THE STUDY ON THE PERFORMANCE OF THE GAS TURBINE FOR POWER GENERATION

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I declare that this thesis entitled ‘The Study on Performance of the Gas Turbine for Power Generation’ is the results of my own research except as cited in the references. The thesis has not been accepted for any degree and is not concurrently submitted candidature of any degree.

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Date	: 24 MARCH 2008

Special dedicated to my beloved father, mother and my whole family members

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ABSTRACT

Gas turbines are becoming increasingly used as power generators for a wide variety of applications around the world. Originally they were developed solely for aircraft propulsion where their inherent low specific weight (i.e. mass/unit power) made them essential for high speed flight. For this particular purpose they have been developed to a high degree of efficiency both thermodynamically and mechanically. The significant of this study is to increase the performance of the gas turbine in term of the efficiency. The lower efficiency of the gas turbine will effect to the performance of the gas turbine itself, the waste of the fuel because of the unburned hydrocarbon and the impact to the environment, while the gas turbine with a incomplete combustion. To increase the performance in term of efficiency, the gas generator speed is controlled from 1500 rotary per second to 1250 rotary per second. In order to increase the efficiency of the gas turbine, the power output must high, because it is proportional to the efficiency. Besides low fuel consumption is also important to evaluate an efficient gas turbine because it is inversely proportional to efficiency of the unit. From the experiment, is at a speed of 1400 rotary per second, it is the optimum speed that make the gas turbine running at the highest efficiency. The fuel rate consumption at this speed is 1.48E-03kg/s and the power produce is 905.04W. In conclusion, the optimum speed to run the unit at a high efficiency is at 1400 rotary per second which has produced high power output and low fuel consumption. As a recommendation, to further improve the overall performance of the gas turbine unit, air to fuel ratio must be analyzed, in order to find an optimum air to fuel ratio in the combustion chamber.

ABSTRAK

Turbin Gas semakin bertambah di dalam banyak kegunaan dan aplikasi dalam dunia ini. Sebenarnya, turbin gas, di kembangkan untuk enjin kapal terbang dan jet kerana beratnya yang rendah dan sesuai untuk penerbangan yang mempunyai hal laju yang tinggi. Disebabkan ini, turbin gas di bangunkan lebih effisiensi dalam kedua-dua termodinamik dan mekanikal. Tujuan pembelajaran ini, adalah untuk meningkatkan kecekapan di dalam effisiensi. Effisiensi yang rendah akan mengakibatkan kesan pada kecekapan turbin gas, pembaziran hidrokarbon di sebabkan pembakaran yang tidak effisien, dan kean pada alam sekitar di sebabkan asap hitam yang keluar dari corong akibat dari pembakaran yang tidak lengkap. Untuk meningkatkan lagi prestasi turbin gas halaju gas generator di kawal dari 1500 rotary per second hingga 1250 rotary per second. Untuk mendapatakan effisien yang tinggi, kuasa yang keluar dari turbin gas mestilah tinggi, ini disebabakan keda-dua ini berkadar langsung. Seperkara lagi, effisien yang tinggi berlaku apbila kadar penggunaan hydrokarbn rendah, yanag mana effisien turbin gas berkadar songsang dengan kadar penggunaan hidrokarbon. Keputusan yang boleh disyorkan yang mana dapat meningkatkan prestasi turbin gas ialah pada gas generator 1400 rotary per second, ini ialah hallaju ptimm untuk mendapat effisien turbin gas yang tinggi. Kadar penggnaan hidrokarbon pada hallaju ini ialah 1.48E-03kg/s dan kuasa yang dihasilkan ialah 905.04W. Kesimpulannya, halaju optimum untuk mengahsilkan effisien yang tinggi ialah 1400 rps dan nisbah udara dan minyak kajian harap dapat dilakukan, untuk meningkatkan lagi prestasi unit ini, kajian yang dibuat, membolehkan nisbah udara dan minyak yang optimum dapat ditentukan.

