Chapter 6

STEAM TURBINES AND STEAM CONDENSERS

6.1 INTRODUCTION

Steam turbine is a rotodynamic machine in which steam flows freely through an impeller to transfer the energy to the rotor. The change of angular momentum of the fluid causes a torque on the rotor.

A steam condenser is a closed vessel in which steam is condensed and heat released by steam is absorbed by water. The steam entering the condenser leaves it as a condensate and the temperature of cooling water passing through the condenser is higher at exit than at entry.

6.2 DEFINITION, FUNCTION AND USE OF STEAM TURBINE

A turbine may be defined in several ways. Some important definitions are given below :-

- *The turbine is a prime mover in which gradual change in the momentum of a fluid is utilised to produce rotation of the mobile member.* **(Jude)**
- *The turbine is a machine in which a rotary motion is obtained by the gradual change of momentum of fluid.* **(Neilson)**
- *The turbine is a prime mover in which a rotary motion is obtained by centrifugal force brought into action by changing the direction of a jet of a fluid escaping from a nozzle at high velocity.* **(Garham)**

The turbine which uses steam as working substance is called steam turbine.

The function of steam turbine is to convert part of the heat energy in the steam into mechanical work. In other words, turbines are energy transformers in which part of the steam energy is changed into mechanical work by imparting rotary motion to the turbine blade wheels. The steam turbines are mainly used for power generation in thermal plants.

6.3 PARTS OF A STEAM TURBINE

The main parts of a steam turbine are give below :

1. **Rotor :** It carries the blades or buckets. The surface of the blades is made very smooth to minimise the frictional losses. The blades are generally made of special steel alloys.
2. **Stator :** It consists of a casing in which the rotor rotates and nozzles are encased.
3. **Nozzles :** The function of a steam nozzle is to produce a jet of high velocity steam which can be directed on the blades of a turbine.

4. **Casing :** It is an air tight metallic case, which contains the turbine rotor and blades. It controls the movement of steam from the blades to the condenser and does not permit it to move into the space.

6.4 CLASSIFICATION OF STEAM TURBINES

The steam turbines may be classified into the following types :

1. According to the mode of steam action :
   (*i*) Impulse turbine, (*ii*) Reaction turbine,
   (*iii*) Combination of impulse and reaction turbine.
2. According to the direction of flow of steam :
   (*i*) Axial flow turbine, (*ii*) Radial flow turbine,
   (*iii*) Mixed flow turbine.
3. According to the exhaust conditions :
   (*i*) Condensing turbine, (*ii*) Non-condensing turbine.
4. According to the number of stages :
   (*i*) Single stage turbine, (*ii*) Multi stage turbine.
5. According to the steam pressure :
   (*i*) High pressure turbine, (*ii*) Medium pressure turbine,
   (*iii*) Low pressure turbine.

6.5 ADVANTAGES OF STEAM TURBINES OVER RECIPROCATING STEAM ENGINES

Following are some of the important advantages of a steam turbine over a reciprocating steam engine :

1. It develops higher speed and has greater speed range.
2. Due to the absence of reciprocating parts, it can be balanced perfectly and so has no vibration.
3. The efficiency of a steam turbine is higher.
4. It has much less frictional losses.
5. It is much safer because all its moving parts are enclosed in a casing.
6. It requires very little lubrication due to the absence of rubbing parts.
7. It develops power at a uniform rate, thus requiring no flywheel.
8. The steam consumption is less.

6.6 DESCRIPTION OF COMMON TYPES OF TURBINES

The common types of steam turbines are :

1. Impulse turbine,
2. Reaction turbine.

The main difference between these two turbines lies in the way of expansion of the steam while it moves through these. In case of impulse turbine, the steam expands in the nozzle and its pressure does not change as it moves over the blades. In case of reaction turbine, the steam expands continuously as it passes over the blades and thus there is a gradual fall in the pressure during expansion below the atmospheric pressure.

1. Impulse Turbine : *The turbine which takes a high pressure and high enthalpy steam, expands it in fixed nozzles and then uses the rate of change of angular momentum of the fluid in a rotating passage(i.e. impeller) to provide the torque to the rotor, is called an impulse turbine.* The simple impulse turbine is called **De Laval turbine**, since it was invented by Dr. Gust of De Laval and patented by him in 1888. The first turbine of 11 kW was developed in 1892. This turbine ran at 16000 r.p.m. with output shaft speed of 330 r.p.m. using double reduction in double helical gears.

The impulse turbine has two principle characteristics :

1. It requires nozzles so that the pressure drop of steam takes place in the nozzles. The steam enters the turbine with a high velocity. The pressure in the turbine remains constant because whole of the pressure drop takes place in the nozzles.
2. The velocity of the steam is reduced as some of the kinetic energy in the steam is used in producing work on the turbine shaft.

Construction : The main parts of the impulse turbine include a rotor, nozzles, blades and casing. The casing forms the outer cover of the turbine and the nozzles are fixed in it. The moving blades are fixed on the rotating element, known as rotor. The rotor is coupled with the shaft of the turbine from which the useful torque is obtained.

