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Preliminary study of Low-Cost Micro Gas Turbine

M. Fikri[1], M. Ridzuan[2], Hamidon Salleh[3]

Fakulti Kejuruteraan Mekanikal dan Pembuatan, Universiti Tun Hussein Onn Malaysia, 86400 Parit Raja, Batu Pahat, Johor

Email : [1] mohdfikriazizan@yahoo.com, [2] dd120015@siswa.uthm.edu.my [3]hamidon@uthm.edu.my

Abstract. The electricity consumption nowadays has increased due to the increasing development of portable electronic devices. The development of low cost micro gas turbine engine, which is designed for the purposes of new electrical generation Micro turbines are a relatively new distributed generation technology being used for stationary energy generation applications. They are a type of combustion turbine that produces both heat and electricity on a relatively small scaled.. This research are focusing of developing a low-cost micro gas turbine engine based on automotive turbocharger and to evaluation the performance of the developed micro gas turbine. The test rig engine basically was constructed using a Nissan 45V3 automotive turbocharger, containing compressor and turbine assemblies on a common shaft. The operating performance of developed micro gas turbine was analyzed experimentally with the increment of 5000 RPM on the compressor speed. The speed of the compressor was limited at 70000 RPM and only 1000 degree Celsius at maximum were allowed to operate the system in order to avoid any failure on the turbocharger bearing and the other components. Performance parameters such as inlet temperature, compressor temperature, exhaust gas temperature, and fuel and air flow rates were measured. The data was collected electronically by 74972A data acquisition and evaluated manually by calculation. From the independent test shows the result of the system, The speed of the LP turbine can be reached up to 35000 RPM and produced 18.5kw of mechanical power.

1. Introduction

Micro turbines are small combustion turbines with ranges of outputs of 25 kW to 500 kW. The innovations are evolved from automotive and truck turbochargers, auxiliary power unit airplanes, and small jet engines. Micro turbines are a relatively new distributed generation technology being used for stationary energy generation applications. There are types of combustion turbine that produces both heat and electricity on a relatively small scaled [1].

A micro gas turbine engine mostly consists of a radial inflow turbine, a centrifugal compressor and also a combustor. The micro turbine is one of the critical components in a micro gas turbine engine, since it is used for generating of output power as well as for rotating the compressor. Micro turbines are becoming widespread for distributed power and combined heat and power applications. There are one of the most promising technologies for powering hybrid electric vehicles. The range from hand held units producing less than a kilowatt, to commercial sized systems that produce tens or hundreds of kilowatts. Besides that, they also can be used of most commercial fuels, such as gasoline, natural gas, propane, diesel, and kerosene as well as renewable fuels such as E85, biodiesel and biogas [2].

This research tends to build a low-cost micro gas turbine based on automotive turbocharged that capable of producing electrical energy for a variety of application. The measurement were carried out in order to perform an evaluation of the performance of the micro gas turbine, thus from the evaluation a further extensive on improvement will continuously improve [3].

2. Methodology

2.1. Compressor and Turbine

The criteria selection of the turbocharger as a part of a gas turbine is basically based on the size of a compressor, turbine and also the types of bearings provided. There are few things must be considered before the selection is made, included of parameters such as power output, mass flow rate, speed ranges and also the operating temperature and pressure. All this primary parameter used for determination of the turbocharger size where the through of calculations in order to obtain the performance of the turbocharger [4,5].

The used of turbocharger provided highest mechanical efficiency of 74% between mass flow rate of 29 lb/min and 57 lb/min under pressure ratio of 1.6 and 3. This turbocharger also capable to operates at highest efficiency up to speeds of 70000 RPM, which is suitable for the design as it able to provide high efficiency at the maximum allowable speeds for the design. Thus, from these data, the power or work produced by this turbocharger can be evaluated based on the following equations [3, 6].

From the equation (1), the isentropic temperature and pressure relation produced by the turbocahrger can be predicted [7];

$$\left(\frac{P2}{P1}\right)^{(K-1)/K} = \frac{T2}{T1} \tag{1}$$

The power produced by the turbocharger can be estimated based on the compressor work of the turbocharger as shows in equation (2):

$$Work(kW) = \dot{m}_{air} \times (h_2 - h_1) \times Ef \tag{2}$$

Based on the calculations, the power generated by the selected turbocharger can produce the mechanical power up to 30kW until to 37kw in specific. However, due to the cost of this turbocharger surpassingly expensive, the selection had to be replaced by the use of used turbocharger that can be found in the laboratory.

