9.14 GAS TURBINE

A machine which produces power by utilizing the kinetic energy (obtained by having the burnt gases and air undergone a pressure drop in a nozzle), is known as Gas Turbine.

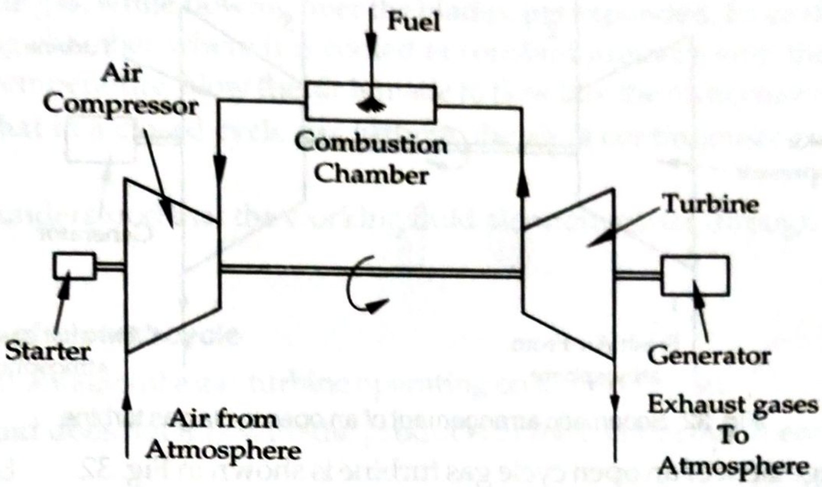

Fig. 31 Gas Turbine

The cycle of operation of this type of turbine is same as the Joule cycle.

As the combustion of this fuel takes place continuously, that is why this type of the turbine is also known as continuous combustion type.

The basic elements of this type of turbine are shown in the Fig. 31. They are:

(i) An air compressor (ii) Combustion chamber
(iii) A turbine

In the gas turbine, air is obtained from the atmosphere and compressed in an air compressor. The compression ratio may be from 4 to 6. In some cases the compression may be up to 18 : 1. The compressed air is then passed into the combustion chamber, where it is heated. The hot air is then made to flow over the moving blades of the gas turbine, which imparts rotational motion to the runner. During this process the air gets expanded and finally it is exhausted into the atmosphere.

A major part of the power developed by the turbine is consumed for driving the compressor which supplies the compressed air to the combustion chamber. The remaining power is utilized for doing some external work.

A electric motor is employed to start the turbine initially and after starting the turbine power is supplied by turbine to air compressor.

Thermal efficiency of gas turbine varies from 25 to 35%.

Fuel used in the gas turbine are *oil, coal gas, natural gas, producer gas, blast furnace gas* and *pulverized coal.*

9.15 TYPES OF GAS TURBINE

The gas turbine cycles refer to the path of the working fluid. Basically there are two types of gas turbine circuits or cycles, namely;

(i) Open cycle gas turbine (ii) Closed cycle gas turbine

9.15.1 Open cycle gas turbine

The cycle of the gas turbine plant, in which the oxygen for the combustion of the fuel is supplied by the air entering form the atmosphere, is known as *open cycle.*

An open cycle gas turbine, in its simplest form, consists of a compressor, combustion chamber and a gas turbine which drives the generator and compressor.

