Theoretical Analysis of Gas Turbine Power Plant

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ABSTRACT
This paper deals with the principles of the types of a gas turbine, its components & types & it also covers the analytical part where we have discussed its industrial uses by looking into the thermal efficiencies with a certain change in the parameters.

Keywords- *Gas Turbine, Analysis, Efficiency, Power plant*

1.1 INTRODUCTION

Gas turbines now-a-days has brought quite revolutionary changes in industrial life. It has become an attractive option to those who want a highly reliable and flexibly operative power generation system in a low budget. A wide variety of fuels like from natural gas to coal can be used to operate it. Based on the material being used in a gas turbine, inlet gas temperature can exceed 1200°C, resulting in overall efficiency to reach 35% which is almost the same as a traditional steam power plant.

As it has a low weight per unit power, so that gas turbine is extensively being used in the aviation system, bus, trucks even in locomotive drives and marines. Even if it is now being employed to drive auxiliaries like compressors, pumps and blowers. This paper, therefore, gives us the idea of theoretical know-how & analysis of gas turbines.

1.2 LITERATURE SURVEY

Types of gas turbines-

Generally, it complies of two types, are as follows,

1. Open Cycle (internal type)
2. Closed Cycle (external type)

In an open cycle generally, the output by-products are released to the atmosphere. Whereas in the closed cycle the working fluid like air, argon, helium are externally heated by burning fuel and then cooled to be operated in a closed cycle. Gas turbine cycle is solely based on the Brayton cycle. So its working principle follows the Brayton cycles.

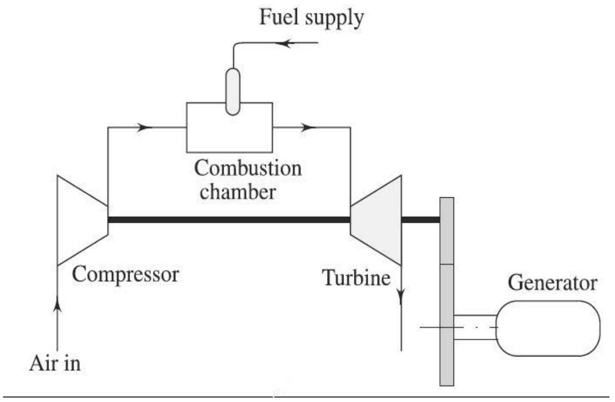

Fig 1.1: *Open Cycle Gas Turbine*

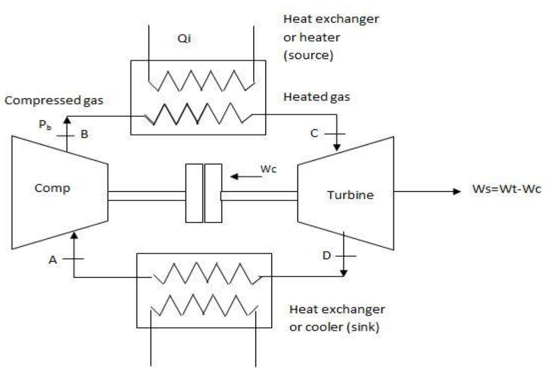

Fig 1.2: *Closed Cycle Gas Turbine*

Advantages-
1. The turbine is started & reaches rated speed, the ignition occurs & the gas turbine accelerates towards full power eliminating the time of warm-up.
2. The gas turbine plant is lightweight which is extremely favorable for all vehicles.
3. Ranges of fuel are available such as High octane gases, heavy diesel oil and pulverized coal.
4. This gas turbine requires less floor space.
5. Gas Turbine plants can be turned on & off quickly.
6. Gas Turbine provides high efficiency.

Disadvantages-
1. The efficiency of the partial load is low.
2. It is sensitive to compressor & turbine efficiencies.
3. Gas turbine efficiency varies with a change in ambient temperature & pressure.
4. Rate of air required is high.
5. High compressor work.
6. High-quality air & gas filters are required to protect turbine blades from corrosion.

