International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 2 Issue 9, September - 2013

Overview of a Gas Turbine and the different methods to improve its Thermal Efficiency

* Gubbala Sesha Saikrishna ** Mallavolu Sai Nithish *** Nekkanti Raviteja
*\&*** *Department of Mechanical Engineering, St. Martins Engineering College, Hyderabad, A.P, India- 500014*
** *Department of Mechanical Engineering, Guru Nanak Institute of Technology, Hyderabad, A.P, India- 501510*

Abstract

The world we are living in today is pushing the technology harder and harder. Which implies the products necessity to get better and better today they also need to be friendlier to the environment. To get better products we need better analysis tools to optimize them and to get closer to the limit what the material can withstand. BHARAT HEAVY ELECTRICALS LIMITED, at which thesis work is made, BHEL is constructing gas turbines. Gas turbines are important in producing power and electricity. Electricity is our most important invention we have and most of the people are just taking electricity for granted. One way to produce electricity is to use a gas turbine which is connected to a generator and by combing the turbine with a steam turbine the efficiency can be up to 60 %.The purpose of this thesis work is to provide the information of different types of industrial gas turbines which are manufactured at BHEL with some details about different turbines for production of electricity in industries with the methods to improve the efficiency of gas turbines.

1. Introduction

A gas turbine is an engine designed to convert the energy of a fuel into some form of useful power such as mechanical power or high - speed thrust of a jet. A Gas turbine basically consists of a gas generator section and a power conversion section.

Gas turbine is also known combustion turbine. It is a type of internal combustion engine. It works under the principle of brayton cycle. It consists of three main sections:

1. Compressor
2. Combustor
3. Power turbine

In the turbines, the air gets pumped in the compressor and is mixed with the fuel and is burned under constant pressure conditions. These use one or more multiple compressors. The fuel injected is gaseous or liquid spray form. The resulting hot gas is allowed to expand through the turbines to perform work. In general the turbine is to extract the energy from the high pressure, high velocity gas flowing from the combustion chamber. In efficient gas turbines 60% of this work is spent on compressing the air. The rest of the work is available for mechanical and electrical generation.

2. Birth of Gas Turbine

A the history of gas turbine all started in 1899 when charles gordon curtis patented the first gas turbine engine in USA and later in 1900 Sanford Alexander Moss submitted a thesis on gas turbines. and later in 1903 a Norwegian, Ægidius Elling built the first gas turbine that was able to produce 11 HP and in 1906 Armengaud-Lemale turbine engine in France with water-cooled combustion chamber and in 1910 Holzwarth impulse turbine (pulse combustion) achieved 150 kilowatts.

3. Description

The process in the gas turbine is as same as a normal si engine. It consists of suction, compression, ignition and exhaust and n gas turbine this process takes place in 3 sections they are

- Compressor Section
- Combustion Section
- Turbine Section

Compressor Section

Compressor is placed in front of the engine or turbine which compresses the outer air and feeds into the combustion chamber through driven shaft passes through centre of the engine it may be of two types centrifugal compressor or axial compressor. The important parts of a Compressor section are Rotor, Stator, Blades, Variable inlet guide vanes and of these stator is further divided into four sections which are

Inlet Casing, Forward Casing, Aft Casing, Discharge Casing.

Combustion section

The fuel is added to compressed air in combustion chamber thereby producing high velocity exhaust gases. A flame tube in the combustor where the fuel is injected is placed down the middle of compressor. It has a set of holes variously sized. Smaller holes in primary zone, where fuel is added for effective burning. There after secondary zone where extra air is injected for complete combustion of fuel. Then the final set of holes provide air for the flue gasses to cool before hitting the turbine. The various parts of Combustion section are Combustion chamber, Spark plugs, Ultra violet flame detector, fuel nozzles, Crossfire Tubes, Transition pieces.

Turbine section

The turbine rotates producing mechanical output as compressor and turbine are mounted on the same rotor shaft at front of the engine. It extracts enough power to turn the compressor and their rest of fuel gasses are left out through exit.