Working : In these turbines, the steam is supplied through a set of convergent-divergent nozzles. The steam expands completely in the nozzles and leaves with a high velocity. The absolute velocity of steam is increased at the cost of pressure in these nozzles. Now, the pressure remains constant in the moving blades of the turbine and the velocity of steam is reduced as some of the kinetic energy in steam is used in producing work on the turbine shaft. It rotates the turbine at a very high speed of about (18000 – 25000) r.p.m.. This high speed of rotation restricts the size of the turbine disc for mechanical reasons such as centrifugal force. Due to this high speed of rotation, a direct drive between the turbine disc and external equipment is not possible. The speed of these turbines may be reduced by three techniques :

(*i*) Velocity compounding,

(*ii*) Pressure compounding,

(*iii*) Pressure velocity compounding.

It can be observed from Fig. 6.1 that complete expansion of steam from the steam chest pressure to the exhaust or condenser pressure takes place in only one set of nozzles. The pressure in the recess between nozzles and blades remains the same. The steam at condenser pressure enters the blades and comes out at the same pressure. The velocity of steam continuously decreases in moving blades, but does not come to zero value. The velocity of steam at exit results in an energy loss called carry over loss or leaving velocity loss.

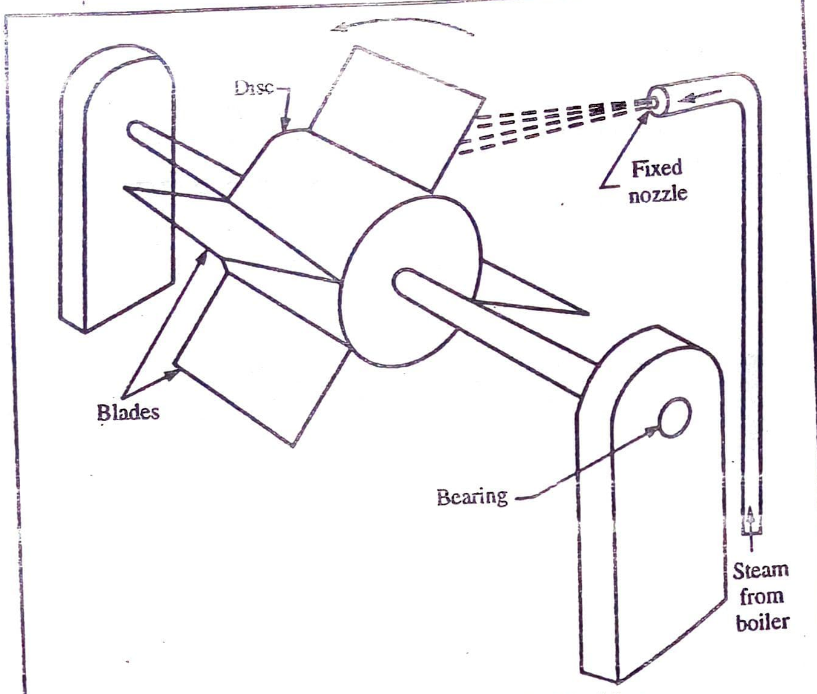


Fig. 6.1. (*a*) Principle of Impulse Turbine.

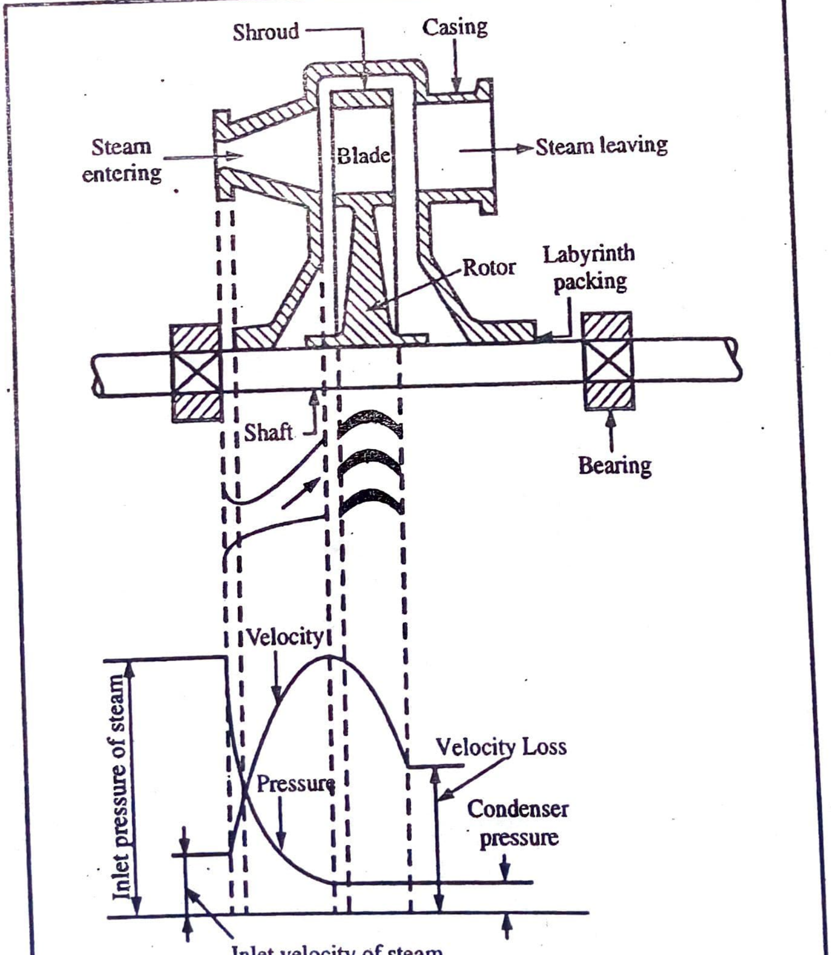


Fig. 6.1 (*b*) Diagramatic Arrangement of a Simple Impulse Turbine.