1.3 WORKING PRINCIPLES

Components & Working of a Gas Turbine Power Plant-

A typical gas turbine essentially consists of the following components-

1. Compressor
2. Combustion chamber
3. Gas Turbines
4. Blading

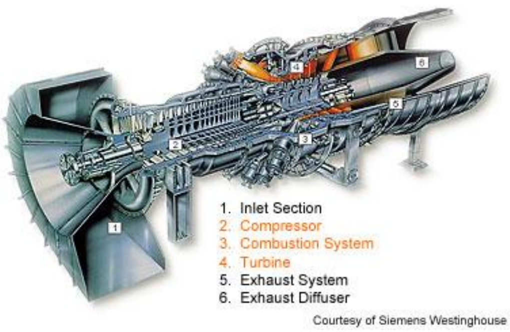

Fig 1.3: *Gas Turbine*

Compressor- A rotary compressor supplies sufficient air at moderate pressure to the turbine. There are two types of compressor used in a gas turbine,

1) Centrifugal compressor
2) Axial flow compressor

In a centrifugal compressor where the air is sucked in the impeller eye and is forced to whirl about at high speed by the vanes on the impeller rotating at high rpm. The pressure of air in the gas turbine increases from the impeller eye to the tip of the impeller. Air leaving the impeller tip flows through diffuser space which converts the kinetic energy into pressure energy and the blade velocity at the outlet is larger, since the radius of the impeller is larger at outlet than the inlet.

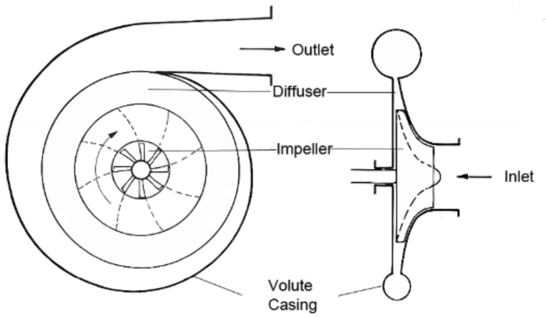

Fig 1.4 *Centrifugal compressor*

In an axial-flow compressor air flows in the axial direction through the fixed and moving blades, through a diffuser which continuously increases the pressure and decreases the velocity. Inside the casing, the stationary guide vanes are provided at the entry to the first slot of moving vanes. The work input to the rotor is then transferred by the moving blades to the air, therefore initiating acceleration. The spaces provided between the blades and the stator blades from diffusing passages decrease the velocity and increase the pressure.

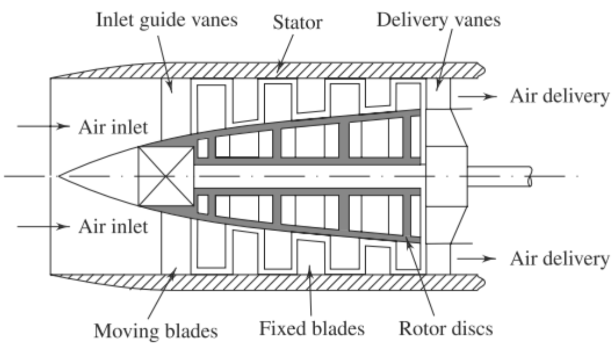

Fig 1.5: *Axial Flow compressor*

Combustion system- Combustion may be arranged to take place in GT plant in one or two large cylindrical can-type combustion chambers with ducting to convey the gases with high temperature to the turbine. Combustion is initiated in the chamber by an electric spark and when the fuel starts burning inside the combustion chamber, the flame needs to be stabilized. A recirculated zone is created inside the main flow to ensure establishment of a stable flame which helps to sustain combustion simultaneously. There are some common methods for flame stabilization like swirl flow stabilization and bluff body stabilization.

