thrust obtained. At maximum RPM, the thrust obtained from the experiment was 18.57 kg while the theoretical calculations gained was 18.97 kg. This shows 2% of error. However, at minimum RPM, the percentage error was up to 30 %. This happened due to the assumption made for the mass flow rate of air that may be less at minimum RPM. Overall, the theoretical model can be considered accepted as the theoretical calculation nearly verified the experimental data obtained.

Concluding Remarks

The K-180 G micro gas turbine was tested and analyzed at static condition where the current capabilities performances were extracted and used to create the theoretical model calculation. The generated theoretical model calculation data then were compared with the experimental results which gave 1 to 30 % of percentage error.

The K-180 G micro gas turbine was tested several times in order to obtain the average results that used to produce the theoretical model calculation. The parameters involved were thrust produced, exhaust gas temperature (EGT) and pump power. The NGV temperature was fixed by the manufacturer which at range 500 to 700 ˚C. The mass flow rate of fuel can be generated from the relationship of pump power and EGT and the mass flow rate of air is assumed to be 40 times of mass flow rate of fuel.

FADEC software system can only measure the exhaust gas temperature, pump power and RPM. However, the thrust generated by the turbine measured by the thrust device and there were no records after each testing. The thrust obtained may not be precise because of the values keep changing as the RPM increased. In order to solve the problem, software should be designed to measure and store the thrust produced as the RPM increase. This will help to get more accurate data of the micro gas turbine.

Acknowlegement

Authors would like to express deepest gratitude to the Ministry of Higher Education for granting research funding (600-RMI/FRGS 5/3 (0117/2016), FRGS/1/2016/TK09/UITM/02/1) to this experiment. Our thanks is also to the Research Management Institute of UiTM and the Faculty of Mechanical Engineering of Universiti Teknologi MARA for various support and facilities.

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