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LIST OF SYMBOLS

g	-	Gram
L	-	Liters
ml	-	Milliliters
Q	-	Heat transfer
S.G.	-	Standard gravity
T	-	Temperature
W	-	Work
η	-	Efficiency
KPa		Kilo Pascal
rps		Rotary Per Second
V		Volts
A		Ampere

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CHAPTER 1

INTRODUCTION

Gas turbine is heat engine which uses fuel energy to produce mechanical output power, either as torque through a rotating shaft (industrial gas turbines) or as jet power in the form of velocity through an exhaust nozzle (aircraft jet engines).

1.1. Background of Study

A gas turbine, also called a combustion turbine, is a rotary engine that extracts energy from a flow of hot gas produced by combustion of gas or fuel oil in a stream of compressed air. It has an upstream air compressor with radial or axial flow mechanically coupled to a downstream turbine and a combustion chamber in between. Gas turbine may also refer to just the turbine element. Energy is released when compressed air is mixed with fuel and ignited in the combustor. The resulting gases are directed over the turbine blades, spinning the turbine, and mechanically powering the compressor. Finally, the gases are passed through a nozzle, generating additional thrust when accelerating the hot exhaust gases by expansion back to atmospheric pressure. Energy is extracted in the form of shaft power, compressed air and thrust, in any combination, and used to power aircraft, trains, ships, electrical generators, and even tanks[2]. Gas turbines are always used if high power density, low weight and quick starting are required. As the moving parts of a gas turbine only perform rotary motion, almost vibration free running can be achieved if turbine is well balanced.

Gas turbines are becoming increasingly used as power generations for a wide variety of applications around the world. Originally they were developed solely for aircraft propulsion where their inherent low specific weight (i.e. mass/unit power) made them essential for high speed flight. For this particular purpose they have been developed to a high degree of efficiency both thermodynamically and mechanically.

Due partly to the impetus from the aircraft engine field and also to other significant operational advantages, industrial gas turbines have been and are being developed for such diverse applications as electrical power peak lopping stations, fire fighting pump sets, natural gas pumping and compressor units, factory power and process heating plants, heavy lorry propulsion, rail and ship propulsion.

1.2 Problem Statement

Basically, gas turbine which operates at lower turbine inlet temperatures will result in low performance and decrease efficiency. Lower efficiency of gas turbine means the lower power output is produced. To increase the performance of gas turbines there have several approaches. One of them is by controlling the gas generator speed. Basically, gas generator is the main constituents to run the gas turbine because of the speed of gas generator effect to the combustion at the combustion chamber. By finding the optimum condition of this speed, the efficiency of the gas turbine then can be improved and increased.

1.3 Scope of Research Work

P9005 Cussons Two Shaft Gas Turbine is studied in this work. This turbine is can be found in Mechanical Engineering lab, Malaysia Pahang University. Efficiency of this P9005 Cussons Two Shaft Gas Turbine is the scope of this work.

1.4 Objective of Research Work

Objective of this work is to increase the performance P9005 Cussons Two Shaft Gas Turbine by optimizing the air to gas generator speed in order to produce an efficient power produce and then get the higher efficiency process.

CHAPTER 2

LITERATURE REVIEW

There are several published articles are referred for this work. They are from the previous researches, journals and books. This work is more focus at gas turbine efficiencies.

2.1 History

Nowadays, a number of industrial engines made by manufacturers who also make aircraft engines, such as Rolls-Royce and General Electric, are essentially similar to their aircraft engine sibling but are mounted on a skid. Support systems however, both operational and condition monitoring, will not have the same complexity and degrees of redundancy as the aircraft engine counterpart.

2.2 Gas Turbine Usage

In an aircraft gas turbine the output of the turbine is used to turn the compressor (which may also have an associated fan or propeller). The hot air flow leaving the turbine is then accelerated into the atmosphere through an exhaust nozzle to provide thrust or propulsion power. The jet engine of Fig. 2.1 is a turbofan engine, with a large diameter compressor-mounted fan. Thrust is generated both by air passing through the fan (bypass air) and through the gas generator itself. With a large frontal area, the turbofan generates peak thrust at low (takeoff) speeds making it most suitable for commercial aircraft.

