STUDY OF HIGH SPEED GAS TURBINE IN INDUSTRY BY FUEL RATIO AND TURBINE SPEED

MOHAMAD SUFIAN BIN KHALID

UNIVERSITY MALAYSIA PAHANG

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MOHAMAD SUFIAN BIN KHALID

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ABSTRACT

The gas turbine is one of the power plant units which will produces electrical energy in high amount and continuously production. The gas turbine makes a great service namely in the past 40 years in the electrical power industry both with utilities and merchant plants as well as the petrochemical industry throughout the world. It is a system with compact low weight, and can use multiple fuel application such as a natural power plant for offshore platforms. Therefore, the purpose of the study for the high speed gas turbine is to determine the effect of turbine speed on the gas turbine operation. This study currently been done by using ET792 Two-Shaft Gas Turbine Demonstration Unit and which liquefied Petroleum Gas (LPG) used as a fuel. The experiment was performed by manipulating the gas generator speed and the gas turbine speed to determine the power output, the fuel consumption and the specific thrust output of the gas turbine. From the given result, gas turbine speed shown a great affects to the gas turbine performances. The power output and the reduced output thrust of the gas turbine increase when the gas turbine speed increase, but the fuel consumption decreasing when the gas turbine speed increases. The decreasing of the fuel consumption with the power output and the reduced output thrust increasing will reduce the overall operating cost. And also it will decrease the usage of fuel by the mean of the system.

ABSTRAK

Penggunaa Turbin gas sebagai salah satu kaedah dalam proses penghasilan tenaga dilihat memberi sejumlah tenaga yang besar berdasar kan kepadatan dan beratnya. Penggunaan Turbin gas dalam industri penjanaa kuasa dilihat telah meningkat dalam tempoh masa 40 tahun kebelakangan ini, samaada di kalangan indusrti penjanaan kuasa ataupun industri petrokimia di seluruh dunia. Kepadatan, berat badan rendah, dan kebolehupayaan untuk beroperasi meggunakan pelbagai bahan bakar menjadikan turbin gas sebagai pilihan utama dalam proses penjanaan tenaga di pelantar minyak. kajian ini adalah bertujuaan untuk mengetahui kesan peningkatan kelajuaan turbin gas terhadap operasi turbin gas. Penyelidikan ini telah dilakukan dengan menggunakan *ET792 Two-Shaft Gas Turbine Demonstration Unit* dan cecair Petroleum Gas (LPG) digunakan sebagai bahan bakar. Kajian ini dijalankan dengan memanipulasi kadar kelajuaan gas generator dan kelajuan turbin gas untuk menentukan tenaga yang terhasil, kadar penggunaan bahan bakar dan daya tujah yang dihasil kan oleh turbin gas. Secara keseluruhannya, kelajuan turbin gas memberi pengaruh yang besar terhadap prestasi turbin gas. Tenaga dan daya tujah yang dihasilkan meningkat apabila kelajuan turbin gas meningkat, tetapi kadar penggunaan bahan bakar akan berkurangan apabila kelajuaan turbin gas meningkat. Penurunan penggunaa bahan bakar bukan sahaja dapat mengurangkan kos operasi tetapi dapat juga meningkatkan jumlah tenaga dan daya tujah turbin yang dihasil kan.

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LIST OF SYMBOLS

Btu = British Thermal Unit
Wt = Turbine Work
Wc = Compressor work
P = Pressure
T = Temperature
Rpm = Revolution per minute
s = Second
MW = Megawatt
kW = kilowatt
LPG = Liquefied Petroleum Gas
U.S = United State
LHV = Lower Heating Value
Lbm = Pound mass
Ft^3 = Feet cubic
kJ = Kilojoule
m^3 = Meter Cubic
CO = Carbon Monoxide
CO_2 = Carbon Dioxide
H = Hour
Kg = Kilogram
kWh = Kilowatt per hours
W = Watt