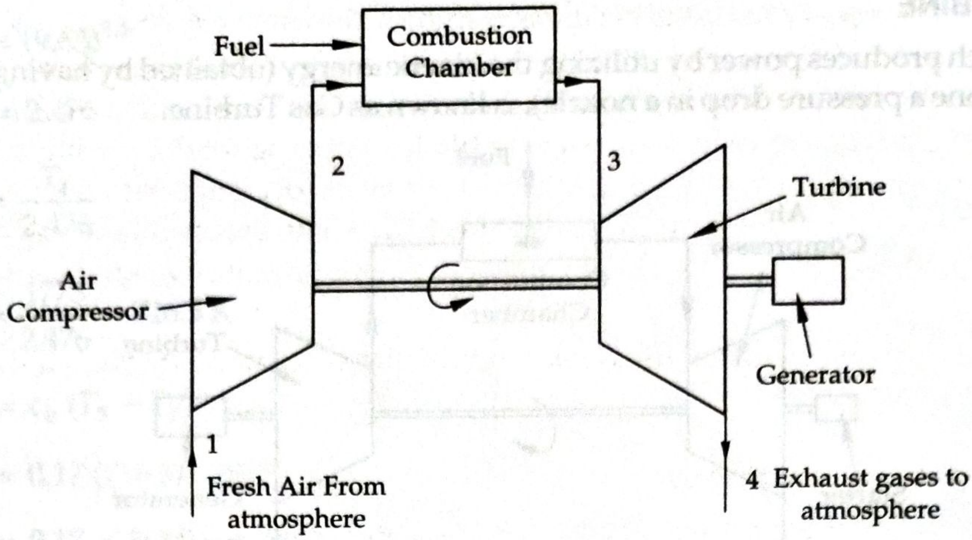

Fig. 32 Schematic arrangement of an open cycle gas turbine

The schematic arrangement of an open cycle gas turbine is shown in Fig. 32.

In this turbine the air is first sucked from the atmosphere and then compressed isentropically or adiabatic (generally in a rotary compressor) and then passed into the combustion chamber. The compressed air is heated by the combustion of fuel and the products of combustion (i.e. hot gases formed by combustion of fuel) also get mixed up with the compressed air, thus increasing the mass of compressed air. The hot gas is then made to flow over the turbine blades. The gas while flowing over the blades, get expanded and finally exhausted into the atmosphere.

An open cycle gas turbine is also called a continuous combustion gas turbine as the combustion of fuel take place continuously. This turbine works on Joule's cycle.

9.15.2 Closed cycle gas turbine

The gas turbine cycle in which the working agent (air) is confined within the plant and receives heat from the external source, is known as *closed cycle gas turbine*.

A closed cycle gas turbine, in its simplest form, consists of a compressor, heating chamber, gas Turbine which drives the generator and compressor, and a cooling chamber.

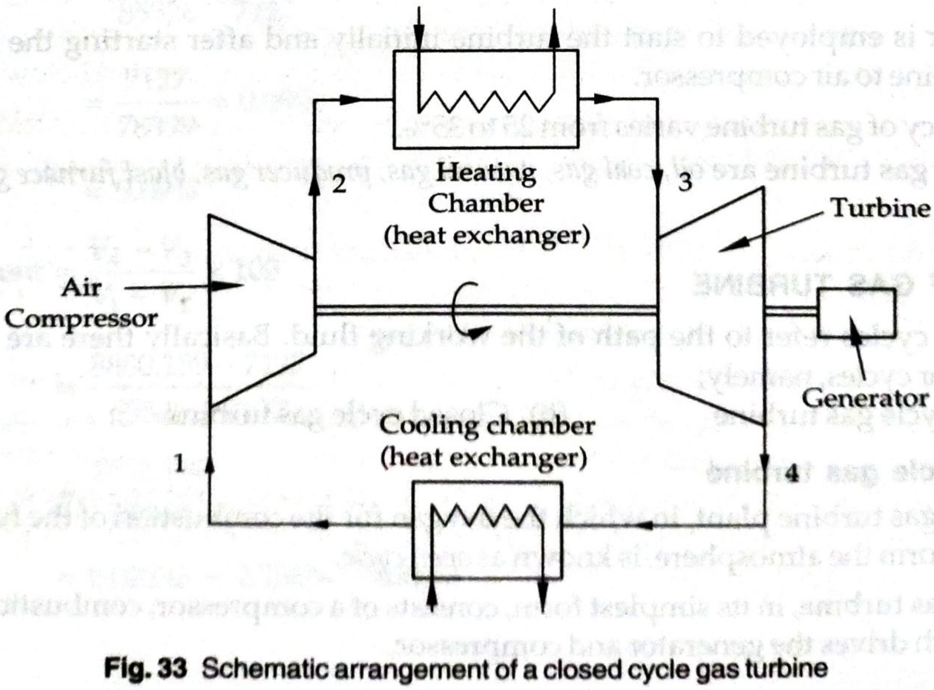

Fig. 33 Schematic arrangement of a closed cycle gas turbine

The schematic arrangement of a closed cycle gas turbine is shown in Fig. 33.

