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Research and Development of 30kW Micro Gas Turbine

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Abstract: The design of high performance micro gas turbine is considered as one of the most challenges that an engineer would face. It involving in balancing between the performance output and efficiency during operating. The objective of this paper is to produce a 30kW micro gas turbine in development stage through designing and fabrication process. In this paper, only preliminary calculations related to a certain major parts are shown. It will cover the evaluation of reference quantities, calculation of required dimensions, calculation of air distribution and pressure drop, estimation of number and diameters for admission holes for a combustion chamber as one of it major components. Besides that, the selection of a turbocharger will also be evaluate to reuse the compressor and turbine from the turbocharger components to develop as one of this project major components. The turbocharger will be selected based on the capable power output from the compressor and turbine performances. To achieve this project objective in developing a 30kW micro gas turbine, the power output performance from the turbocharger must reaches a 30kW power output. The complete design will be illustrate through the Solidworks, a Computer Aided Design (CAD) software. As a result, a complete design of the major component and fully assemble of the product is produce.

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Keywords: Compressor, Turbine, Turbocharger, Combustion Chamber

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1. Introduction

The compressor, turbine and combustion chamber are describe as the major components for developing a gas turbine. This paper will present the preliminary design of the combustion chamber with the method of selection of a turbocharger that will be reuse it compressor and turbine as the parts of this project major components.

The compressor and turbine are the first major components that were selected as base development of this project. They were choose from a turbocharger that matches an output power approximately to 52.95kW. The turbocharger was choose over than 30kW because it was the closes output power that available from the market. Despite the losses that the turbocharger should have after it been dissected later on through changes of design dynamics.

The combustion chamber can be designed considering wide range of requirements such as high combustion efficiency, low fuel consumption, low pressure loss, high durability and reliability, optimum size and shape as well as low emissions and gaseous pollutant species. This paper presents only the preliminary design of an annular combustion chamber that suits the requirements of a micro gas turbine engine with 30kW power. From data and finding from the methodology detailed drawing have been described by using solidworks software. As a results, assembly of the combustor has been completed through several fabrication process.

1. Compressor and Turbine Designation

Turbocharger Selection

A conventional turbocharger will be builds with both compressor and turbine operates in the same components. The selection of using a turbocharger is to save cost and time of fabrication in developing this project. In this project, the type of turbocharger that has been decided to choose is the Garret model GT4508R as shown in Figure 1.

Figure 1 GT4508R Garret model turbocharger

2.2 Methods

The turbocharger will be dissected during fabrication process and the compressor and turbine parts will be reuse as the major components of this project development.

2.3 Compressor and Turbine Configurations

From the GT4508R turbocharger, it was built with a centrifugal compressor design and can generate a high pressure ratio relatively easier compare with an axial type of compressor that requires several stages to reach a high pressure ratio.

From the Figure 2 the compressor wheel that made from this turbocharger has fixed dimension to allow the air flow through it. The dimensions for the inducer is in 79.8 mm while for the exducer is 108.0 mm [1].

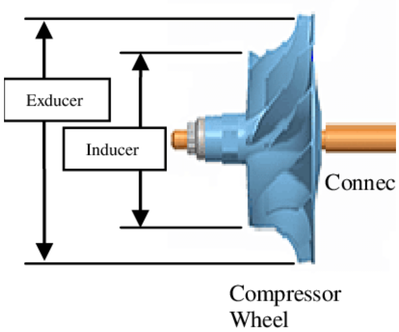

Figure 1 The compressor wheel

Based on Figure 3, the graph shows that the highest mechanical efficiency that this turbocharger could reach is at 79%. Assume that this project could reach it highest efficiency in both compressor and turbine, the value of the pressure ratio and the corrected air flow that goes into the compressor should be known.