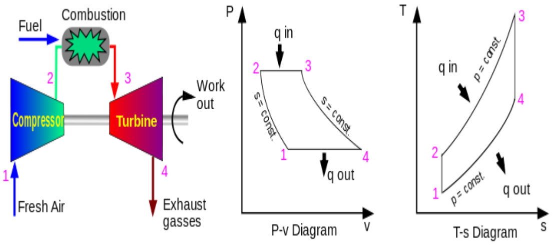
In case of turbine an extra stage of turbine may be added to make more mechanical output over rotor which can be connected to electrical generator for electricity or can be connected to mechanical machinery like propellers of ship.

Other important parts of Gas Turbine:

- Bearings
- Lubrication System
- Couplings.

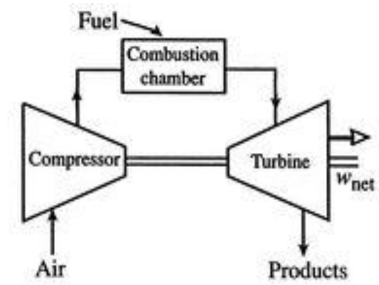
4. Working of a Gas Turbine

Gas Turbines work on the basis of Brayton Cycle, where in the air is compressed isentropically followed by Combustion Process under constant pressure condition, then expansion occurs isentropically and back to the initial condition.

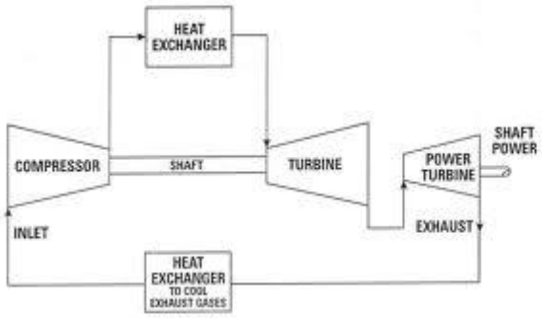


a) Isentropic Process: Here the air is drawn into the compressor, where it is pressurized.
b) Isobaric Process: The compressed air then enters into the combustion chamber, where fuel is burned, heating that air at a constant-pressure process, since the chamber is open to flow in and out.
c) Isentropic Process: The heated, pressurized air then gives up its energy, expanding through a turbine. Some of the work extracted by the turbine is used to drive the compressor.
d) Isobaric Process: Exhaust.

The arrangement of the Gas Turbine is of two types they are i) Open cycle & ii) Closed cycle. Among these two usage of Open cycle is more common. In the open cycle arrangement outside air is drawn into the system continuously and the energy is added by the combustion of the fuel in the working fluid. The resultant of combustion are expanded throughout the turbine and exits.



In closed cycle arrangement, the same combustion gas, is repeatedly circulated throughout the turbine and the required energy is added by the external heater or gas boiler for the burning of the fuel.



5. Overview of Industrial Gas Turbine

GAS TURBINE MODELS FROM - BHEL HYDERABAD

Model	ISO RATING OUTPUT (KW)	ISO RATING HEAT RATE (Kcal/Kwhr)	WEIGHT TONS
MS3002J	10450	3357	69
MS5001PA	26300	3022	84
MS6001B	39620	2699	91
MS6001FA	70140	2515	110
MS9001E	123400	2545	220

TECHNICAL DETAILS OF FRAMES OF A GAS TURBINE

Description	Frame 1	Frame 3	Frame 5	Frame 6
MW Rating	4.77	10.88	25.25	38.49
Speed	102.9	6500	5105	5105
Efficiency	26	26.4	27.7	36.3
Turbine Inlet Temp ˚C	943.3	943.3	943.3	1104
Turbine Exhaust Temp ˚C	535	526.7	493	543
No. of shafts	2	2	1	1
No. of combustors	1	6	10	10
No. of compression stages	15	15	17	17
No. of Turbine Stages	1+1	1+1	2	3
No. of journal Bearings	4	4	2	2
Weight of packed Unit (Tonnes)	30.4	51.26	83.2	89.9
Weight Flange to Flange	12.1	21.64	29.5	31.8

DISCRIPTION ABOUT THE GAS TURBINES:

MODEL MS3002J (FR 3):

MS3002J is a two shaft machine along with simple cycle operation or regenerative cycle variants. This gas turbine is ideally suited as a prime mover for mechanical drives or for captive power generation. Suitable gear box if required is provided between gas turbine and driven equipment. These gas turbines are compact and hence suitable for transportation to inaccessible areas. BHEL's experience includes supplies to industries and utility for mechanical drive application as well as captive power generation.