In this turbine, the air is compressed isentropically in compressor and then passed into the heating chamber. The compressed air is heated with the help of some external source, and made to flow over the turbine blade. The gas, while flowing over the blades, get expanded. From the turbine, the gas is passed to the cooling chamber where it is cooled at constant pressure with the help of circulating water to its original temperature. Now the air is made to flow into the compressor again.

It is thus obvious, that in a closed cycle gas turbine, the air is continuously circulated with in the turbine.

It should be clearly understood that the working fluid alone circulates through the compressor and turbine.

9.15.3 Advantages of closed cycle

Following are the advantages of a gas turbine operating on a closed cycle:

1. The working fluid does not mix with the products of the combustion therefore, any type of the fuel may be used.
2. The working pressure in the plant may be kept higher. This will help in reducing the size of the plant for the given output.
3. The higher working pressure in the system improves the heat transfer coefficient. This way smaller cooling or heating surface may be used.
4. No harmful gases etc. can enter into the system as the combustion of the fuel takes place externally.
5. The plant does not require any internal clearing as there is no corrosion or carbon deposit formation in the plant. It is because of the fact that the working fluid remains free from pollution of products of combustion.
6. Any gas whose properties are superior to those of air may be used as a working fluid.
7. The thermal efficiency of the plant is higher.

9.16 APPLICATION OF GAS TURBINES

Gas turbines is a very important power producing machine. It is used in variety of areas. Aviation is an important area where gas turbine are used. Apart from the uses of gas turbine in aviation, the areas like electricity generation industry etc. are the areas where gas turbine finds very useful applications. The various areas of application of gas turbine are enumerated below.

1. **Aviation:** The main advantages of gas turbine are its high power to weight ratio. For a gas turbine plant power is about 140 kW/ton whereas for steam and diesel plants is about 10 and 27 kW/ton respectively.

2. **Central electric generation stations:** Gas turbines are used as base load plants and peak load plants. The quick starting and good response characteristic of the gas turbine plant make the gas turbine as desirable peak load and essential stand by plant.

3. **Use in combined cycle power plant:** In combined cycle heat of exhaust gases in gas turbine are used for power generation using steam as working fluid. The exhaust of gas turbine is at around 450°. Combined cycle recover much of exhaust energy by passing high temperature exhaust gases to heat recovery boiler to generate steam which can be further used to drive a steam turbine. Thus, this concept of combined cycle reduces cost of additional equipment and lowers the generating cost if the number of operating hours per year substantially increased.

9.17 COMPARISON OF GAS TURBINE AND I.C. ENGINE

Following are the points of comparison between the Gas Turbine and I.C. Engine.

Gas Turbine	I.C. Engine
1. Balancing of gas turbine is perfect.	1. The balancing of I.C. engine is not perfect.
2. The pressure used are very low (about 5 bar).	2. The pressure used are high (above 60 bar).
3. The installation and running cost is less.	3. The installation and running cost is more.
4. The running speed of gas turbine is high as having rotary part.	4. The running speed of I.C. engine is low as having reciprocating part.
5. Weight of gas turbine is less for same power output.	5. Weight of I.C. engine is more for same power output.
6. Maintenance cost is less.	6. Maintenance cost is more.
7. The lubrication and ignition system are simple.	7. The lubrication and ignition system are difficult.
8. Its efficiency is higher.	8. Its efficiency is less.
9. Cooling system is simple.	9. Cooling system is complex.
10. The torque produced is uniform. Thus no flywheel is required.	10. The torque produced is not uniform. Thus flywheel is required.
11. The starting of a gas turbine is, not simple.	11. The starting of an I.C. engine is simple.
12. They are very suitable for air crafts.	12. They are less suitable for air crafts.
13. The exhaust of a gas turbine is free from smoke and less polluting.	13. The exhaust of an I.C. engine is more polluting.