There is a term "combustion efficiency" is often used, which defines the efficiency of a combustion chamber are as follows,

$$\text{Combustion efficiency} = \frac{\text{Theoretical fuel-air ratio for actual temperature rise}}{\text{Actual fuel air ratio for actual temperature rise}}$$

The expression for combustion intensity of gas turbine are as follows,

$$\text{Combustion intensity} = \frac{\text{Heat release rate}}{\text{Volume of CC} \times \text{inlet pressure}}$$

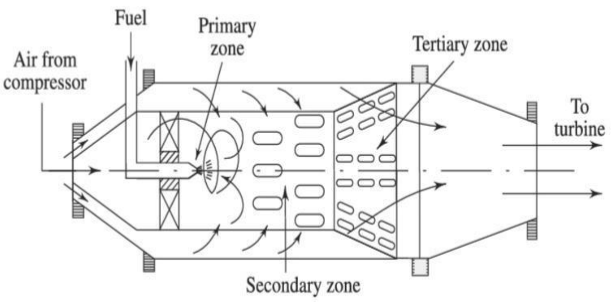

Fig 1.6: *Can-type combustor with swirl flow flame Stabilizer*

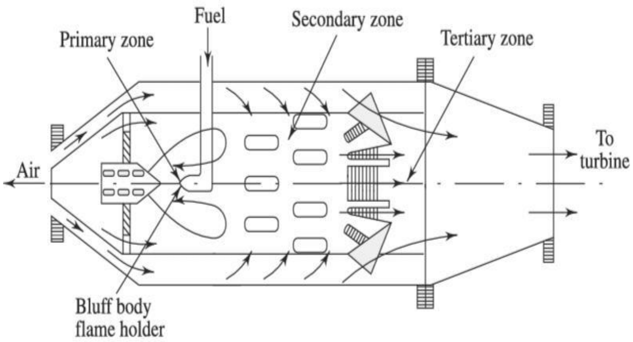

Fig 1.7: *Can type combustor with fluffy body flame Stabilizer*

Gas Turbine - In gas turbines plants, turbines are of the axial-flow type. Some basic requirements for the turbines are high efficiency, light weight, reliable operation and long life. Blades are designed in such a way so that it can withstand high level stress and also large work output can be obtained. Gas turbine consists of more stages because it reduces the stresses in the blades and increases turbine life. As the turbine blades are open to high temperature inlet gases, an efficient cooling system is required for that purpose.

Vortex Blading- These are twisted blades with a motive to decrease losses of fluid flow made by using 3D equations. Vortex blading have some special conditions to be followed like

1) Axial velocity along the blades is constant.
2) Specific work over the annulus is constant.
3) Free vortex at entry to the moving blades is constant.

Analysis of Gas Turbines

The backbone of the gas turbine is the Brayton cycle. The cycle can be divided into four steps, two involving heat transfer Q_1 & Q_2 & two involving work transfer W_1 & W_2. The efficiency is given by-

$$\eta_{\text{cycle}} = 1 - \frac{1}{r_p^{(\gamma-1)/\gamma}} = 1 - \frac{T_1}{T_{4s}} r_p^{(\gamma-1)/\gamma}$$

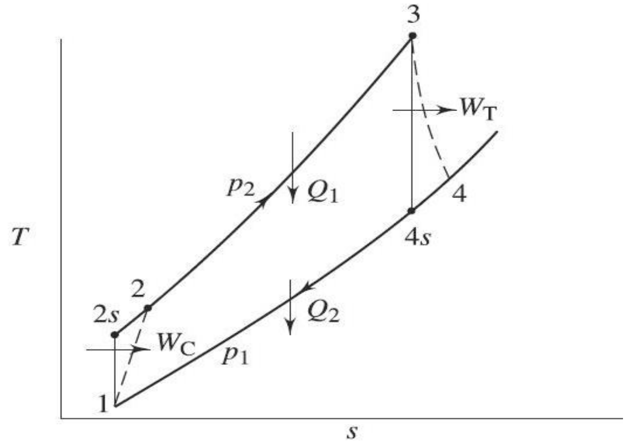

Fig 1.8: *Brayton Cycle*

Regeneration Effect- When the exhaust gas is taken & utilised to heat the air at intake, then this high temperature is somehow utilised. This process is regeneration. The effectiveness is given by-

$$\in \; = \frac{\text{Actual temperature rise of air}}{\text{Maximum temperature rise possible}}$$

□ = $(T_5 - T_2)/(T_4 - T_2)$

Intercooling Effect- With perfect intercooling, the cycle efficiency decreases but by heating air leaving the compressor, it increases recovery of heat from the turbine exit.