A turbojet does not have a fan and generates all of its thrust from air that passes through the gas generator. Turbojets have smaller frontal areas and generate peak thrusts at high speeds, making them most suitable for fighter aircraft. In non-aviation gas turbines, part of the turbine power is used to drive the compressor. The remainder, the "useful power", is used as output shaft power to turn an energy conversion device such as an electrical generator or a ship's propeller. A typical land -based gas turbine is shown in Fig. 2.2. Such units can range in power output from 0.05 MW (Megawatts) to as high as 240 MW. The unit shown in Fig. 2.2 is an aeroderivative gas turbine; i.e., a lighter weight unit derived from an aircraft jet engine. Heavier weight units designed specifically for land use are called industrial or frame machines.

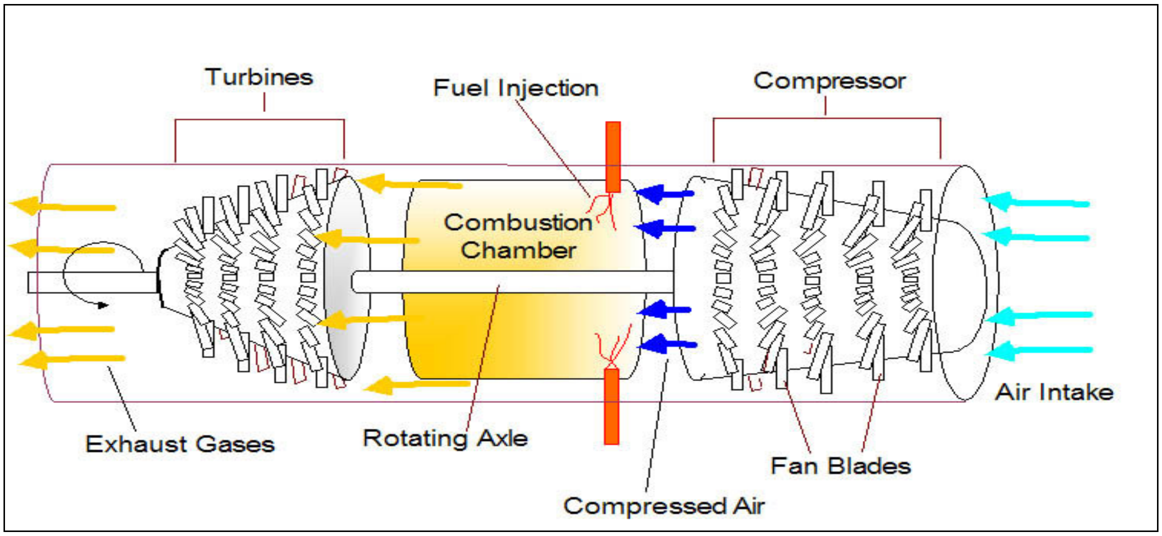

Figure 2.1: Modern Jet Engine to Power Boeing 777 Aircraft

Although aeroderivative gas turbines are being increasingly used for base load electrical power generation, they are most frequently used to drive compressors for natural gas pipelines, power ships and provide peaking and intermittent power for electric utility applications. Peaking power supplements a utility's normal steam turbine or hydroelectric power output during high demand periods such as the summer demand for air conditioning in many major cities.