2. **Reaction Turbines :** *A turbine in which the steam pressure decreases gradually while expanding through the moving blades as well as while passing through the fixed blades or nozzles is called a reaction turbine.* The reaction turbine has different constructional features from that of the impulse turbine.

Construction : It consists of rows of moving blades mounted on a drum. These moving blades are separated by rows of fixed blades mounted in the casing. Unlike impulse turbine, the reaction turbine has following features :

1. The reaction turbine has no nozzle as such, but the fixed blades act as nozzles, in which the velocity of steam is increased and is also directed correctly on the moving blades.
2. Steam also expands in moving blades, so pressure drops and velocity increases. It gives an extra reaction and a continuous pressure drop through the turbine.
3. The steam in these turbines enters the whole blade annulus. This condition is called full admission.
4. The diameter of the rotor and casing gradually increases to allow the increasing volume of the steam as the pressure falls gradually.

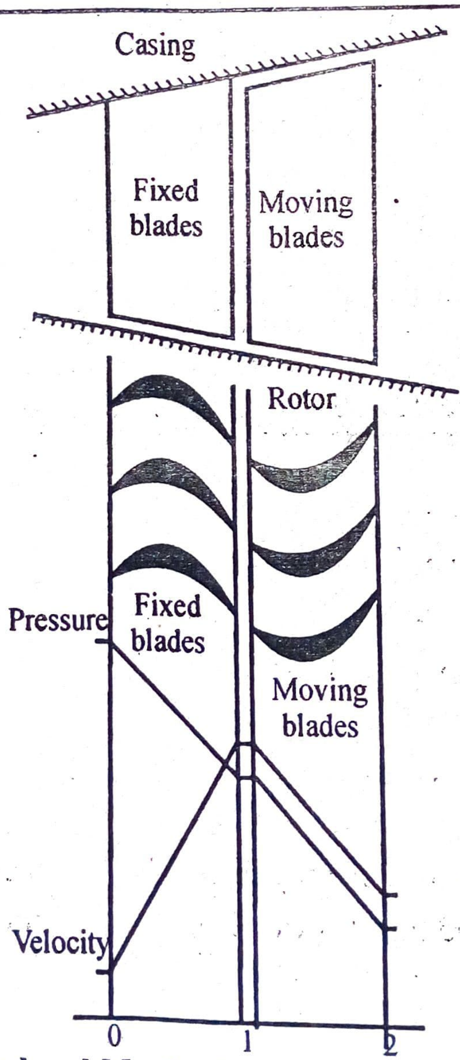


Fig. 6.2. Fixed and Moving Blades of a Reaction Turbine.

Working : The reaction turbine has different construction details, so the working of this turbine is also different. The steam in the reaction turbine enters the whole blade annulus. This condition is called full admission. The steam not only expands in fixed blades, but also in the moving blades with consequent drop in pressure and increase in velocity. This expansion in the moving blades gives an extra reaction to the moving blades beyond that obtainable in an impulse turbine, other conditions remaining same.

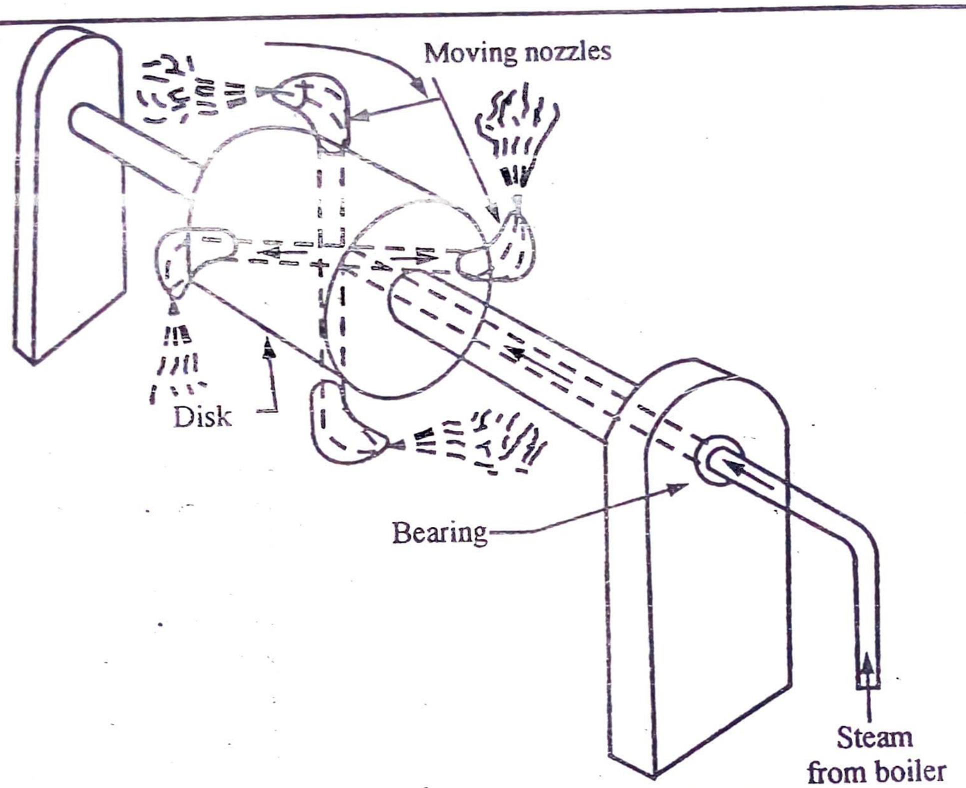


Fig. 6.3. Principle of Reaction Turbine.