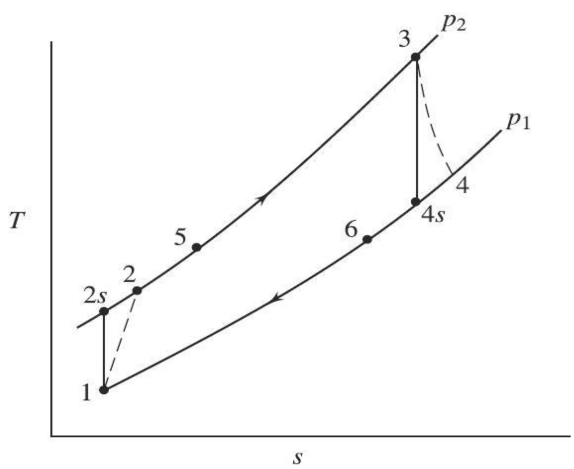

Fig 1.9: *Intercooling Effect on Brayton Cycle*

Reheating Effect- If we use a combustor and a reheater to stage heat supply, the cycle efficiency decreases but it allows more exhaust gas heat recovery.

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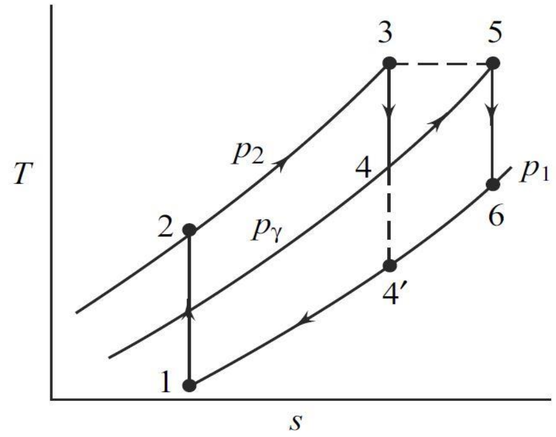

Fig1.10: *Reheating Effect on Brayton Cycle*

Gas turbine power plants performance

The variable parameters dictate the gas turbine efficiency & thus is related to the cost of running the power plant. If the parameters are set to an optimal point, it may reduce the running cost of the plant. ***Part Load Efficiency-*** The part-load efficiency of several cycles are presented in the graph, but the semi-closed cycle efficiency is the highest.

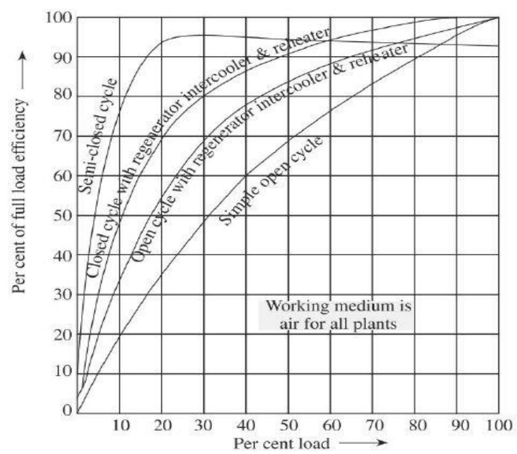

Fig 1.11: *Efficiency (Part Load) of different plants*

Fuel Consumption- For a particular value of regenerator effectiveness, there exists a pressure ratio for which the specific fuel consumption of the gas turbine has a minimum value.

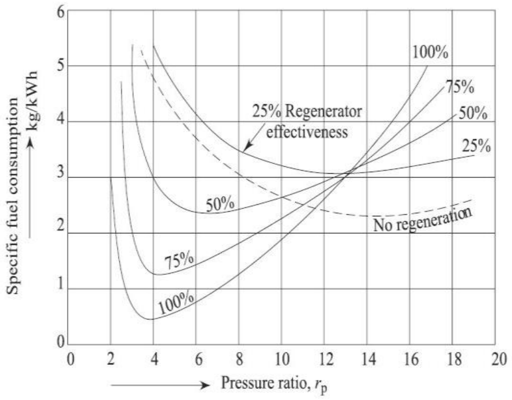

Fig 1.12: *SFC vs. Pressure Ratio (Effect of Regenerative Effectiveness)*

Air Flow Rate- It has been established that minimum air-flow rate (kg/kWh) dictates optimum pressure ratio.