N = Newton

^{o}C = Degree Celsius

NOx = Nitrogen Oxide

ppm = Part per millon

P_{Te} = Power Output, W

η_{el} = Efficiency of the Generator, %

P_{el} = Electrical Power Output, W

S_{Red} = Reduced Output Thrust,N

S = Thrust,N

b_e = Specific Fuel Consumption, kg/kWh

$\dot{m}_G$ = Gas Flow Rate, g/s

P_{Tred} = Reduced Output Power,W

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CHAPTER 1

INTRODUCTION

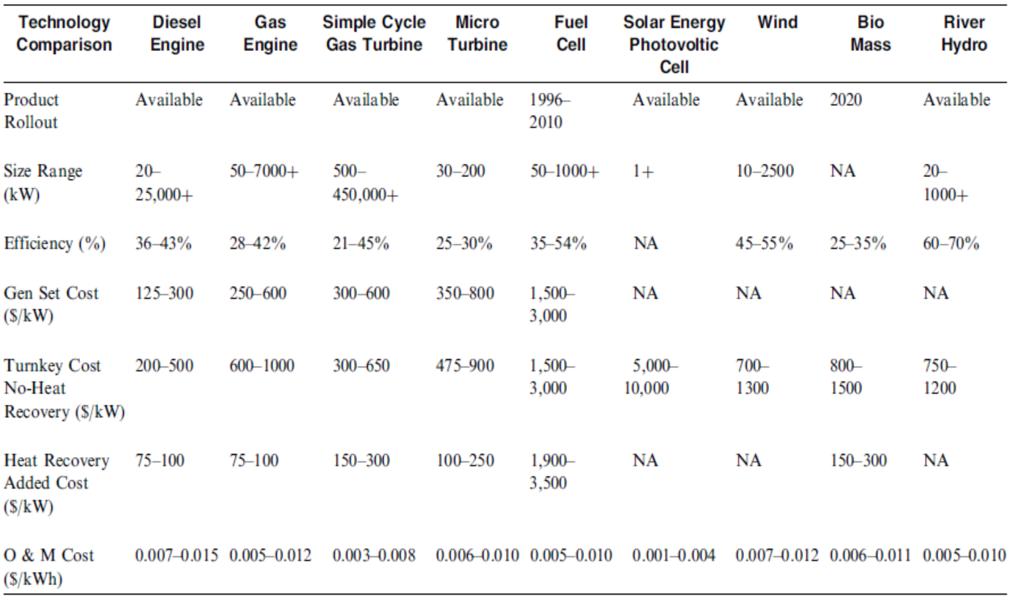
1.1 Background of Study

The gas turbine is a power plant, which produces a great amount of energy for its size and weight. The gas turbine has found increasing service in the past 40 years in the power industry both among utilities and merchant plants as well as the petrochemical industry, and utilities throughout the world. Its compactness, low weight, and multiple fuel application make it a natural power plant for offshore platforms. Today there are gas turbines, which run on natural gas, diesel fuel, naphtha, methane, crude, low-Btu gases, vaporized fuel oils, and biomass gases.

The last 20 years has seen a large growth in Gas Turbine Technology. The growth is spearheaded by the growth of materials technology, new coatings, and new cooling schemes. This, with the conjunction of increase in compressor pressure ratio, has increased the gas turbine thermal efficiency from about 15% to over 45%.

Table 1-1 (Meherwan P. Boyce (2010) *Gas, Turbine Engineering Handbook*, 3rd edition, Gulf Professional Publishing) gives an economic comparison of various generation technologies from the initial cost of such systems to the operating costs of these systems. Because distributed generation is very site specific the cost will vary and the justification of installation of these types of systems will also vary. Sites for distributed generation vary from large metropolitan areas to the slopes of the Himalayan mountain range. The economics of power generation depend on the fuel cost, running efficiencies, maintenance cost, and first cost, in that order. Site selection depends on environmental concerns such as emissions, and noise, fuel availability, and size and weight.