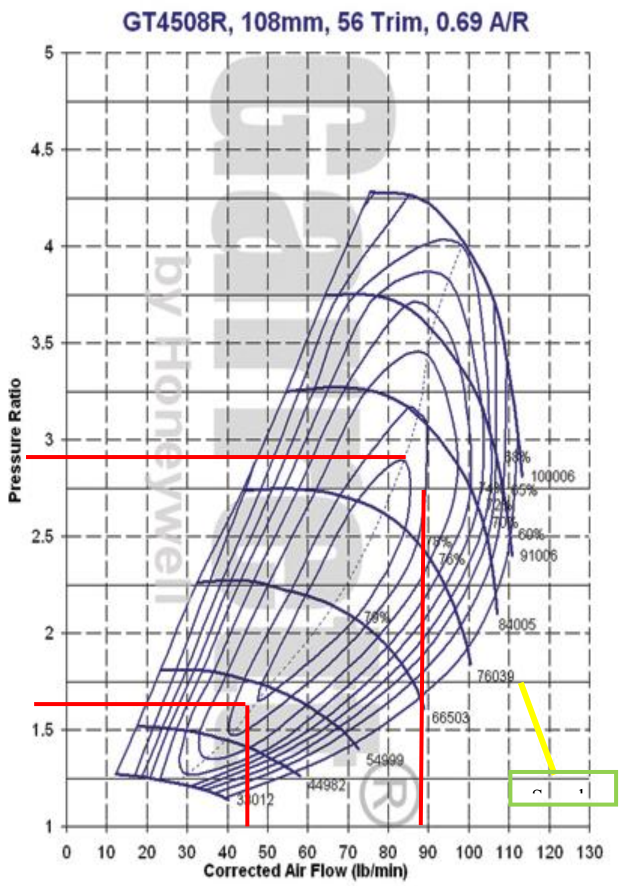

Figure 2 The graph of corrected air flow versus pressure ratio of the compressor [1]

Data from Figure 3 shows that the maximum pressure ratio of the compressor will reach up to 2.80. As we assume the inlet pressure, P_1 of this compressor as 1 bar (101.3 kPa), the outlet pressure, P_2 can be calculated using equation (1.0).

$$\frac{P_2}{P_1} = 2.80 \qquad (1.0)$$

$$\frac{P_2}{101.3\ \text{kPa}} = 2.80$$

$$P_2 = 286.64\ \text{kPa}$$

From the data from Figure 1.3, the value of the outlet temperature, T_2 can be obtain as we assume the inlet temperature, T_1 that flow through the compressor is in basic room temperature, 300K (27°C). Due to the process that occurs in the compressor is in isentropic compression, the outlet temperature, T_2 can be calculate with the equation (2.0).

$$\frac{T_2}{T_1} = \left(\frac{P_2}{P_1}\right)^{(k-1)/k} \qquad (2.0)$$

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$$\frac{T_2}{300} = (2.80)^{(1.4-1)/1.4}$$
$$T_2 = 402.61 \text{ K}$$

The specific-heat-ratio of k will be equal to 1.4 which is for the air in room temperature as shown in Figure 4. While for value of pressure ratio, $\frac{P_2}{P_1}$, the value of 2.80 is taken due to the highest probability for it to reach highest efficiency. The outlet temperature of T_2 will be 402.61K (129.61 ˚C).

Within the data that has been retrieve, the develop power, $\dot{W}$ of the compressor can be calculate with equation (3.3).

$$\dot{W} = \dot{Q}_{in}.\eta \quad (3.0)$$

$$= \dot{m}_{air} c_p (T_2 - T_1).\eta$$

The maximum air flow rate, $\dot{m}_{air}$ of data that has be consider for this 79% of efficiency will be at 86lb/min (0.650 kg/s) and the specific heats constant at room temperature will be at $c_p = 1.005$ kJ/kg.˚C.

$$\dot{W} = (0.650).(1.005)(129.61 - 27).0.79$$
$$= 52.95 \text{ kW}$$

The value of power of the compressor will be equally to the power produce by the turbine due to the connected shaft that both of the components transmitted. Although the value of power is known as the same, the pressure ratio with inlet, T_3 and outlet, T_4 temperature of the turbine is difference from the compressor, it will increase and the temperature through the combustion chamber.

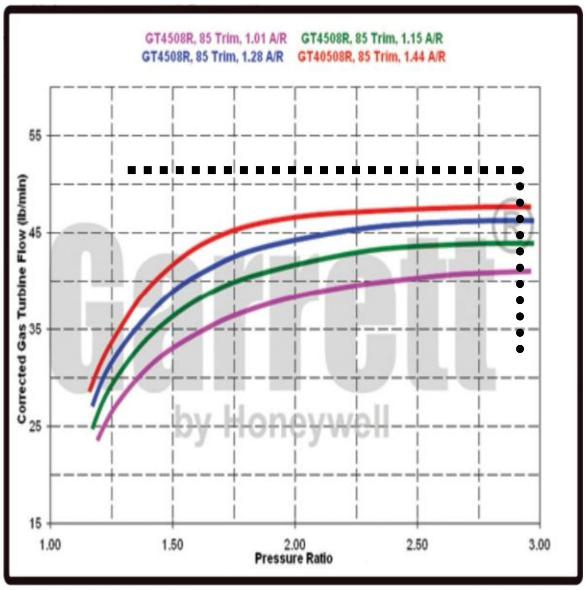

Figure 3 The graph of the corrected gas turbine flow versus the pressure ratio

Based from the data on Figure 3, the value of the angular velocity and acceleration can be calculate by equation (4.0) and (5.0)