The main features of the gas turbine are:

- 15 Stage axial compressor
- Reverse flow type, laterally mounted 6 number of combustion chambers
- Single stage LP & HP turbines
- Variety of starting means like motor, diesel engine
- All major accessories are shaft driven with redundant systems on base
- Second stage variable angle nozzles

- Widely used as mechanical drive for gas/oil transportation/other applications
-

MODEL MS5001PA (FR 5):

This single shaft Heavy Duty Gas turbine, has earned the name as Industry's workhorse and is ideal for base/peak load power generation and cogeneration /combined cycle operations. It is also used as prime mover for mechanical drive applications.

The main features of the Gas turbines are :

- 17 Stage Axial compressor and 2 Stage turbine
- Combustion system consisting of 10 number of reverse flow combustion chambers.
- Provision of modulating inlet guide vanes for decreasing the air flow, independent of unit speed to provide for higher efficiency over a wide load range.
- Long shank buckets designed to isolate turbine wheel rim from Hot gas path. Fist stage buckets with Vacuum plasma spray (VPS) coating
- Long diffuser, turning vanes and generous casing /plenum dimensions to maximize recovery of last stage residual kinetic energy.

BHEL can provide suitable two shaft machines for mechanical drive applications.

MODEL MS6001B (FR 6):

This is one of the most popular 30-40 MW range single shaft gas turbine with traditional features of fuel flexibility, efficiency, compactness and ease of operation & maintenance. Ideally suited for captive generation, cogeneration and combined cycle applications.

Some of the features of the Gas Turbine are:

- 17 Stage axial compressor and 3 Stage Turbine.
- Combustion system consisting of 10 number of reverse flow combustion chambers (Slot cooled).
- First stage VPS coated buckets
- Air cooled first and second stage nozzle segments, precision cast from corrosion resistant super alloys.
- Three stage disc type Turbine with first two stages cooled with compressor discharge and extraction air.
- Modulating inlet guide vanes for higher efficiency over a wide load range in combined cycle/ cogeneration applications.
- Rugged two bearing construction.

BHEL can provide single base as well as split base designs.

MODEL MS6001FA (FR 6 FA)

This model combines the features of Aircraft engines with the heavy duty models without compromising on the reliability / availability aspects. The development of this model takes into consideration the long term IGCC requirement and hence is capable of supplying 20% compressor discharge air for gasification.

Major new generation features ('F' technology) in this model are :

- Directionally solidified first stage buckets with serpentine cooling (to support higher firing temperature)
- Axial exhaust diffuser for optimum performance in heat recovery applications
- Honey comb shroud/diaphragm seals
- Two bearing design

Salient constructional features of the 6FA machine are :

- 18 Stage Axial compressor and 3 stage turbine
- Modulating IGVs for compressor inlet flow variation
- Inlet stage air extraction for cooling, sealing and surge control during startup
- Six combustion liners (inner walls with thermal barrier coating)
- Impingement cooling through a perforated shelf for transition pieces
- Accessory systems like lube oil/ gas fuel module, liquid fuel and atomizing air compressor models are independent with their own drives. There is no accessory gear box
- Off-base turbine enclosure to facilitate more space for maintenance (with a host facility inside)

- Axial Exhaust and front end drive for generator
- Starting through motor or static frequency converter

<u>MODEL MS9001E (FR 9)</u>

Designed specially for 50 Hz operation, the MS9001E has provided to be a workhorse in the global power industry. The design characterizes all well proven and rugged features of across the line BHEL-GE Gas Turbines including excellent fuel flexibility. Like other BHEL-GE GTs, this model is versatile. Its compact design lends itself to flexibility in plant layout and easy addition of increments of power in phased manner. The 3- bearing design of the rotor system provides a dynamically stable and rugged rotor. Whether in simple cycle or combined cycle application, base load or peaking duty, 9E packages are comprehensively engineered with integrated systems that include controls, auxiliaries, ducts and silencing. They are designed for reliable operation and minimum maintenance.