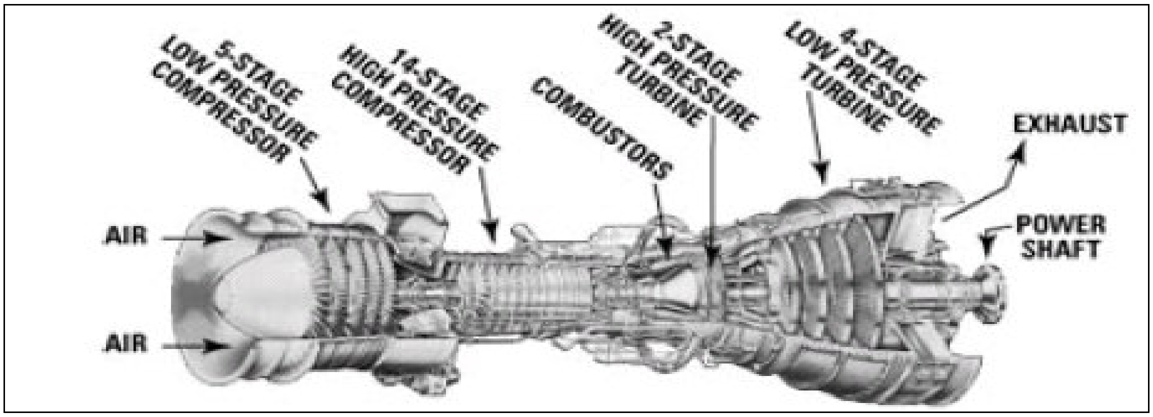

Figure 2.2: A Modern Land Based Gas Turbine Used For Electrical PoweGenration and Mechanical Drives

2.3 Gas Turbine Cycle

A cycle describes what happens to air as it passes into, through, and out of the gas turbine. The cycle usually describes the relationship between the space occupied by the air in the system (called volume, V) and the pressure (P) it is under. The Brayton cycle (1876), shown in graphic form in Fig. 4a as a pressure-volume diagram, is a representation of the properties of a fixed amount of air as it passes through a gas turbine in operation. These same points are also shown in the engine schematic in Fig. 4b.

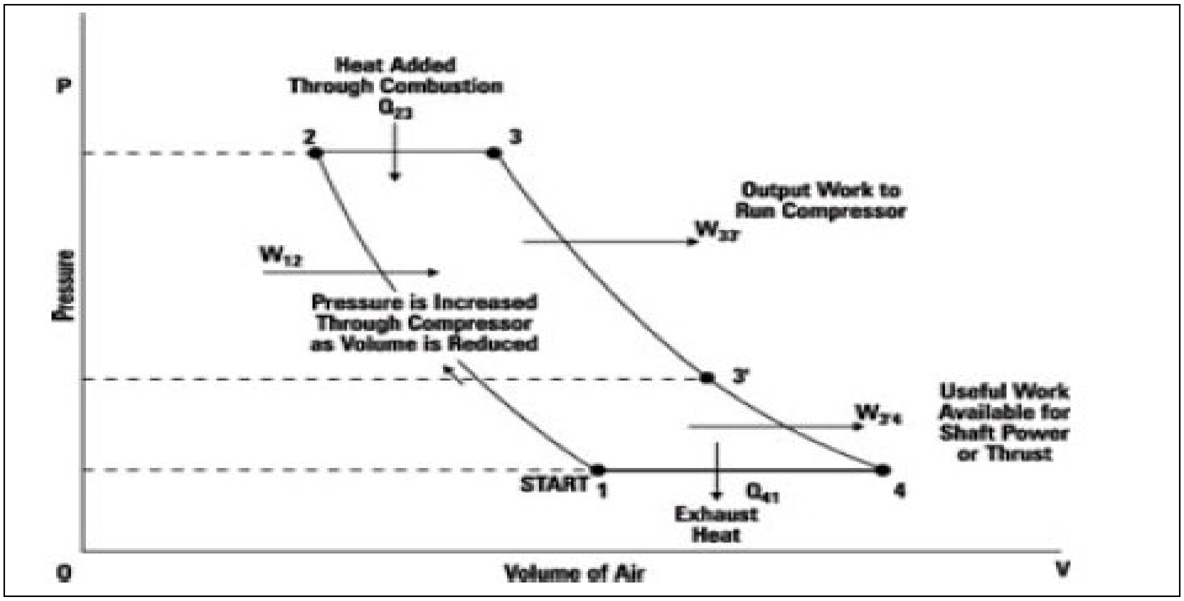

Figure 2.3(a): Brayton Cycle Pressure-Volume, work (W) and heat (Q)