The Nissan turbocharger model 45V3 has been replaced as parts of the compressor and turbine for this project. This turbocharger can be found in a RB20 engine and was originally installed in a 1988 Nissan R32 Skyline. Table 1 shows the specification of the turbocharger and Figure 1 shows an image of the replaced turbocharger. The criteria selection for this turbocharger as part of developed gas turbine are basically based on the size of the compressor, turbine and also the types of bearing provided. Table 1 shows the specification of the turbocharger that has been used for developed MGT [8,9].

Table 1. Specifications of Nissan 45V3 Turbocharger

Turbocharger Model	Compressor				Turbine		
	Inducer Wheel Diameter (mm)	Exducer Wheel Diamter (mm)	Trim	A/R	Wheel Diameter (mm)	Trim	A/R
Nissan 45V3	49.2	71	48	0.6	53.9	76	0.86

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Figure 1. The image of the Nissan 45V3 Turbocharger.

2.2. Combustion Chamber Design
A single type of combustion chamber have been used because of this type combustion chamber has relatively small, easy to fabricate and can be easily fitted with a turbocharger compared to the other combustion chamber. The image of the the Nissan 45V3 turbochager were shown in Figure 2.

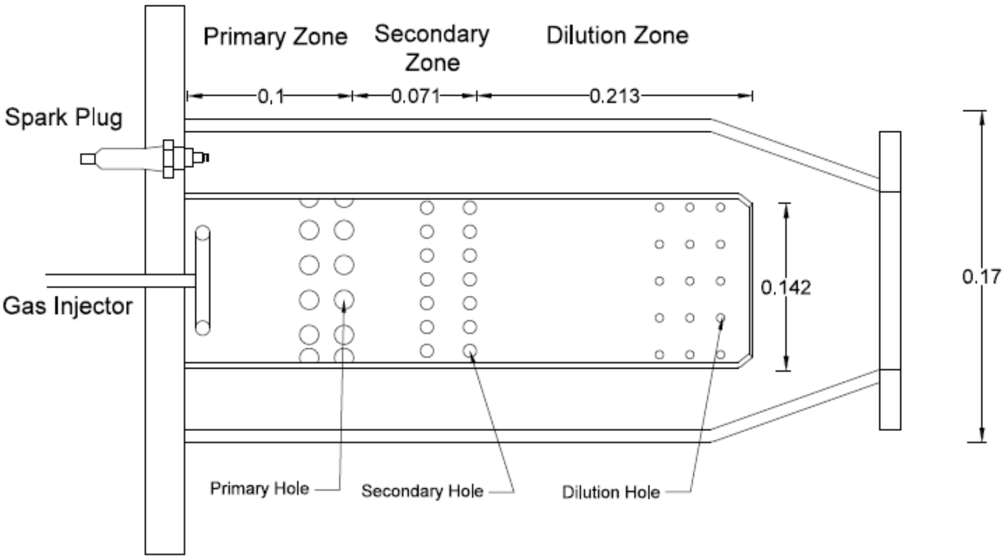

Figure 2. The image of the Nissan 45V3 Turbocharger.

3. Experiment Setup
The experiment started with the use of electrical blower that providing sufficient air to the inlet of compressor at state 1 of the cycle, and then the air is compressed to some higher pressure and temperature at state 2. Exit the compressor is where the air enters to the combustion chamber, the process of mixing between the air and fuel occurs, thus created a high flammable mixture.

The exhaust gasses leave the combustion chamber at state 3 and thus creating interaction of pressure fields to rotate the turbine and directly drove the compressor. The expanded gasses at state 4 flows through a joint that connected to the inlet of LP turbine at state 5 and then aerodynamically rotate the LP turbine at state 6. Figure 3 represent process of micro gas turbine.