The path of the steam in a reaction turbine is divided into stages *i.e.* into a row of fixed blades followed by a row of moving blades. The steam acceleration usually occurs both in rows of fixed blades and rows of moving blades due to nozzle shaped blades. The enthalpy drop in the steam during its passage through blades causes acceleration. If all the enthalpy drop occurs in moving blades, the turbine will have 100% reaction.

As the steam volume becomes very large in low pressure section of the turbine, the low pressure section is made double flow. In this case the steam enters at the centre of the section and divides to flow in opposite directions along the shaft axis. This method also helps to balance end thrusts on the turbine shaft. The end thrust is caused by the pressure difference across the reaction turbine blading.

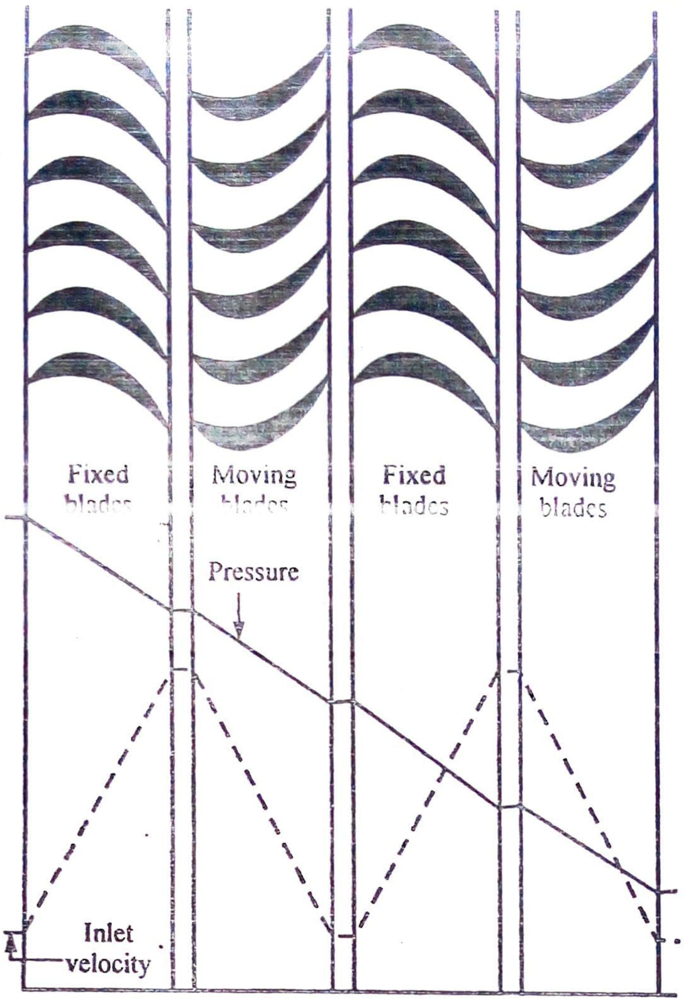


Fig. 6.4. Reaction Turbine.

6.7 COMPOUNDING OF STEAM TURBINES

In case of Impulse turbines, the speed of rotation of turbine shaft is very high and it cannot be coupled directly to an external equipment. *Compounding is a method for reducing the rotational speed of the impulse turbine to practical limits.* This is done by making use of more than one set of nozzles, blades, rotors in different configurations as per requirement. It helps to absorb the pressure or velocity during the stages in the turbine. There are three methods for compounding of turbines :

1. Velocity Compounding,
2. Pressure Compounding,
3. Pressure-velocity Compounding.

1. Velocity Compounding : In this case, all the expansion of the steam takes place in a single row of nozzles. The high speed steam leaving the nozzles passes on to the first row of moving blades where its velocity is only partially reduced. After leaving the first row of moving blades steam passes into a row of fixed blades which are mounted in the turbine casing. These fixed blades are needed to change the direction of the steam between one set of moving blades and the next. The steam velocity is again reduced partially in the second row of moving blades as some of the kinetic energy in the steam is used in producing work on the turbine shaft. Only a part of the velocity of the steam is used in each row of blades, so it results in a slow turbine.