Table 1-1
Economic Comparison of Various Generation Technologies



Technology Comparison	Diesel Engine	Gas Engine	Simple Cycle Gas Turbine	Micro Turbine	Fuel Cell	Solar Energy Photovoltic Cell	Wind	Bio Mass	River Hydro
Product Rollout	Available	Available	Available	Available	1996–2010	Available	Available	2020	Available
Size Range (kW)	20–25,000+	50–7000+	500–450,000+	30–200	50–1000+	1+	10–2500	NA	20–1000+
Efficiency (%)	36–43%	28–42%	21–45%	25–30%	35–54%	NA	45–55%	25–35%	60–70%
Gen Set Cost ($/kW)	125–300	250–600	300–600	350–800	1,500–3,000	NA	NA	NA	NA
Turnkey Cost No-Heat Recovery ($/kW)	200–500	600–1000	300–650	475–900	1,500–3,000	5,000–10,000	700–1300	800–1500	750–1200
Heat Recovery Added Cost ($/kW)	75–100	75–100	150–300	100–250	1,900–3,500	NA	NA	150–300	NA
O & M Cost ($/kWh)	0.007–0.015	0.005–0.012	0.003–0.008	0.006–0.010	0.005–0.010	0.001–0.004	0.007–0.012	0.006–0.011	0.005–0.010

1.2 Problem Statement

Gas turbine speed gives a great impact on the performance of the gas turbine. The steady growth of power demand around the world continues to drive governments, power authorities and independent power providers to look for solutions to meet world energy requirements. To overcome these increasing energy requirements, these organizations must cope with issues of fuel supplies and cost. Using gas turbine as a new power generation plant is a great idea due to the fuel flexibility and low primary investment cost. Gas turbine based generation systems offer efficient energy conversion solutions for meeting the challenge of fuel diversity while maintaining superior environmental performance. Combustion design flexibility allows operators a broad spectrum of gas and liquid fuel choices, including emerging synthetic choices

1.3 Objective of study

To analyze the effect of turbine speed on the gas turbine operation.

1.4 Scope of Study

To achieve the objectives, scopes have been identified in this research. The scopes of this research are listed as below:-

i. To understand the principle of gas turbine used in industry.
ii. To determine the factor most affect gas turbine operation.

1.5 Significance of study

The steady growth of power demand around the world continues to drive power authorities and independent power providers to look for solutions. To provide for these increasing requirements these companies must come out with a new solution. Gas turbine is one of the most effective technologies that being used now a day to provide power supply to the industry. Gas turbine based generation systems offer efficient energy conversion solutions for meeting the challenge of power demand while maintaining superior environmental performance (Steve Rahm, Jeffrey Goldmeer, Michel Molière, Aditya Eranki, Addressing Gas Turbine Fuel Flexibility). Combustion design flexibility allows operators a broad spectrum of gas and liquid fuel choices, including emerging synthetic choices. Gases include and are not limited to ultra-low heating value process gas, syngas, ultra-high hydrogen or higher heating capability fuels.

CHAPTER 2

LITERATURE REVIEW

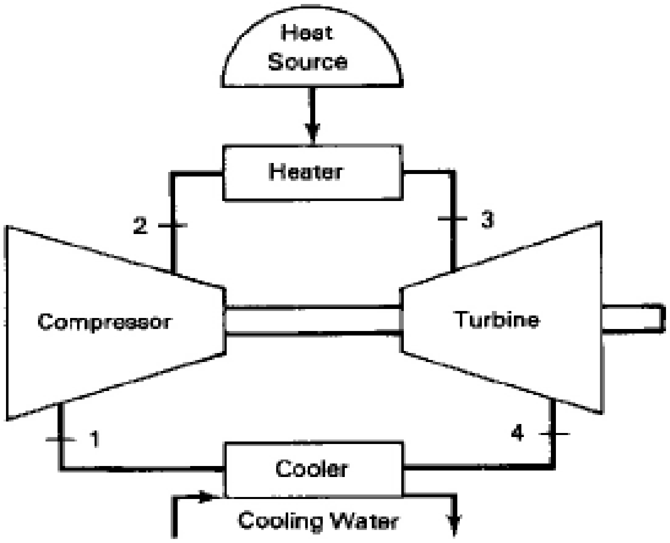
2.1 Gas Turbine

A gas turbine, also called a combustion turbine, is a rotary engine that extracts energy from a flow of combustion gas. It has an upstream compressor coupled to a downstream turbine, and a combustion chamber in-between (Lee S. Langston, George Opdyke, *Introduction to Gas Turbines for Non-Engineers, the Global Gas Turbine News,Volume 37: 1997, No. 2*). Energy is added to the gas stream in the combustor, where air is mixed with fuel and ignited. Combustion increases the temperature, velocity and volume of the gas flow. This is directed through a (nozzle) over the turbine's blades, spinning the turbine and powering the compressor. Energy is extracted in the form of shaft power, compressed air and thrust, in any combination, and used to power aircraft, trains, ships, generators, and even tanks. This machine has a single-stage radial compressor and turbine, a recuperator, and foil bearings.