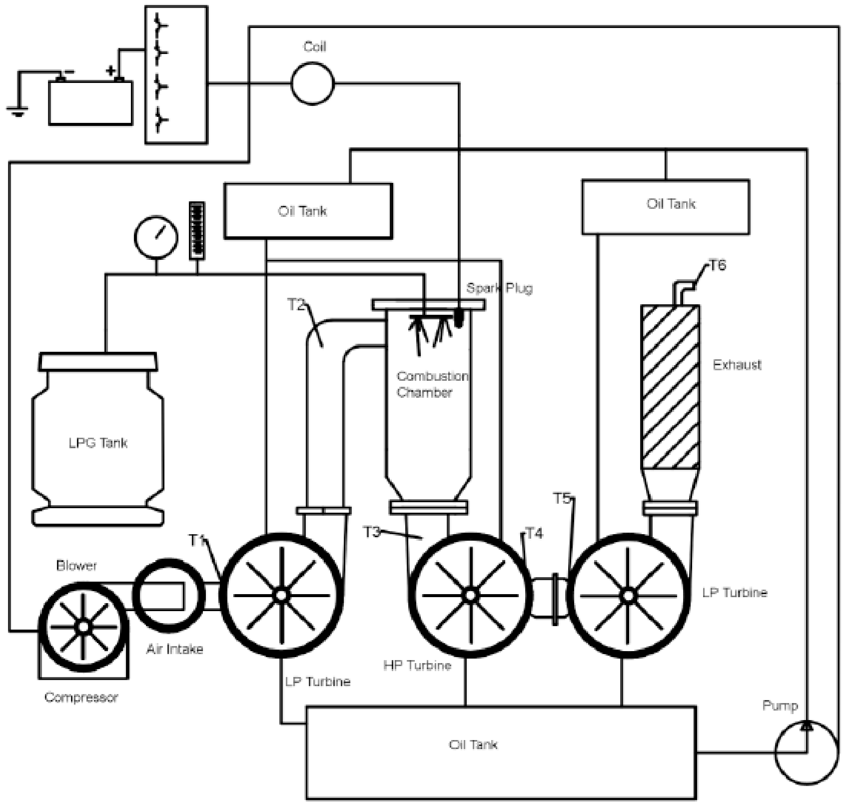

Figure 3. Schematic diagram of micro gasturbine.

4. Result and Discussion

This test was made at the automotive laboratory in UTHM with room temperature air of 32 degree Celsius and pressure was considered as atmosphere pressure above sea level, which is 101.3Kpa.

To perform the test, the speeds for HP turbine ranged from the lowest speed for combustion chamber to obtain self-sustaining operation, which is at 30000 rpm to the highest allowable operation speed, which is at 70000 RPM. An increment of 5000 rpm was selected in order to observe the temperature changes within the system, these increments are useful to verify the effect of the temperature changes consequence with system performance, particularly in terms of energy efficiency and the work carried out by the compressor, turbine and also the LP turbine of both turbochargers.

4.1. Temperature

Figure 4 shows the graph temperature of the system against the speeds of HP compressor. From the data thermocouples, the temperature reading on T3, T4 and T5 have the higher reading because the location of these thermocouples were the nearest to the combustion process. T1 is located at the inlet of the compressor where it shows the reading state of air entering the system. There was only small change on the compressor inlet temperature; it is about 6.6 degree Celsius of different between the lowest speed and the highest speed operation. T2 shows the reading of compressed air that flows to the combustion chamber. The increment of the speed has increased the temperature reading of the flow from 43.6 to 76.2 degree Celsius. T5 is the heat rejection process for the system; the reading climbed approximately 20 % from 617.8 to 767.9 Celsius when the rotation speed increased, then slightly decreased until the reading shows 650.6 degree Celsius.