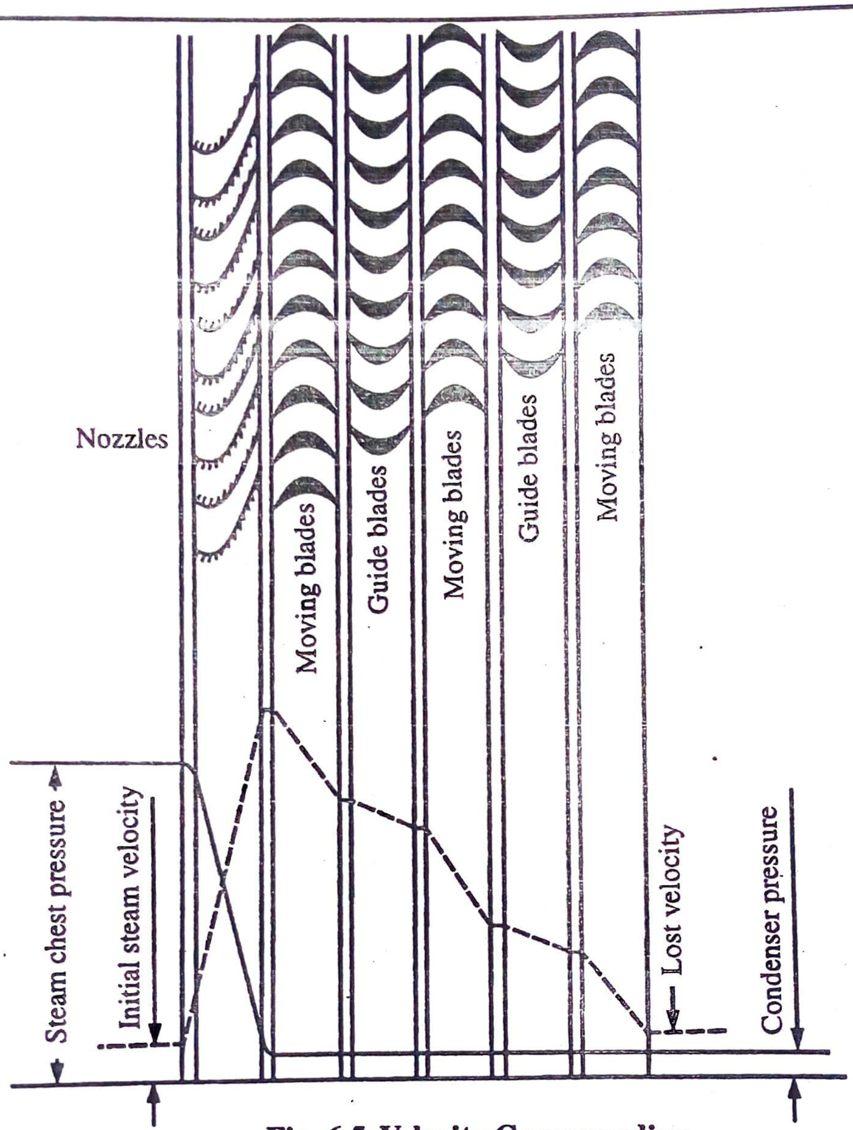


Fig. 6.5. Velocity Compounding.

This type of velocity compounded turbine is sometimes referred to **Curtis turbine.** Such turbines are used as drives for centrifugal compressors, feed pumps and small generators.

Advantages of Velocity Compounding :

1. The length of turbine is shortened. This raises the whirling speed of the shaft.
2. Less initial cost.
3. Number of stages are less.
4. The system is reliable and easy to start.
5. Since the pressure inside the turbine is low, so leakage losses are less.
6. Less space required.

Disadvantages of Velocity Compounding :

1. Friction losses are high.
2. Efficiency is low due to high initial speed.
3. The power developed in the last row is only a fraction of the power developed in first row.
4. The ratio of blade velocity and steam velocity is not optimum for all wheels, so the efficiency is low.

2. Pressure Compounding : In pressure compounding, the steam enters a row of nozzles where its pressure is only partially reduced and its velocity is increased. The pressure drop available to the turbine is used in a series of small increments, each increment being associated with one stage of turbine.

The high velocity steam from the nozzles passes onto a row of moving blades where its velocity is reduced. It then passes into a second row of nozzles where its pressure is again partially reduced and its velocity is again increased. This high velocity steam from the nozzles passes on to a second row of moving blades where its velocity is again reduced. The steam then passes into a third row of nozzles and so on. Since, only a part of the pressure drops in each stage, the steam velocity is not very high and the turbine will run at low speed. Since, all the stages are coupled to the same shaft, there is no loss of output. A commonly known turbine which is based on pressure compounding is Rateau turbine.