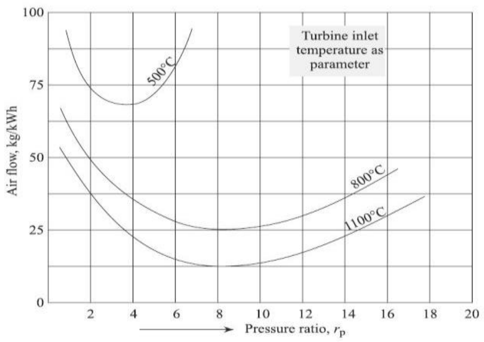

Fig1.13: *Air Flow vs. Pressure Ratio*

Thermal Efficiency- Increase in the turbine inlet temperature helps to increase thermal efficiency for an optimum value of pressure ratio.

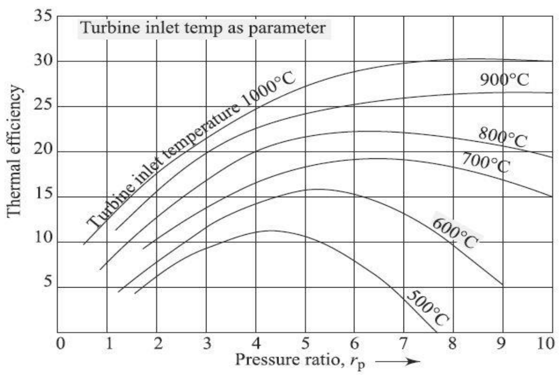

Fig 1.14: *Pressure Ratio effects on Thermal Efficiency of an open cycle power plant with a parameter of Turbine Inlet Temperature*

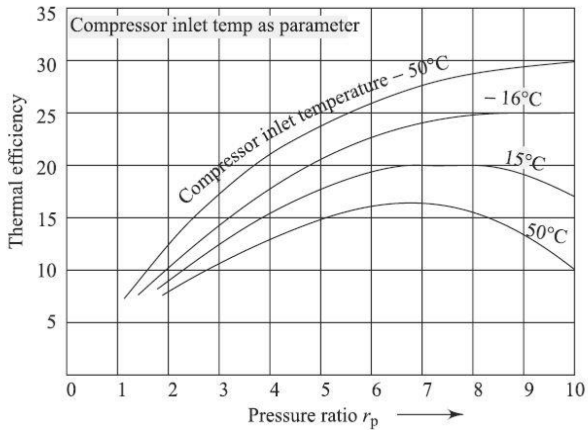

Fig1.15: *Pressure Ratio effects on Thermal Efficiency of an open cycle power plant with a parameter of Compressor Inlet Temperature*

Regeneration- The thermal efficiency of a gas turbine power plant increases with the increase in the percentage of regeneration.

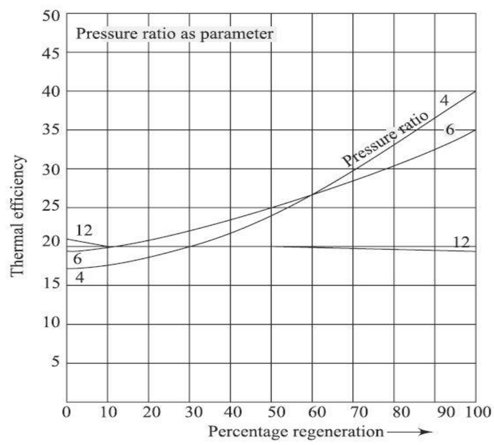

Fig 1.16: *Regeneration effects on Thermal Efficiency of an open cycle power plant with a parameter of Pressure Ratio*