$$\omega = \frac{\pi N_{RPM}}{30} \quad (4.0)$$
$$= \frac{\pi(76039)}{30}$$
$$= 7962.8 \text{ rad/s}$$

$$\alpha = \frac{\Delta\omega}{\Delta t} \quad (5.0)$$
$$= \frac{7962.8 \text{ rad/s}}{60 \text{ s}}$$
$$= 132.71 \text{ rad/s}^2$$

Therefore, the torque develop from this turbocharger is,

$$\text{Torque}, \tau = \frac{\dot{W}}{\omega} \quad (6.0)$$
$$= \frac{52.95 \text{ kW}}{7962.8 \text{ rad/s}}$$
$$= 6.65 \text{ Nm}$$

Table 1. Summarize data for compressor and turbine development

Compressor	
Inducer Wheel Diameter (mm)	79.8
Exducer Wheel Diameter (mm)	108.0
Air Flow (kg/s)	0.650
Pressure ratio	2.80
Rotational speed (RPM)	76039
Inlet Temperature, T_1 (˚C)	27
Outlet Temperature, T_2 (˚C)	129.61
Inlet Pressure, P_1 (kPa)	101.3
Outlet Pressure, P_2 (kPa)	286.64
Power Developed, $\dot{W}$ (kW)	52.95
Turbine	
Power Developed, $\dot{W}$ (kW)	52.95
Pressure ratio	2.80
Air Flow (kg/s)	0.3062
Angular velocity, ω (rad/s)	7962.8
Angular acceleration, α (rad/s^2)	132.71
Torque, τ (Nm)	6.65

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2. Combustion Chamber Designation

3.1 Preliminary design

Table 1 Summarize data for compressor and turbine development. The initial step of designing this combustion chamber is needed to wisely plan to avoid any lethal incident. The preliminary design procedure from J. Andrea will be referred as the initial step in design this combustion chamber as in Figure 5 [2]

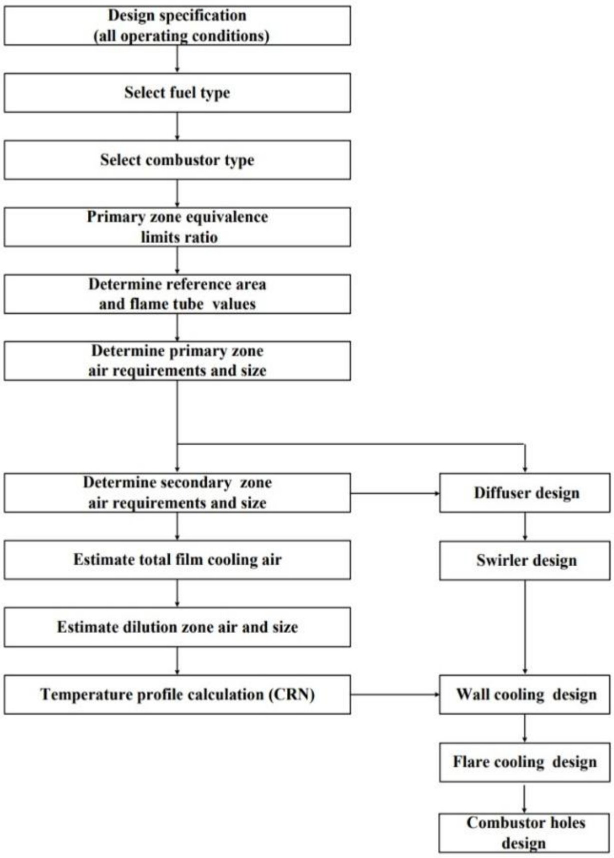

Figure 4 Preliminary design procedures

3.2 Initial Design Parameters

The initial design parameters are mostly from the compressor exit and turbine inlet constraints, which is usually absorbed for any combustion chamber design. Others include customer specifications, constants, experimental value and limits. Table 2 will shows the initial parameters used for this combustion chamber design, which were obtained from the performance of the selected turbocharger.