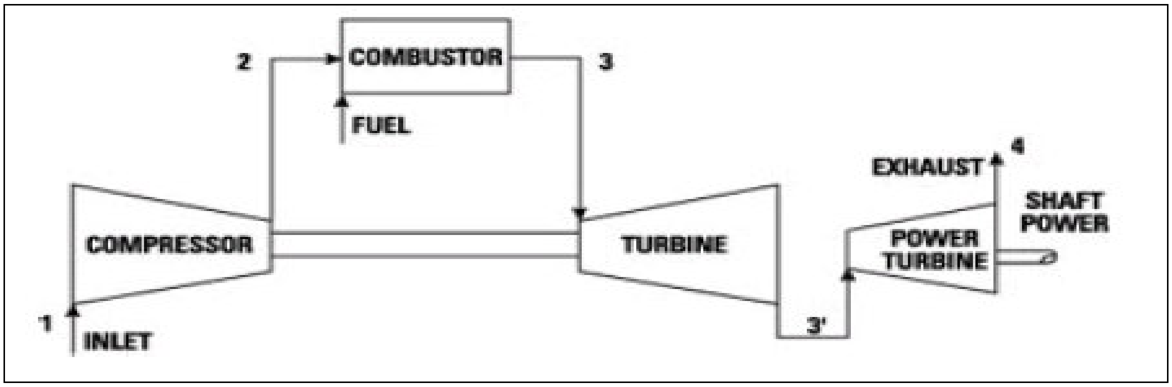

Figure 2.3(b): Gas Turbine Schematic Diagram Showing Relative Points of The Brayton Cycle

Air is compressed from point 1 to point 2. This increases the pressure as the volume of space occupied by the air is reduced. The air is then heated at constant pressure from 2 to 3 in Fig. 4. This heat is added by injecting fuel into the combustor and igniting it on a continuous basis. The hot compressed air at point 3 is then allowed to expand (from point 3 to 4) reducing the pressure and temperature and increasing its volume. In the engine in Fig. 4b, this represents flow through the turbine to point 3’ and then flow through the power turbine to point 4 to turn a shaft or a ship’s propeller. The "useful work" in Fig. 2.3(a) is indicated by the curve 3’- 4. This is the energy available to cause output shaft power for a land-based gas turbine , or thrust for a jet aircraft. The Brayton cycle is completed in Fig. 2.3 by a process in which the volume of the air is decreased (temperature decrease) as heat is absorbed into the atmosphere.