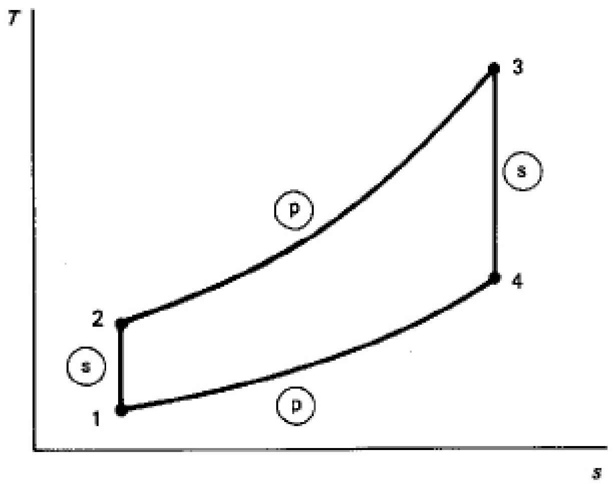
2.1.1 Theory of operation

The fundamental thermodynamic cycle on which gas turbine engines are based is called the Brayton Cycle or Joule cycle. A temperature-entropy diagram for this ideal cycle and its implementation as a closed-cycle gas turbine is shown in Figure 2.1. The cycle consists of an isentropic compression of the gas from state 1 to state 2; a constant pressure heat addition to state 3; an isentropic expansion to state 4, in which work is done; and an isobaric closure of the cycle back to state 1.

As Figure 2.1(a) shows, a compressor is connected to a turbine by a rotating shaft. The shaft transmits the power necessary to drive the compressor and delivers the balance to a power-utilizing load, such as an electrical generator. The turbine is similar in concept and in many features to the steam turbines discusssed earlier, except that it is designed to extract power from a flowing hot gas rather than from water vapor. It is important to recognize at the outset that the term "gas turbine" has a dual usage: It designates both the entire engine and the device that drives the compressor and the load. It should be clear from the context which meaning is intended. The equivalent term combustion turbine. Is also used occasionally, with the same ambiguity.



(a) Flow diagram



(b) Temperature –entropy diagram

Figure 2.1 Closed-cycle gas turbine (a) Flow diagram (b) Temperature-Entropy diagram

Like the simple Rankine-cycle power plant, the gas turbine may be thought of as a device that operates between two pressure levels, as shown in Figure 2.1(b). The compressor raises the pressure and temperature of the incoming gas to the levels of P_2 and T_2. Expansion of the gas through the turbine back to the lower pressure at this point would be useless, because all the work produced in the expansion would be required to drive the compressor.

Instead, it is necessary to add heat and thus raise the temperature of the gas before expanding it in the turbine. This is achieved in the heater by heat transfer from an external source that raises the gas temperature to T_3, the turbine inlet temperature. Expansion of the hot gas through the turbine then delivers work in excess of that needed to drive the compressor. The turbine work exceeds the compressor requirement because the enthalpy differences, and hence the temperature differences, along isentropes connecting lines of constant pressure increase with increasing entropy (and temperature), as the figure suggests.

The difference between the turbine work, Wt, and the magnitude of the compressor work, |Wc|, is the net work of the cycle. The net work delivered at the output shaft may be used to drive an electric generator, to power a process compressor, turn an airplane propeller, or to provide mechanical power for some other useful activity.

In the closed-cycle gas turbine, the heater is a furnace in which combustion gases or a nuclear source transfer heat to the working fluid through thermally conducting tubes. It is sometimes useful to distinguish between internal and external combustion engines by whether combustion occurs in the working fluid or in an area separate from the working fluid, but in thermal contact with it. The combustion-heated, closed-cycle gas turbine is an example, like the steam power plant, of an external combustion engine. This is in contrast to internal combustion engines, such as automotive engines, in which combustion takes place in the working fluid confined between a cylinder and a piston, and in open-cycle gas turbines.