Table 1 initial parameters used for the design

Rotational speed (RPM)	76039
Pressure ratio	2.80
Inlet Compressor Temperature, T_1 (°C)	27
Inlet Compressor Pressure, P_1(kPa)	101.3
Outlet Compressor Temperature, T_2 (°C)	129.61
Outlet Compressor Pressure, P_2(kPa)	286.64
Air Flow (kg/s)	0.650
Power Developed, $\dot{W}$ (kW)	52.95

3.3 Dimension

3.3.1 Reference Area

Reference area (casing area) for this combustion chamber design can be calculate with equation (7.0)

$$A_{ref} = \left| \frac{R_{ar}}{2} \cdot \left(\frac{\dot{m}_3 \cdot \sqrt{T_3}}{P_3} \right) \cdot \left(\frac{\frac{\Delta P_{3-4}}{q_{ref}}}{\frac{\Delta P_{3-4}}{P_3}} \right) \right|^{1/2} \quad (7.0)$$

$$A_{ref} = 0.0131\ m^2$$

3.3.2 Combustor Area

The combustor area (liner area) is given by the relationship of equation (8.0) below:

$$A_{ft} = 0.7 \cdot A_{ref} \quad (8.0)$$

$$A_{ft} = 0.00917\ m^2$$

3.3.3 Reference and Combustor Diameter

Both of the reference diameter and combustor diameter can be calculated from the basic equation of (9.0).

$$D = \sqrt{\frac{4 \cdot A}{\pi}} \quad (9.0)$$

Therefore,

$$D_{ref} = 0.129m$$

$$D_{ft} = 0.1081m$$

3.3.4 Length of primary, secondary and dilution zone

The designation of zone in the combustion chamber are based from the metering airflow distribution from the Figure 6. Primary and secondary zone are assumed with $\frac{3}{4} D_{ft}$ and $\frac{1}{2} D_{ft}$ respectively.

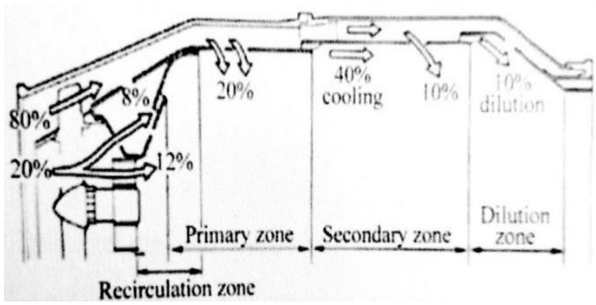

Figure 5 Metering airflow distribution around the combustion chamber [3]

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$$\text{Length of primary zone} = 0.081\text{m}$$

$$\text{Length of secondary zone} = 0.054\text{m}$$

The length of dilution zone is a function of temperature traverse quality (TQ) and pressure loss. It is calculate based from the ratio of dilution zone length to flame tube diameter or equation (10.0)

$$\frac{L_{DZ}}{D_{ft}} = 2.28 \qquad (10.0)$$

$$L_{DZ} = 0.1081(2.28)$$

$$\text{Length of dilution zone}, L_{DZ} = 0.25\text{ m}$$

3.3.5 Admission holes area for primary, secondary and dilution zone

By referring from Figure 1.6, the percentage of airflow distribution is used to calculate the primary, secondary and dilution zone air hole area. The data of airflow, $\dot{m} = 0.650$ from Table 2 will determine the air quantity that admits through the zones with equation (11.0)

$$\text{Air quantity by zone} = \text{Percentage of airflow distribution by zone} \times \dot{m} \qquad (11.0)$$

Therefore,

$$\text{Air quantity in primary zone} = 0.13\text{ kg/s}$$

$$\text{Air quantity in secondary zone} = 0.065\text{ kg/s}$$

$$\text{Air quantity in dilution zone} = 0.065\text{ kg/s}$$

To calculate the area of air hole by zone, the basic equation (12.0) is used,

$$\text{Area of air hole}, A = \frac{\dot{m}}{\rho v} \qquad (12.0)$$

Therefore,

$$\text{Area of air hole for primary zone} = 1.234 \times 10^{-4}\text{m}^2$$
$$\text{Area of air hole for secondary zone} = 6.17 \times 10^{-5}\text{m}^2$$
$$\text{Area of air hole for dilution zone} = 6.17 \times 10^{-5}\text{m}^2$$