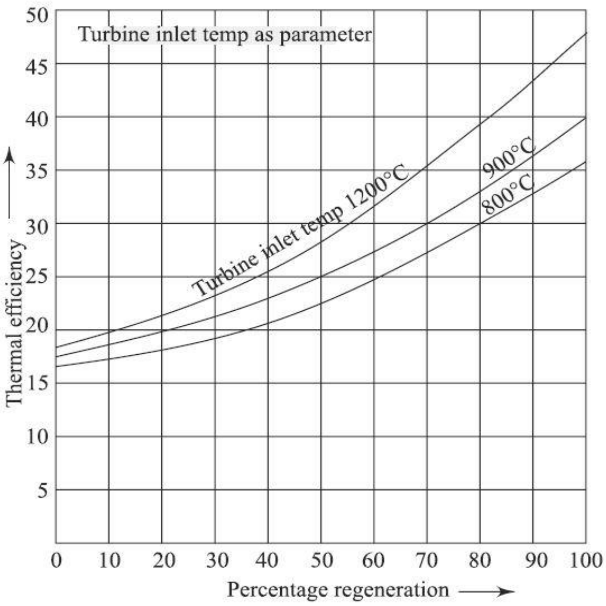

Fig1.17: *Regeneration effects on Thermal Efficiency of an open cycle power plant with a parameter of Turbine Inlet Temperature*

1.4 FUELS

Gas Turbines can work on petroleum fuels, powdered coal, sewage gas etc. So, we should take a look about the types of fuel used-

1. ***Natural Gas***- Large content of methane & smaller percentages of propane, butane & ethane are found.H_2S is less than 0.1 %. Oil field wells are a source of natural gas.
2. ***Liquid Fuel***- These are cheap, which is why it is preferred. But, heat flow arrangements must be made if the oil has high viscosity. Also, when these liquid fuels burn, they can corrode the turbine blades.
3. ***Solid Fuel***- Coal is universally used for closed cycle gas turbines. With the use of proper pollution combat processes this can be used.

1.5 MATERIALS

Parts of a gas turbine power plant undergo a lot of stress & have to tolerate a high temperature. There is no single material which can act everywhere in the components. Thus the materials for-

1. ***Turbine Rotor Disc***- Metal with high conductivity & low expansion coefficient is required to combat the thermal & centrifugal stresses within a turbine rotor disc. Austenite steel (12-14% Cr, 8-12% Ni, Small amounts of T, Mo, Ti),
2. ***Turbine Rotor Blade***- Blades have to endure highest stresses & temperature. They are made of stainless steel alloys & 8-20 Ni-Cr alloys.
3. ***Combustion Chamber***- These are made of Nimonic 75 alloy as they have impressive creep resistance, oxidation resistance & also endures heavy thermal shocks.
4. ***Compressor***- The compressor is exposed to high thermal & centrifugal stress which can be taken care by using Aluminium alloys which are lighter in weight. Titanium alloys provide attractive features to a turbine blade as they are corrosion resistant, lightweight & possess good strength.

1.6 CONCLUSION

This paper touched the aspects of a Gas Turbine Power Plant, its components, working & performance. While theoretically there are certain ways in which we can curtail maintenance cost of a power plant but practically these parameters are challenging to introduce & execute. Thus we would conclude by stating the theoretical analysis of the gas turbine power plant.

1.7 FUTURE SCOPE

From the above theoretical analysis, we can say that Gas Turbine plant have several future scopes as follows,

1) Here if we try to increase the area of the curve, then the efficiency will increase respectively.
2) It is also possible to increase the efficiency of the gas turbine power plant if we increase the turbine inlet gas temperature.

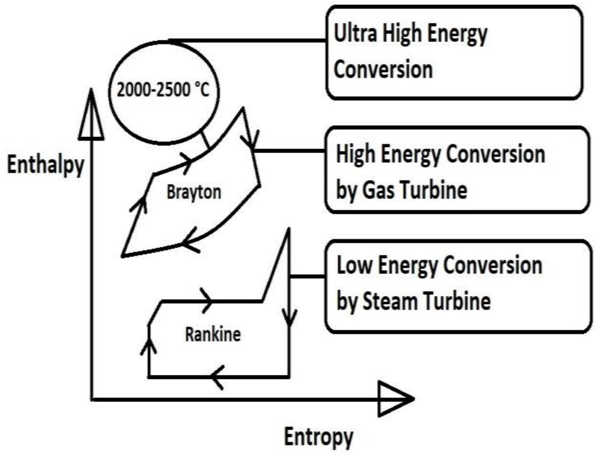

Fig 1.18: *Combinations of Cycle for more power extraction*

1.8 REFERENCE

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