9.18 COMPARISON OF GAS TURBINE AND STEAM TURBINE

Following are the points of comparison between Gas Turbine and Steam Turbine.

Gas Turbine	Steam Turbine
1. The main component are compressor and combustion chamber.	1. The main components are steam boiler and accessories.
2. The gas turbine unit is more compact then steam turbine as there is no boiler.	2. The steam turbine is big unit as it have boiler and accessories.
3. It require less space for installation.	3. It require more space for installation.
4. The control of gas turbine is easy.	4. The control of steam turbine is difficult.
5. The starting of gas turbine is very easy and quick.	5. The starting of steam turbine is difficult and takes long time.
6. The installation and running cost is less.	6. The installation and running cost is more.
7. Gas turbine does not depend upon water supply.	7. Steam turbine depends on water supply.

9.19 COMPARISON OF CLOSED CYCLE AND OPEN CYCLE GAS TURBINE

Following are the points of comparison between closed and open cycle gas turbine:

Closed Cycle Gas Turbine	Open Cycle Gas Turbine
1. The compressed air is heated in a heating chamber. Since the gas is heated by an external source, so the amount of gas remains the same.	1. The compressed air is heated in a combustion chamber. The products of combustion get mixed up in the heated air.
2. The gas from the turbine is passed into the cooling chamber.	2. The gas from the turbine is exhausted into the atmosphere.
3. The working fluid is circulated continuously.	3. The working fluid is replaced continuously.
4. Any fluid with better thermodynamic properties can be used.	4. Only air can be used as the working fluid.
5. The turbine blades do not wear away earlier, as the enclosed gas does not get contaminated while flowing through the heating chamber.	5. The turbine blades wear away earlier, as the air from the atmosphere get contaminated while flowing through the combustion chamber.
6. Since the air, from the turbine, is cooled by circulating water, it is best suited for stationary installation or marine uses.	6. Since the air, from the turbine, is discharged into the atmosphere, it is best suited for moving vehicles.
7. Its maintenance cost is high.	7. Its maintenance cost is low.
8. The mass of installation per kW is more.	8. The mass of installation per kW is less.

9.20 CONSTANT PRESSURE GAS TURBINE CYCLE

This gas turbine works on Joule's or Brayton's Cycle.

The $p-V$ and $T-s$ diagram of the Joule's cycle for gas turbine is shown in the Fig. 34.

The cycle consists of two isentropic process and two constant pressure process.

Heat addition is take place at constant pressure process so it is called as constant pressure Gas Turbine Cycle.