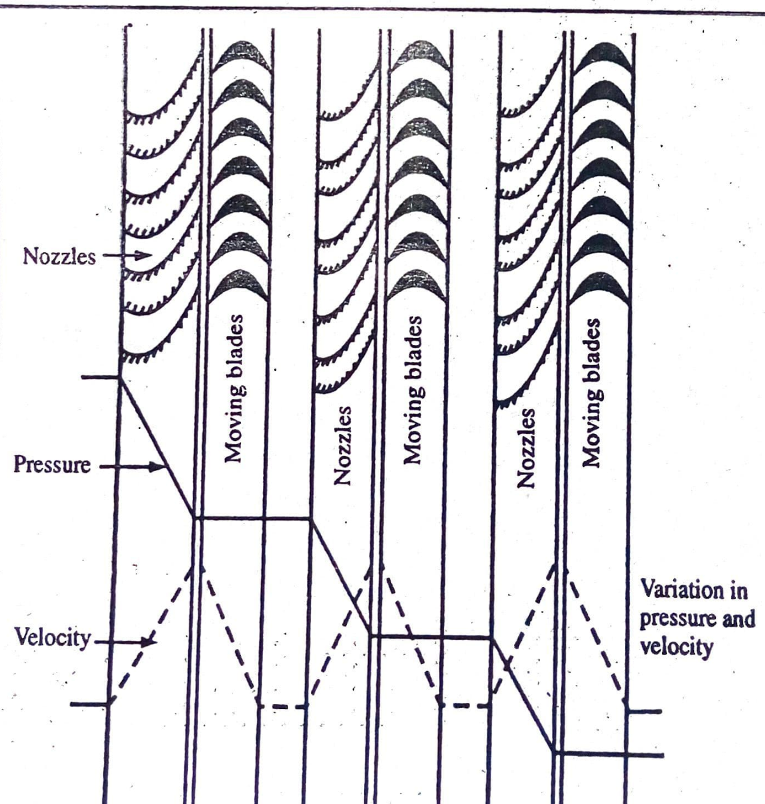


Fig. 6.6. Pressure Compounding.

Advantages of Pressure Compounding :

1. It is more expensive.
2. It has high efficiency than velocity compounding.
3. The velocity of steam entering each stage is considerably reduced.
4. Ratio of blade velocity and steam velocity remains constant.

Disadvantages of Pressure Compounding :

1. It requires large space for installation.
2. It is more expensive.
3. Velocity fluctuation is more as compared to velocity compounding.

3. Pressure-Velocity Compounding : It is a combination of the above two methods and is illustrated diagrammatically in Fig. 6.7.

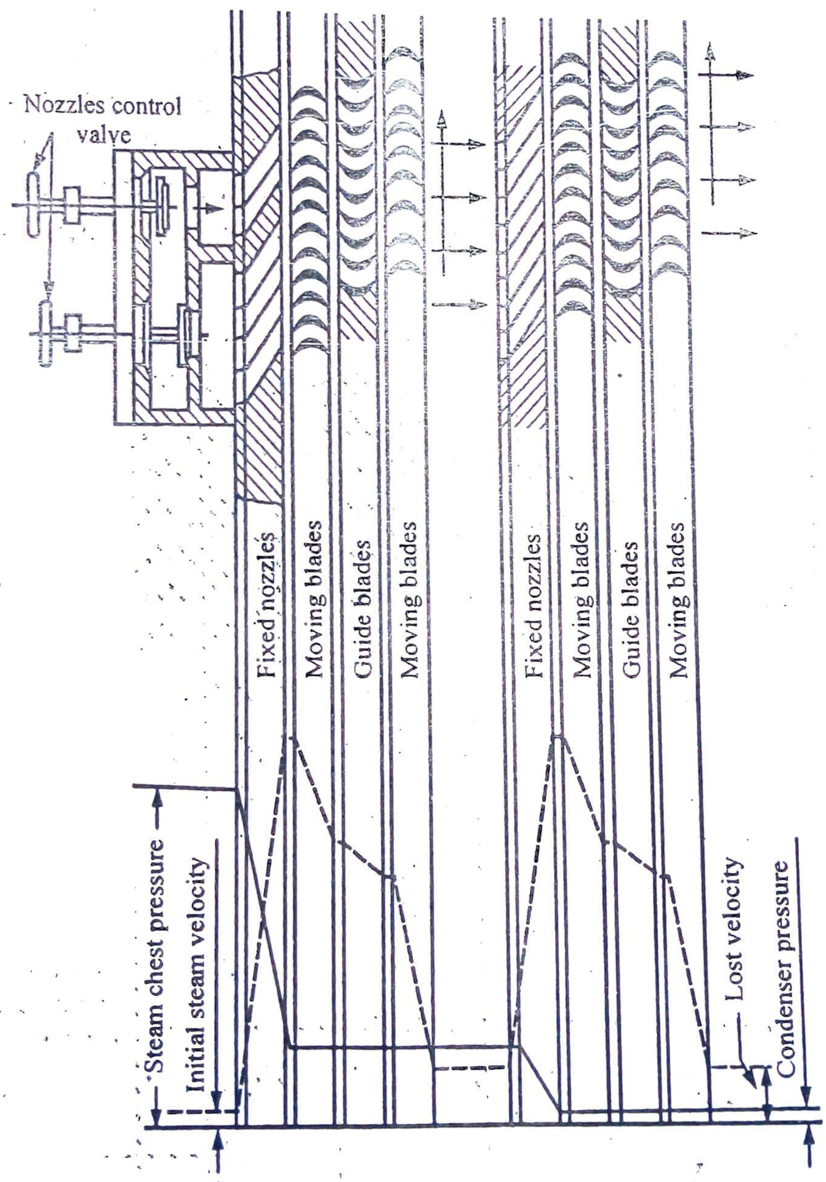


Fig. 6.7. Pressure-Velocity Compounding.

In this, the steam is partially expanded in a row of nozzles where its velocity is increased. The steam then enters a few rows of velocity compounding. After one stage the steam enters a second row of nozzles, where its velocity is again increased. This is followed by another few rows of velocity compounding and so on. The pressure of steam falls partially in nozzles at each stage. As the pressure falls, the specific volume increases and it requires a greater space to pass the steam. This can be accommodated either by increasing the diameter of the turbine discs or by increasing the height of the blades.