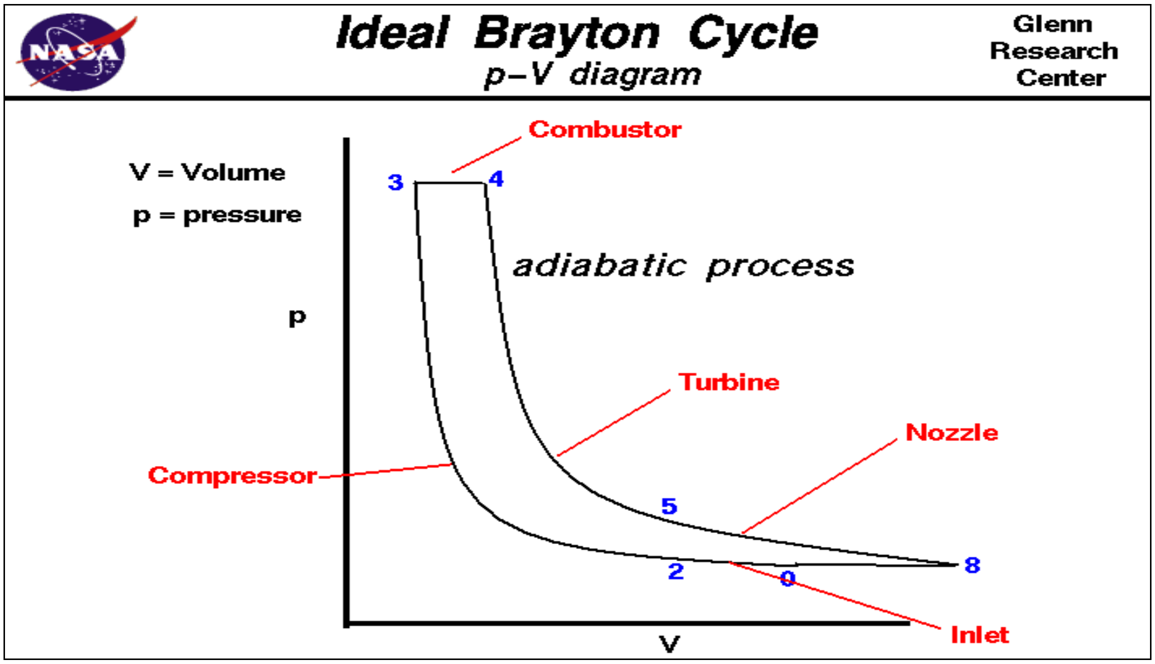

Figure 2.4: P-V Diagram

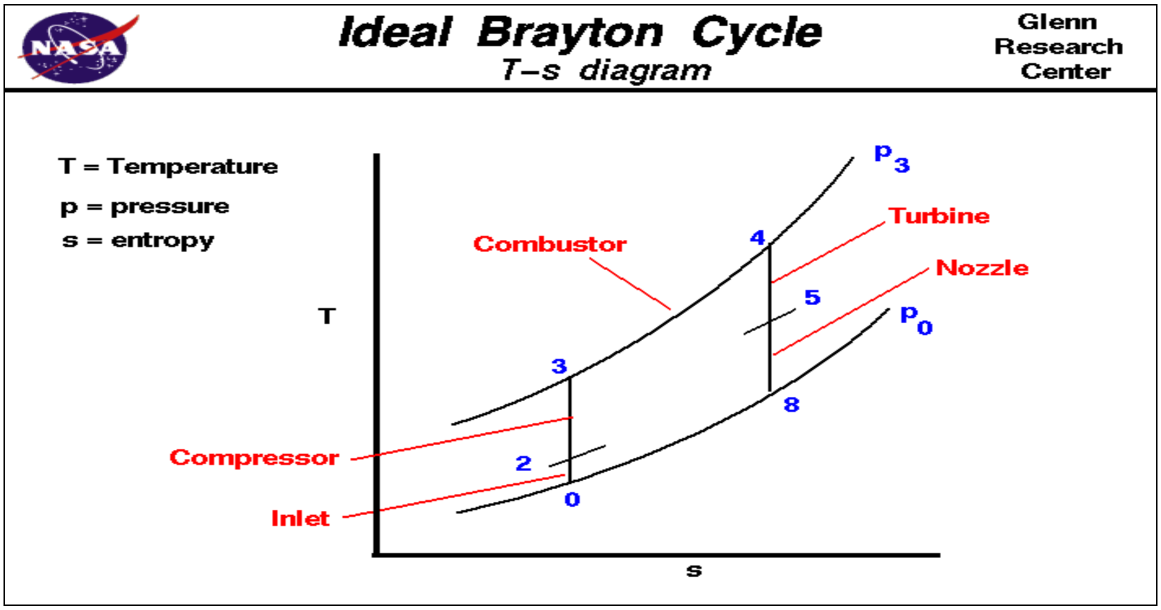

Figure 2.5: T-S Diagram

The P-v and T-s diagrams of an ideal Brayton cycle are shown in Fig. 2.3. Notice that all four processes of the Brayton cycle are executed in steady-flow devices; thus, they should be analyzed as steady-flow processes. When the changes in kinetic and potential energies are neglected, the energy balanced for steady-flow process can be expressed, on a unit-mass basis as (qin – qout) + (win - wout) = hexit - hinlet Eqn. 2.1