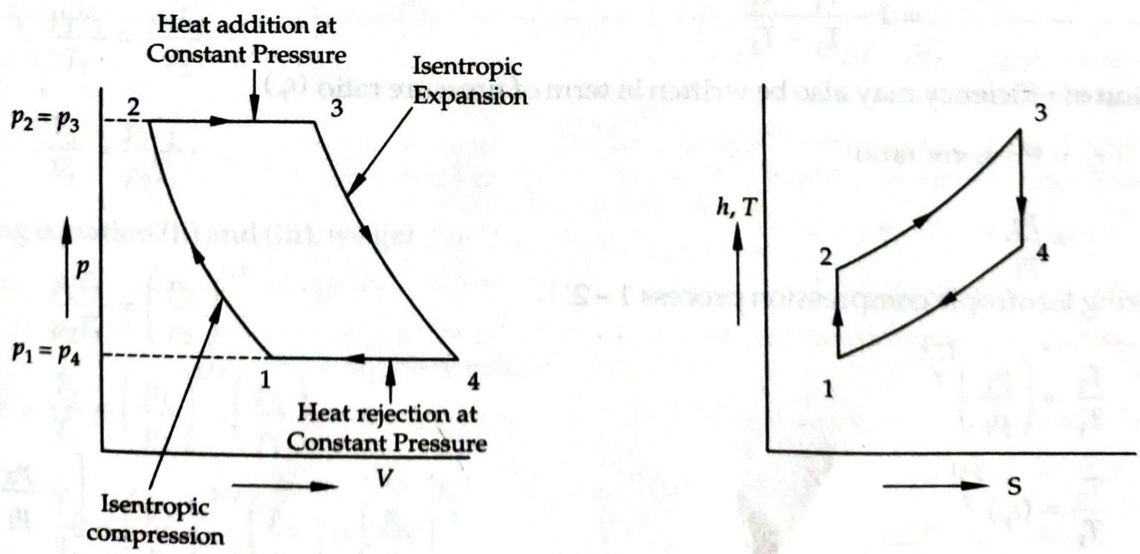

Fig. 34 Constant Pressure Gas Turbine Cycle

Process 1 – 2 is the isentropic compression in the compressor.

Process 2 – 3 is constant pressure heat addition in the combustion chamber.

Process 3 – 4 is isentropic expansion in the turbine.

Process 4 – 1 is constant pressure heat rejection.

Atmospheric air is compressed from p_1 to a high pressure p_2 in the compressor and delivered to the combustion chamber where fuel is injected and burned. The combustion process occurs at constant pressure.

Due to the combustion heat is added to the working fluid from T_2 to T_3. The product of combustion from the combustion chamber are expended in the turbine from p_3 to the atmospheric pressure and then discharge into the atmosphere.

The turbine and compressor are mechanically coupled, so that net work is equal to the difference between the work done by the turbine and work consumed by the compressor. To first, run the compressor a starter is needed when the turbine start running the starter is cut-off.

Let c_p = Specific heat of air at constant pressure.

Considering 1 kg of air

$$\text{Heat supplied} = h_3 - h_2 = c_p (T_3 - T_2)$$

$$\text{Heat rejected} = h_4 - h_1 = c_p (T_4 - T_1)$$

$$\text{Net work} = \text{Heat supplied} - \text{Heat rejected} = c_p (T_3 - T_2) - c_p (T_4 - T_1)$$

$$\text{Efficiency, } \eta = \frac{\text{Net work}}{\text{Heat supplied}} = \frac{c_p (T_3 - T_2) - c_p (T_4 - T_1)}{c_p (T_3 - T_2)}$$

$$= 1 - \frac{T_4 - T_1}{T_3 - T_2} \quad \text{...(i)}$$

Expression of efficiency may also be written in term of pressure ratio (r_p)

Let r_p = Pressure ratio

$$= \frac{p_2}{p_1}$$

Considering isentropic compression process 1 – 2.

$$\frac{T_2}{T_1} = \left(\frac{p_2}{p_1}\right)^{\frac{\gamma-1}{\gamma}}$$

$$\frac{T_2}{T_1} = (r_p)^{\frac{\gamma-1}{\gamma}} \qquad \left[\because \frac{p_2}{p_1} = r_p\right]$$

$$T_2 = T_1(r_p)^{\frac{\gamma-1}{\gamma}} \qquad \text{... (ii)}$$

Similarly considering the isentropic compression process 3 – 4.

$$\frac{T_3}{T_4} = \left(\frac{p_3}{p_4}\right)^{\frac{\gamma-1}{\gamma}} = \left(\frac{p_2}{p_1}\right)^{\frac{\gamma-1}{\gamma}}$$

$$= (r_p)^{\frac{\gamma-1}{\gamma}} \qquad \left[\because \begin{array}{l} p_3 = p_2 \\ p_4 = p_1 \end{array}\right]$$

$$T_3 = T_4\,(r_p)^{\frac{\gamma-1}{\gamma}} \qquad \text{... (iii)}$$

Putting the values of T_2 and T_3 from equation (ii) and (iii) in equation (i),

We get

$$\eta = 1 - \frac{T_4 - T_1}{T_4\,(r_p)^{\frac{\gamma-1}{\gamma}} - T_1\,(r_p)^{\frac{\gamma-1}{\gamma}}}$$

For Ref.