The major constructional features are:

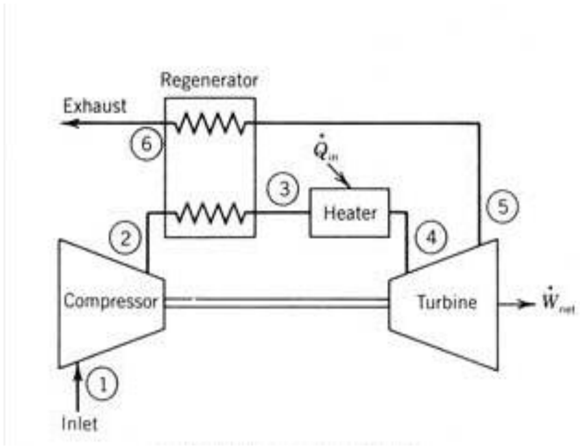
- 17 Stage axial compressor
- Variable inlet guide vanes for optimum efficiency
- Pressure lubricated three bearing system
- Combustion system consisting of 14 number of reverse flow combustors
- 3 Stage turbine, air cooled First stage and Second stage nozzles and buckets
- Factory packed and tested accessory

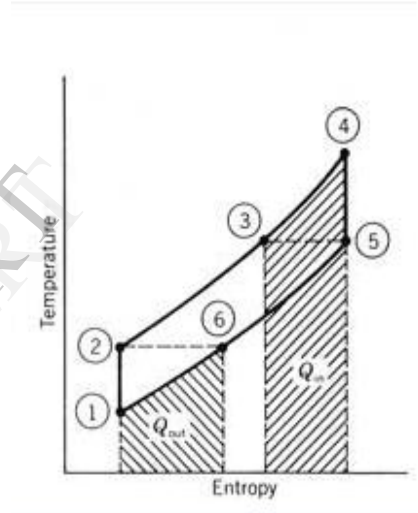
6. Methods to improve Thermal Efficiency:

Increasing the thermal efficiency of a gas turbine involves three types of methods. They are

6.1. Reducing the amount of fuel required:

This method is known as "Regeneration". In this method working fluid is preheated by using exhaust gases of the turbine so the heat supplied is reduced. Thereby reducing the mass of fuel supplied in the combustion chamber. Hence the thermal efficiency can be obtained.





The effectiveness of regenerator,

$$\eta_{th} = \frac{\text{Actual Heat Transfer}}{\text{Ideal Heat Transfer}}$$

$$\text{Effectiveness, } \epsilon = \frac{T_5 - T_2}{T_4 - T_2}$$

$$\epsilon\,(T_4 - T_2) = (T_4 - T_6) = (T_5 - T_2)$$

The energy required from the fuel increase the temperature from T_5 to T_3.

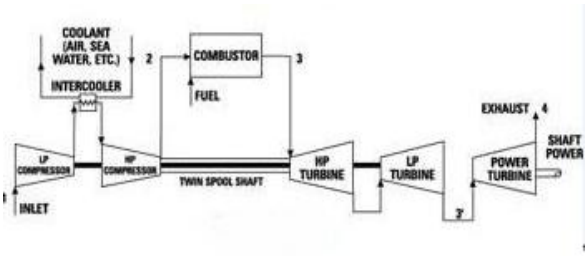
$$= mC_p(T_3 - T_5) \text{ or } (T_3 - T_5)$$

Assuming 'm' and 'C_p' constant.

$$\text{Thermal Efficiency, } \eta_{th} = \frac{(T_3 - T_4) - (T_2 - T_1)}{(T_3 - T_5)}$$

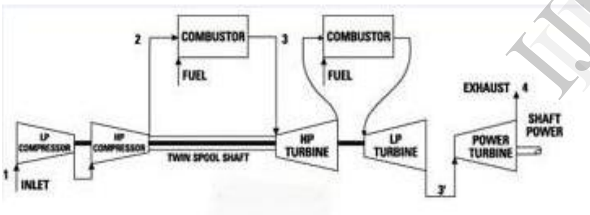
6.2. Reducing compression work needed:

This method is known as 'Inter-cooling'. In this method two to three staged inter-cooling are used by employing multi stages compression with inter-cooling between compression process we can make it approach isothermal compression.