3. Results and Discussion

3.1 Components Design Drawing

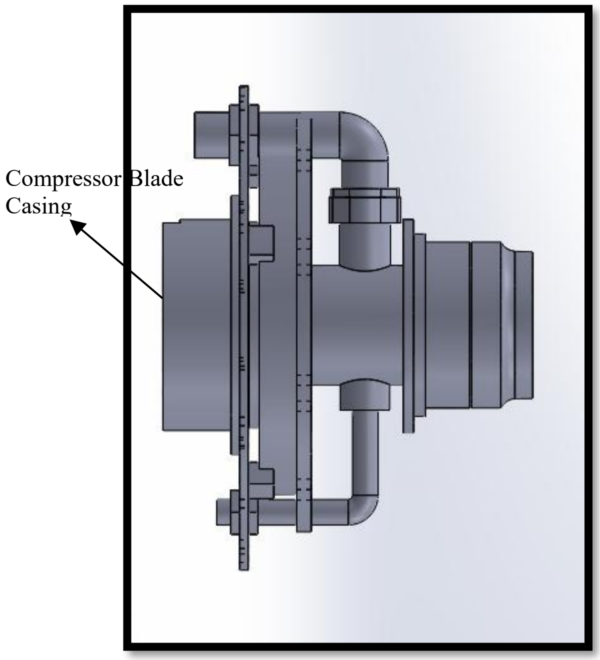

Figure 1. 6 Side view of compressor and turbine

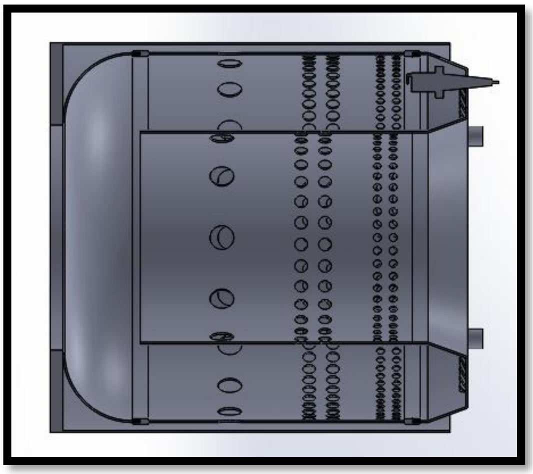

Figure 1. 8 Section view of combustion chamber

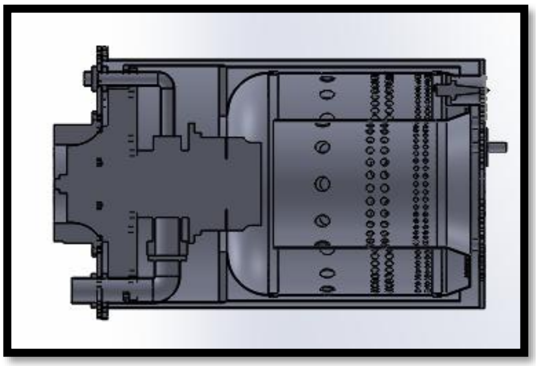

Figure 1. 7 Section view of Full assemble product

The drawing from Figure 7 shows the illustrated major components of compressor and turbine from a turbochargers. The dimension and geometric parameters of this compressor and turbine are based from the selected turbocharger itself. Their parameters are taken as a base dimension for this project. The original casing for both compressor and turbine blade are remove and designed to fits with the other component design. For safety purpose during high temperature operating rotation in the future, cooling systems are added for the connecting shaft in between the compressor and turbine with fluid.

The design of combustion chamber in Figure 8 is design based on the suitable dimension from the previous compressor and turbine components. However, others parameter such as the hole and length of zone for the combustion chamber parameter are refers based on the calculation that has been made.

For full assembly product in Figure 9, it shows the complete product of the development of a 30kW micro gas turbine. Other minor parts such as the outer wall is an essential parts that needed to be design to help during operational. The majority material used in developing this product is Stainless Steel as it have high thermal heat resistance.

3.3 Components Final Product

Figure 8 Side view of finished fabricated compressor and turbine

Figure 1. 9 Finished fabricated of combustion chamber

Figure 10 Full assemble final product

Figure 1: Example of presenting data using a figure

4. Conclusion

The design and fabrication of this project manage to be completed based from the findings in the previous chapter. The design of the major components on compressor and turbines are based from the configuration data of the selected turbocharger. Same goes to the combustion chamber component, the size of the combustor, length of each zone in a combustion chamber and admission hole were design according to data and finding based from the methodology chapter. Thus, as for recommendation, a proper testing and analysis could help to find any flaws from the fabricated product. A pre-test could also be done from every major components to ensure any failure before full assembly testing.

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