Therefore, heat transfers to and from the working fluid are

qin = h3 – h2 = cp(T 3 – T2) Eqn. 2.1a

and

qout = h4 – h1 = cp(T4 - T1) Eqn. 2.1b

Then the thermal efficiency of the ideal Brayton cycle under the cld-air-standard assumptions becomes

$$\eta_{th,Brayton} = \frac{w_{net}}{q_{in}} = 1 - \frac{q_{out}}{q_{in}} = 1 - \frac{c_p(T_4 - T_1)}{c_p(T_3 - T_2)} = 1 - \frac{T_1(T_4/T_1 - 1)}{T_2(T_3/T_2 - 1)} \quad \text{Eqn. 2.2}$$

Process 1-2 and 3-4 are isentropic, and P2 = P3 and P4 = P1. Thus,

$$\frac{T_2}{T_1} = \left(\frac{P_2}{P_1}\right)^{(k-1)/k} = \left(\frac{P_3}{P_4}\right)^{(k-1)/k} = \frac{T_3}{T_4} \quad \text{Eqn.2.3}$$

Substituting these equations into the thermal efficiency relation and simplifying give

$$\eta_{th,Brayton} = 1 - \frac{1}{r_p^{(k-1)/k}} \quad \text{Eqn.2.4}$$

$$r_p = \frac{P_2}{P_1} \quad \text{Eqn. 2.5}$$

is the pressure ratio and k is the specific heat ratio. Equation 2.5 shows that under the cold-air-standard assumptions, the thermal efficiency of an ideal Brayton cycle depends on the pressure ratio of the gas turbine and the specific heat ratio of the working fluid.[1]

2.4 Adiabatic Flame Temperature

There are not so many researches about the efficiency of the gas turbine. One of the researches about the efficiency of the gas turbine is ambient temperature on the electricity production and fuel consumption of simple cycle gas turbine.

Flame temperature is perhaps the most important property in combustion because it has a controlling effect on the rate of chemical reaction. The term “flame temperature” may imply a measured value or a calculated one. If the latter, it is usually the adiabatic flame temperature. This is the temperature that the flame would attain if the net energy liberated by the chemical reaction that converts the fresh mixture into combustion products were fully utilized in heating those products. In practice, heat is lost from the flame by radiation and convection, so the adiabatic flame temperature is rarely achieved. Nevertheless, it plays an important role in the determination of combustion efficiency and in heat-transfer calculations. In high-temperatures flames, say above 1800 K, dissociation of combustion products occurs to significant extent and absorbs much heat. At low temperatures, combustion of a stoichiometric or lean fuel-air mixture would be expected to give only CO2 and H2O; however, at higher temperatures, these products are themselves unstable and partly revert to simpler molecular and atomic species and radicals, principally CO, H2, O, H, and OH[2]. The energy absorbed in dissociation is considerable, and its effect is to reduce substantially the maximum flame temperature.

2.5 Combustion Efficiency

The efficiency of a combustion process may be found from a chemical analysis of the combustion products. Knowing the air/fuel ratio used and the proportion of incompletely burnt constituents, it is possible to calculate the ratio of the actual energy released to the theoretical quantity available. This approach via chemical analysis is not easy, because not only it is difficult to obtain truly representative samples form the high velocity stream, but also, owing to the high air/fuel ratis employed in gas turbines, the unburnt constituents to be measured are a very small proportion of the whole sample.

If an overall combustion efficiency is all that is required, however, and not an investigation of the state of the combustion process at different stages, it is easier to conduct development work on a test rig on the basis of the combustion efficiency which was defined,[3]

$$\eta_b = \frac{theoreticalf}{actualf} \text{(actual}\Delta\text{T)} \qquad \text{Eqn. 2.6}$$