The increase in height of the turbine blades is limited by their strength, so the increase in disc diameter is necessary. The turbine discs thus increase in diameter from inlet to outlet at each stage.

6.8 COMPARISON BETWEEN IMPULSE TURBINE AND REACTION TURBINE

S. No.	Impulse Turbine	Reaction Turbine
1.	The total pressure drop occurs in the nozzles only.	The pressure drops continuously both in fixed and moving blades.
2.	It is suitable for small capacity of power generation.	It is suitable for medium and high capacity power generation.
3.	Less space is needed per unit power.	More space is needed per unit power.
4.	There are more frictional losses as compared to leakage losses.	The leakage losses are more compared to frictional losses.
5.	The power is obtained due to the impulsive forces of the incoming steam.	The power is obtained due to the impulsive forces of the incoming steam and due to the reaction of the steam leaving the blade as well.
6.	The blades are of symmetrical profile type having constant blade channel area.	The blades are of non symmetrical shape and have aerofoil cross-section. The blade channel area thus continuously varies.
7.	The steam velocity in an impulse turbine is very high, thus the speed of the turbine is high.	The steam velocity in a reaction turbine is not very high, thus the speed of the turbine is low.
8.	The size of the turbine is smaller for same power output as the number of stages are less due to heavy pressure drop in each stage.	The size of the turbine is larger for same power output as the number of stages are more for the same pressure drop due to gradual and small drop in each stage.

6.9 LOSSES IN STEAM TURBINES

Following losses take place in a steam turbine :

1. **Residual Velocity Loss :** The steam always leaves the turbine with a certain absolute velocity which results in loss of kinetic energy.
2. **Losses in Regulating Valves :** The steam generated in boiler is carried to the turbine through a pipe line having stop and regulating valves. At these valves, the high pressure steam gets throttled and hence a pressure drop occurs which reduces enthalpy drop available for work.
3. **Loss Due to Steam Friction :** It consists of steam friction loss both in the nozzles and the blades.
4. **Loss due to Leakage :** The steam leakage occurs at the clearance space provided between the disc and nozzles carrying diaphragm in the case of impulse turbines and at the blade tips in the case of reaction turbine.
5. **Loss due to Mechanical Friction :** This occurs in the bearings and can be minimised by proper lubrication.
6. **Loss Due to Disc Friction and Windage :** It includes windage loss and loss due to friction between steam and high-speed disc and blades.
7. **Loss Due to Wetness of Steam :** In multistage turbine, steam usually becomes wet towards its last stages of expansion and consists of a heterogeneous mixture of dry steam and water particles. The steam and water particles have different velocities. But these particles have to be dragged along the steam and in doing so, part of kinetic energy is lost.
8. **Loss Due to Radiation :** This loss is negligible.

6.10 STEAM TURBINE GOVERNING

The function of a governor is to regulate the supply of steam to the turbine in such a way as to keep its speed fairly constant from no-load to full-load. Following methods are commonly used for governing of steam turbines :

1. Throttle governing,
2. Nozzle control governing,
3. By-pass governing.

1. Throttle Governing : In this method, flow of steam entering the turbine is varied with the help of a double beat valve which itself is controlled by a centrifugal governor as shown in Fig. 6.8

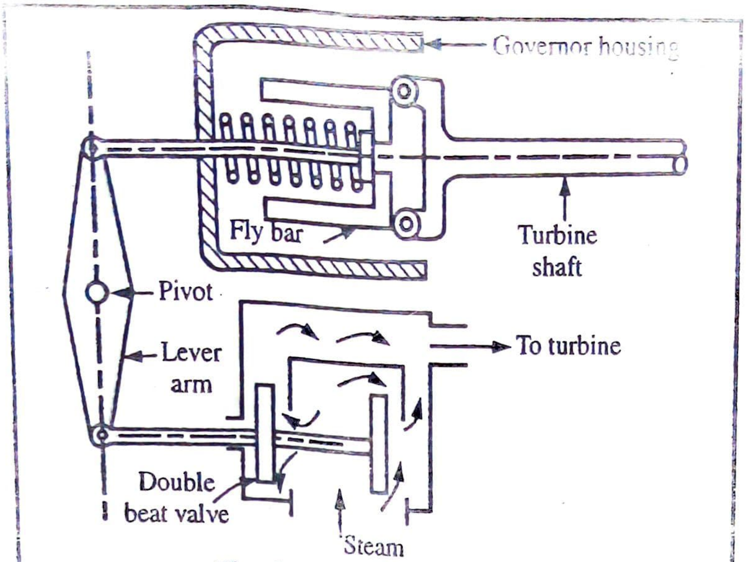


Fig. 6.8. Throttle Governing

When load on the turbine decreases, its speed tends to increase. The centrifugal force on the fly-bar increases and the fly-bar moves outwards. This movement of the fly-bar actuates the lever arm which in turn controls the double beat valve so as to throttle the steam. This throttling tends to restore the original speed.

When load on turbine increases, its speed tends to decrease and hence centrifugal force acting on the fly-bar is decreased. The fly bar moves inwards, thereby allowing beat valve to open up and permit more steam to enter the turbine. This tends to increase the turbine speed.

Throttle governing is mechanically simple, but thermodynamically inefficient. Hence, it is used for small units only.