6.3. First expanding the gas in various steps and reheating the gas between the expanders:

This method is also know as 'Reheating'. Here the expansion is carried out in number of steps and reheating of gas is done between the expanders.



Reheating requires extra combustors which obviously increase cost of equipment and also fuel to reheat the gas. But, reheating is properly utilised when it is used in combustion with regeneration and also inter-cooling.

7. Advantages and Disadvantages of Gas Turbine:

7.1. Advantages:

- It has very high power-to-weight ratio, compared to reciprocating engines.
- It is smaller than most reciprocating engines of the same power rating.
- It moves in one direction only, with far less vibration than a reciprocating engine.
- Fewer moving parts than reciprocating engines.
- Low operating pressures.
- High operation speeds.
- Low lubricating oil cost and consumption
- Low lubricating oil cost and consumption

7.2. Disadvantages:

- Cost is much greater than for a similar-sized reciprocating engine since the materials must be stronger and more heat resistant. Machining operations are also more complex;
- Usually less efficient than reciprocating engines, especially at idle.
- Delayed response to changes in power settings.

8. Applications of Gas Turbine

Gas Turbines are used in various fields for various applications such as:

8.1. POWER GENERATION

Higher capacity gas turbines are widely used in power generation and stand by generation.

The grid system: Power is produced and distributed continuously to large distances through a grid systems

Stand by generation: Power is produced for emergency uses in hospitals, public building only for local purpose.

8.2. MECHANICAL DRIVE APPLICATION

- To pump gas and oil through pipeline.
- Instead of engines where power ranger is of range above 6 MW where the scope of diesel engines is almost nil.

- **8.2.1 AUTOMOTIVE APPLICATION**

  - For high speed engines.
  - For gas cars.

- Hybrid electric vehicles. (The gas turbines supply power to recharge batteries of electric motors).
- For racing cars.
- In battle tanks.

- **8.2.2 MARINE APPLICATION**

  - Merchant containers.
  - Submarines.

- **8.2.3 AIR CRAFT APPLICATION**

  - Unmanned vehicle systems.
  - Commercial aircrafts and military trainee.
  - Advanced military fighters.
  - Missiles.

- **8.2.4 CHEMICAL PROCESSING**

  - Process drivers.
  - Petroleum production.
  - Natural gas manufacturing.
  - Plastics manufacturing.
  - Ethylene production

9. Conclusion

From this we just want to conclude how useful can a Gas Turbine be and all the necessary methods to improve its Thermal Efficiency. Also, there is a further necessity to find the methods and reasons to overcome the various flaws that are obtained during the functioning of a Gas Turbine. Due to its outstanding features like low capital cost and capability of quick starting made this machine more and more attractive and a prolific machine.

10. References

[1] P. K. Nag's , "*Power Plant Engineering*", by *the mcgraw-hill companies*

[2] Gas turbine theory 5th edition, by *hih savavanamutto gfc rogers h.cohen* from pearsons Education
.

[3] E. Y. W. Leung's *A Universal Correlation for the Thermal Efficiency of Open Gas Turbine Cycle With Different Fuels.*

[4] M. M. Rahman, Thamir K. Ibrahim, Ahmed N. Abdalla's *Thermodynamic performance analysis of gas-turbine power plant* of *International Journal of the Physical Sciences* Vol. 6(14), pp. 3539-3550, 18 July, 2011

[5] Wadhah Hussein, Abdul Razzaq, Al- Doori's *Parametric Performance of Gas Turbine Power Plant with Effect Intercooler* published in ccsenet's *Vol. 5, No. 3; June 2011.*

[6] O. Sulaima, H. Saharuddin, A.S.A.kader & M.Zamani's *Modeling of Gas Turbine Co-Propulsion Engine to Ecotourism Vessel for Improvement of the Sailing Speed* published in *International Journal of Engineering (IJE), Volume (4): Issue (6).*