2.6 ASME, Performance Test Code on Gas Turbine, ASME PTC 22 1997

The object of the code is to detail the test to determine the power output and thermal efficiency of the gas turbine when operating at the test conditions, and correcting these test result to standards or specified operating and control conditions. Procedures for conducting the test, calculating the results, and making the corrections are defined.The codes provide for the testing of gas turbines supplied with gaseous or liquid fuels (or solid fuels converted to liquid or gas prior to entrance to the gas turbine). Test of gas turbines with water or steam injection for emission control and/or power augmentation are included. The tests can be applied to gas turbines in combined-cycle power plants or with other heat recovery systems. Meeting should be held with all parties concerned as to how the test will be conducted and an uncertainty analysis should be performed prior to the test. The overall test uncertainty will vary because of the differences in the scope of supply, fuel used, and driven equipment characteristics. The code establishes a limit for the uncertainty of each measurement required; the overall uncertainty is then calculated in accordance with the procedures defined in the code and by ASME PTC 19.1 [3]

2.7 Previous Research

There are not so many researches about the efficiency of the gas turbine. One of the researches about the efficiency of the gas turbine is ambient temperature on the electricity production and fuel consumption of simple cycle gas turbine and Robust Control of gas generator.

2.7.1 Effect of Ambient Temperature

Efficiency and electric-power output of gas turbines vary according to the ambient conditions. The amount of these variations greatly affects electricity production, fuel consumption and plant incomes. Since ambient conditions are dependent upon the place where gas turbine is installed, they cannot be changed. At the same time, the amount of performance variation with the ambient conditions also depends on the gas turbines design parameters. Therefore, in order to determine the actual performance variation with the ambient conditions, gas turbine design parameters and ambient conditions of the installed place should be known. For this purpose, two gas turbine models and seven climate regions of Turkey are considered in this study. For both two models, by using average monthly temperature data of the regions, annual electricity production loss and fuel consumption increase compared to those in standard design conditions (sea level, 15 ^{o}C, 60% relative humidity)[6]. Electricity production loss is about 2.87–0.71% take place, compared to the standard annual production rate in hot regions. Electricity production loss occurs in all regions during the periods when the temperature is above the 15 ^{o}C standard ambient temperature and loss rates vary between 1.67% and 7.22% depending upon the regions. Electricity generation increases for about 0.27–10.28% when inlet air is cooled to 10 ^{o}C.

2.7.2 Robust Control of Gas Generator in a 1.5MW Gas Turbine Engine

This paper describes the robust control design of a gas generator engine. A non-linear model of the engine has been developed within Simulink from details previously presented in reference. State space H, control designs are performed using a linearised model to represent the key components in the single loop control configuration. The performance criteria are specified in terms of stability margins, bandwidth and desired response of the engine to large step input. The engine is subject to constraints on its manipulated variable (i.e. the throttle valve angle) which cause integral wind up. The H, design is simplified to a classical Proportional-Integral (PI) controller. To take a full advantage of the design a technique so-called Utilise Saturation Feedback is used to reduce the effect of the integral windup. The results show that the PI control produces results similar to H, at low speeds but that H , gives better robustness and performance at higher speeds. Nonlinear simulations with parameter changes support the conclusion that the design is robust [8].

CHAPTER 3

METHODOLGY

3.1 Solving Technique

Figure 3.1 shows the flow diagram of the research. The research starts with obtaining the process flow diagram of gas turbine. Then obtain study and understand the lab manual of P9005 Cussons Two Shaft Gas Turbine to make the research work done properly. After that, determine the gas generator speed used to run this research work. Fuel used to run this research work is LPG. The performance is calculated. After obtaining the existing performance, propose the gas generator speed in order to increase the gas turbine performance.

3.2 General Notes on Operation

When ignition initially occurs, a slight ‘pop’ is heard, and a sharp rise of combustion chamber temperature take place. If the gas valve is then opened too quickly, T3 will rise above 950oC and the over temperature protection will operate. Should this occur, close the gas valve, press the ‘reset’ button and restart the turbine. Whilst accelerating, T3 should be kept below 850oC by ‘slowly’ opening gas valve as the turbine speed increase. When the gas generator speed reaches 1000 rps, leave the gas valve in this position and turn the air inlet control switch to the run position and switch off the blower.