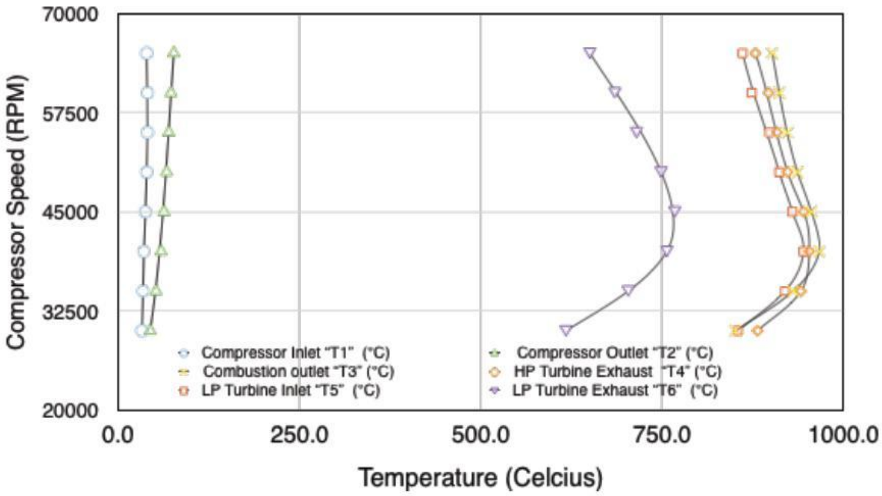

Figure 4. Graph of Compressor Speed vs Operating Temperature

4.2. Speed

Figure 5 show a trend line between the speed of high-pressure turbine and the speed produced by low-pressure turbine. As shown in Figure 9, the speed of LP turbine increased approximately 20% with the increments of 5000rpm on HP turbine speed. The main reason for this behaviour because of the speed of the LP turbine depends on the HP turbine output. By increasing the speed and temperature allows the HP turbine provides high firing gas at higher energy to the LP turbine, and thus making it more power on interaction of pressure fields for rotating the turbine.

4.3. Mechanical Power

Figure 6 shows the increases of mechanical power for both HP and LP turbine as the increases of the speed on a compressor. The highest power obtained by HP turbine is 3 kW at the highest compressor speed and approximately 20% increased from the lowest power produced which is 0.55kw at the lowest compressor speed. This resultant indirectly has increased the power of the LP turbine from 12.5kw to 18.5kw.

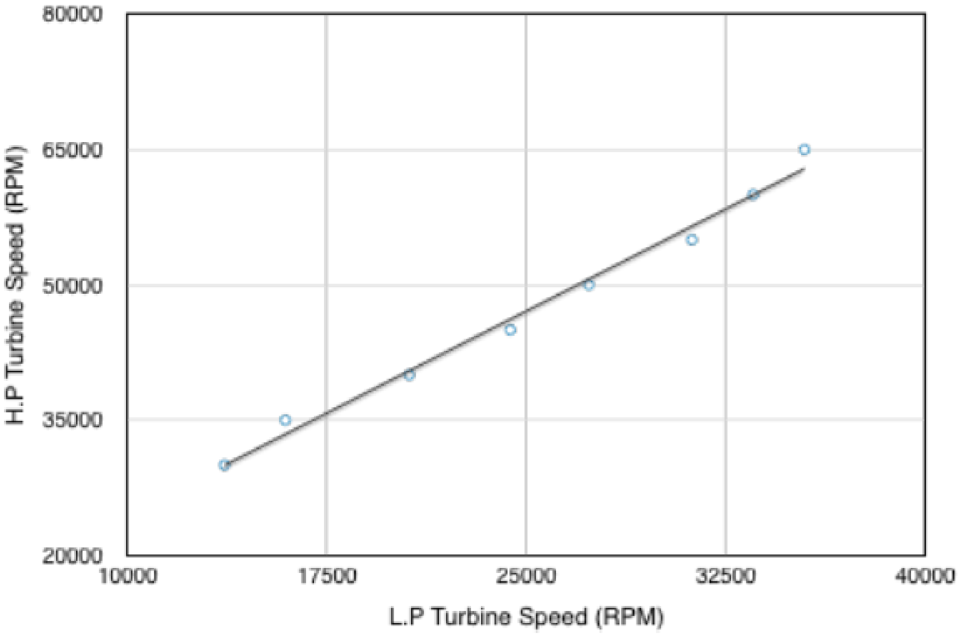

Figure 5. Graph of HP turbine speed vs LP turbine speed.