2.1.1.1 Brayton cycle

As with all cyclic heat engines, higher combustion temperature means greater efficiency. The limiting factor is the ability of the steel, nickel, ceramic, or other materials that make up the engine to withstand heat and pressure. Considerable engineering goes into keeping the turbine parts cool. Most turbines also try to recover exhaust heat, which otherwise is wasted energy. Recuperators are heat exchangers that pass exhaust heat to the compressed air, prior to combustion. Combined cycle designs pass waste heat to steam turbine systems. And combined heat and power (co-generation) uses waste heat for hot water production.

Mechanically, gas turbines can be considerably less complex than internal combustion piston engines. Simple turbines might have one moving part: the shaft/compressor/turbine/alternative-rotor assembly, not counting the fuel system.

More sophisticated turbines may have multiple shafts (spools), hundreds of turbine blades, movable stator blades, and a vast system of complex piping, combustors and heat exchangers.

As a general rule, the smaller the engine the higher the rotation rate of the shaft(s) needs to be to maintain tip speed. Turbine blade tip speed determines the maximum pressure that can be gained, independent of the size of the engine. Jet engines operate around 10,000 rpm and micro turbines around 100,000 rpm. Thrust bearings and journal bearings are a critical part of design. Traditionally, they have been hydrodynamic oil bearings, or oil-cooled ball bearings. These bearings are being surpassed by foil bearings, which have been successfully used in micro turbines and auxiliary power units.

2.1.2 Gas Turbine Design Considerations

The gas turbine is the best suited prime mover when the needs at hand such as capital cost, time from planning to completion, maintenance costs, and fuel costs are considered. The gas turbine has the lowest maintenance and capital cost of any major prime mover. It also has the fastest completion time to full operation of any plant. Its disadvantage was its high heat rate but this has been addressed and the new turbines are among the most efficient types of prime movers. The combination of plant cycles further increases the efficiencies to the low 60s.The design of any gas turbine must meet essential criteria based on operational considerations. Chief among these criteria are:

1. High efficiency
2. High reliability and thus high availability

3. Ease of service
4. Ease of installation and commission
5. Conformance with environmental standards
6. Incorporation of auxiliary and control systems, which have a high degree of reliability
7. Flexibility to meet various service and fuel needs

2.1.3 Categories of Gas Turbines

The simple-cycle gas turbine is classified into five broad groups:

1. Frame Type Heavy-Duty Gas Turbines. The frame units are the large power generation units ranging from 3 MW to 480 MW in a simple cycle configuration, with efficiencies ranging from 30–46%.

2. Aircraft-Derivative Gas Turbines Aero-derivative. As the name indicates, these are power generation units, which originated in the aerospace industry as the prime mover of aircraft. These units have been adapted to the electrical generation industry by removing the bypass fans, and adding a power turbine at their exhaust. These units range in power from 2.5 MW to about 50 MW. The efficiencies of these units can range from 35–45%.

3. Industrial Type-Gas Turbines. These vary in range from about 2.5 MW– 15 MW. This type of turbine is used extensively in many petrochemical plants for compressor drive trains. The efficiencies of these units are in the low 30s.

4. Small Gas Turbines. These gas turbines are in the range from about 0.5 MW–2.5 MW. They often have centrifugal compressors and radial inflow turbines. Efficiencies in the simple cycle applications vary from 15–25%.

5. Micro-Turbines. These turbines are in the range from 20 kW–350 kW. The growth of these turbines has been dramatic from the late 1990s, as there is an upsurge in the distributed generation market.