We know that

$$p_1 V_1^{\gamma} = p_2 V_2^{\gamma} \qquad [\because pV^{\gamma} = C]$$

$$\left(\frac{V_2}{V_1}\right)^{\gamma} = \left(\frac{p_1}{p_2}\right)$$

$$\frac{V_2}{V_1} = \left(\frac{p_1}{p_2}\right)^{1/\gamma} \qquad \text{... (i)}$$

We know that gas law,

$$\frac{p_1 V_1}{T_1} = \frac{p_2 V_2}{T_2}$$

$$\frac{V_2}{V_1} = \frac{p_1 T_2}{p_2 T_1} \qquad \text{... (ii)}$$

Equating equation (ii) and (iii), we get

$$\frac{p_1 T_2}{p_2 T_1} = \left(\frac{p_1}{p_2}\right)^{1/\gamma}$$

$$\frac{T_2}{T_1} = \left(\frac{p_1}{p_2}\right)^{1/\gamma}\left(\frac{p_2}{p_1}\right)$$

$$\frac{T_2}{T_1} = \left(\frac{p_2}{p_1}\right)^{-1/\gamma}\left(\frac{p_2}{p_1}\right) = \left(\frac{p_2}{p_1}\right)^{\frac{\gamma-1}{\gamma}}$$

$$\eta = 1 - \frac{T_4 - T_1}{(r_p)^{\frac{\gamma-1}{\gamma}} (T_4 - T_1)}$$

$$\eta = 1 - \frac{1}{(r_p)^{\frac{\gamma-1}{\gamma}}}$$

So efficiency, $\eta = 1 - \dfrac{1}{(r_p)^{\frac{\gamma-1}{\gamma}}}$

Assumption made

Following assumptions were made to derive the expression for the efficiency of gas turbine.

1. The compression and expansion processes are as isentropic.
2. The specific heat of the working fluid remains constant throughout the cycle.
3. The pressure losses in the cycle are neglected
4. The heat losses due to various factors are neglected.
5. The kinetic energy of the working fluid, while entering the compressor and leaving the turbine is equal.

HIGHLIGHTS

- The engine which converts the heat energy into the mechanical energy is known as heat engine.
- The engine in which the combustion of fuel takes place outside the cylinder is known as external combustion engine (E. C. engine).
- The engine in which the combustion of fuel takes place inside the cylinder is known as internal combustion engine (I.C. engine).
- The ratio of the total cylinder volume to the clearance volume is known as compression ratio.
- The engine which require four stroke of piston or two revolutions of the crankshafts to complete the cycle is known as four stroke engine.
- Four strokes are:
  1. Function 2. Compression 3. Expansion or working 4. Exhaust
- The engine which require two stroke of piston or one revolution of the crankshaft to complete the cycle is known as two stroke engine.
- The engine which require four stroke of piston or two revolution of the crankshaft to complete the cycle is known as four stroke engine.
- Petrol engine is based on otto cycle.
- Diesel engine is based on diesel cycle.
- Otto cycle is known as constant volume cycle.
- Diesel cycle is known as constant pressure cycle.
- Air standard efficiency of otto cycle

$$\eta_{Otto} = 1 - \frac{1}{r^{\gamma-1}}$$

- Air standard efficiency of diesel cycle

$$\eta_{Diesel} = 1 - \frac{r_c^{\gamma} - 1}{\gamma r^{\gamma-1}(r_c - 1)}$$