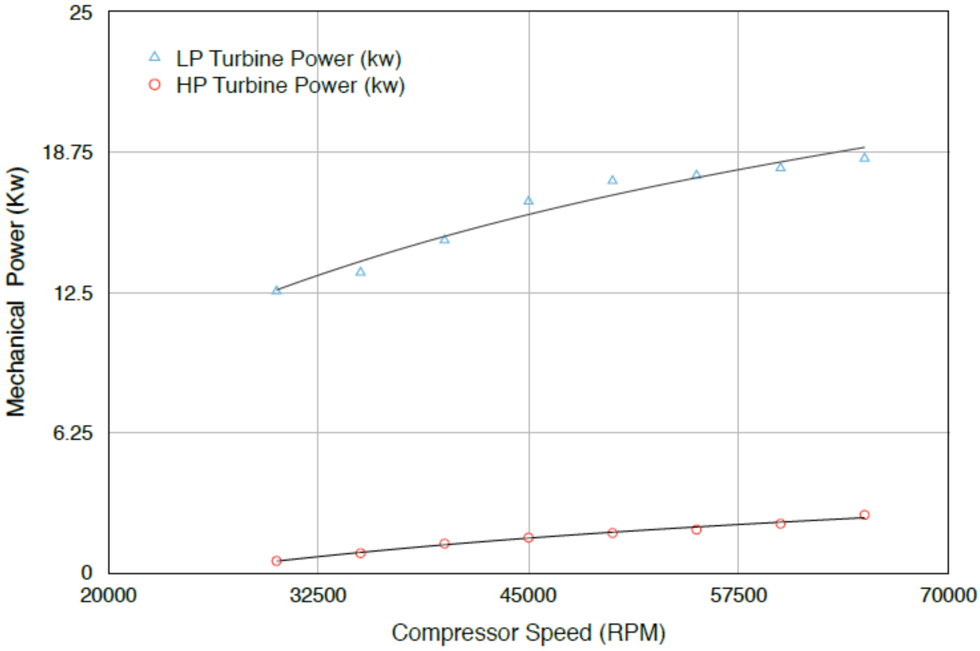

Figure 6. Increases of mechanical power due increases of compressor speed

4.4. Torque Performance

Figure 7 represents the relationship between the rotation of LP turbine and torque produced by the configuration. The torque was dropped off from 8.79 Nm to 4.97 Nm with an increment approximately 15% on the LP turbine speeds. Note that the torque is thus a linear function of the speeds, where it means the faster rotational speed of the LP turbine spin, the less torque it will produce. This is because at the high speed the engine struggles to move the fuel and air in and out. Finally the value of the torque drops with drastically.

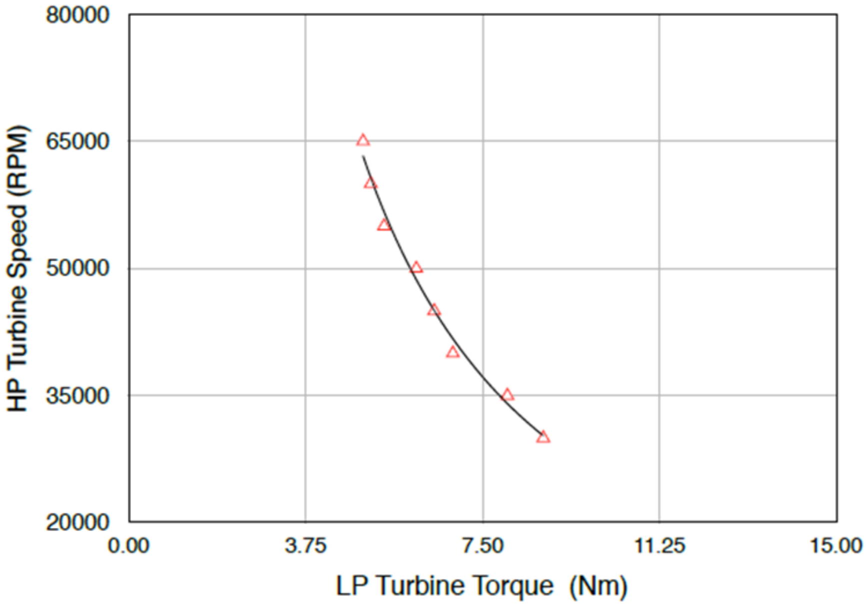

Figure 7. Graph of HP turbine speed vs Torque

5. Conclusion

This experiment was done by the development of the MGT. Following this project effort, finally the assembly has been completed and independent output testing has been initiated. As results come out from experiment, several conclusions can be drawn about the overall success of the project,

i. The developed MGT only produced 18.5kw of mechanical power at LP turbine and it is beyond the attempt to produce 30kw. This shortage of power may be caused by the unsuitable or small use of the turbocharger at the main of the engine.

ii. The differentiation between the calculation (7.6kW) and actual measurements (2.6kW) showed quite a big different of 5kW of power that would have resulted. This may be due to the turbocharger performance has not been up to the maximum level as the operating speed has not yet reached the maximum due to the disturbance in the tachometer.

iii. The torque was decreased from 8.79 Nm to 4.97 Nm with an increment approximately 15% on the LP turbine speeds. Thus torque a linear function of the speeds, where it means the faster rotational speed of the LP turbine spin, the less torque it will produce.

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