2.2 Fuel

The gas turbine’s major advantage has been its inherent fuel flexibility. Fuel candidates the entire spectrum from gases to solids. Gaseous fuels traditionally include natural gas, process gas, low-Btu coal gas, and vaporized fuel oil gas. “Process gas” is a broad term used to describe gas formed by some industrial process (Meherwan P. Boyce *Gas, Turbine Engineering Handbook*, 3rd edition, Gulf Professional Publishing). Process gases include refinery gas, producer gas, coke oven gas, and blast furnace gas among others. Natural gas is the fuel of choice and is usually the basis on which performance for a gas turbine is compared, since it is a clean fuel fostering longer machine life. Vaporized fuel oil gas behaves very closely to natural gas because it provides high performance with a minimum reduction of component life. About 40% of the turbine power installed operates on liquid fuels. Liquid fuels can vary from light volatile naphtha through kerosene to the heavy viscous residuals.

2.2.1 Liquefied Petroleum Gas (LPG)

Liquefied Petroleum Gas (LPG) is often incorrectly identified as propane. In fact, LPG is a mixture of petroleum and natural gases that exist in a liquid state at ambient temperatures when under moderate pressures (less than 1.5 MPa or 200 psi). The common interchanging of the two terms is explained by the fact that in the U.S. and Canada LPG consists primarily of propane. In many European countries, however, the propane content in LPG can be as low as 50% or less.

The major sources of commercial LPG are natural gas processing and petroleum refining. Raw natural gas often contains excess propane and butanes which must be removed to prevent their condensation in high-pressure pipelines. In petroleum refining, LPG is collected during distillation, from lighter compounds dissolved in the crude oil, as well as generated in the "cracking" of heavy hydrocarbons. Therefore, LPG can be considered a by-product and its exact composition and properties will vary greatly with the source.

LPG provides about 8% more energy per unit weight (LHV = 19,757 BTU/lbm) than gasoline. Theoretically, vehicle operation with LPG should be more efficient than with gasoline, i.e., the vehicle should attain better specific fuel consumption and improved mileage. However, this will only happen if the engine design is optimized for LPG fuel. If a gasoline engine is converted to operate on LPG this increased efficiency will not be realized due to the lower density of LPG compared to gasoline and also its slightly higher oxygen demand (LPG stoichiometric A/F = 15.8). The lighter density fuel displaces air in the intake manifold, and thus, less air per cycle is induced to the cylinders. This translates to a decreased volumetric efficiency and a loss of power compared to the original gasoline rating of the engine.

2.2.2 Fuel Specifications

To decide which fuel to use, a host of factors must be considered. The object is to obtain high efficiency, minimum downtime, and the total economic picture. The following are some fuel requirements that are important in designing a combustion system and any necessary fuel treatment equipment:

1. Heating value
2. Cleanliness
3. Corrosive
4. Deposition and fouling tendencies
5. Availability

The heating of a fuel affects the overall size of the fuel system. Generally, fuel heating is a more important concern in connection with gaseous fuels, since liquid fuels all come from petroleum crude and show narrow heating-value variations. Gaseous fuels, on the other hand, can vary from 1100 Btu/ft3 (41,000 kJ/m3) for natural gas to (11,184 kJ/m3) or below for process gas. The fuel system will of necessity have to be larger for the process gas, since more is required for the same temperature rise.

Cleanliness of the fuel must be monitored if the fuel is naturally “dirty” or can pick up contaminants during transportation. The nature of the contaminants depends on the particular fuel. The definition of cleanliness here concerns particulates that can be strained out and is not concerned with soluble contaminants. These contaminants can cause damage or fouling in the fuel system and result in poor combustion.

Corrosion by the fuel usually occurs in the hot section of the engine, either in the combustor or the turbine blading. Corrosion is related to the amounts of certain heavy metals in the fuel. Fuel corrosivity can be greatly reduced by specific treatments discussed later in this chapter.

Deposition and fouling can occur in the fuel system and in the hot section of the turbine. Deposition rates depend on the amounts of certain compounds contained in the fuel. Some compounds that cause deposits can be removed by fuel treating.

Finally, fuel availability must be considered. If future reserves are unknown, or seasonal variations are expected, dual fuel capability must be considered.

CHAPTER 3

METHODOLOGY

3.1 Materials

The system used in this experiment is ET792 Two-Shaft Gas Turbine Demonstration Unit and liquefied petroleum gas (LPG) will be used as a fuel.

3.2 Procedures

This procedure is divided into three main parts which is general start up procedure, start the experiment and general shut-down procedure as shown in the figure below:.