2. Nozzle Control Governing : As shown in Fig. 6.9, the nozzles are arranged in groups N_1, N_2 and N_3 etc. and supply of steam to each group is controlled by different valves V_1, V_2 and V_3 etc. Under full-load conditions, all valves are fully open, thereby admitting maximum amount of steam to the nozzles. As load on the turbine decreases, its speed tends to increase and supply of steam to group of nozzles is cut-off one after the other. Due to decrease in steam supply, turbine speed tends to fall back to its original value.

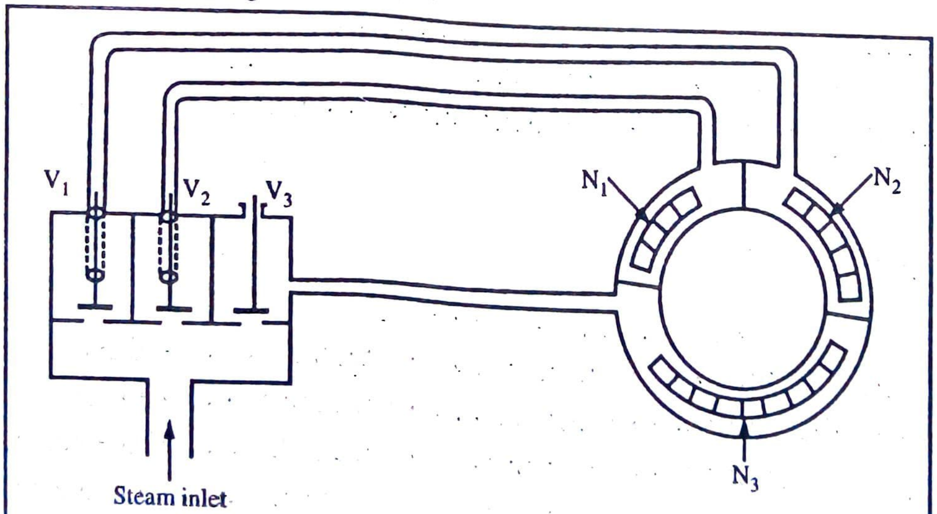


Fig. 6.9. Nozzle Control Covering.

Since steam is used at full boiler pressure, this method of speed control is more efficient than throttle governing and is thus preferred for large units.

3. By-Pass Governing : When the high pressure steam turbines designed to work at economic load, work at maximum load which is greater than economic load, the additional steam required. This additional required steam could not pass through the first stage since the additional nozzles are not available.

By pass regulation allows additional required steam in turbine, which is throttle governed, by-means of a second by-pass valve in the first stage nozzles. This valve opens when throttle valve has opened to a definite amount. The steam is by passed through second valve to a lower stage as shown in Fig. 6.10.

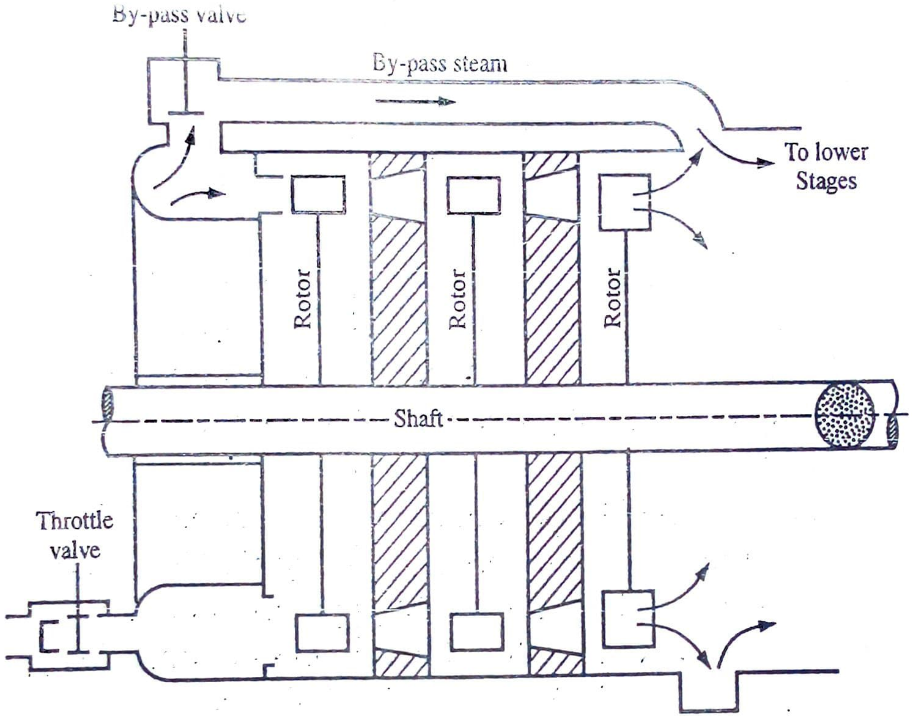


Fig. 6.10. By-Pass Governing

When the by pass valve operates, it is under the control of turbine governor. The secondary and tertiary supplies of steam in lower stage increase the work output in these stages, but there is loss in efficiency.

6.11 STEAM NOZZLE

A steam nozzle is a passage of varying cross-section, which converts heat energy of steam into kinetic energy. The fluid enters the nozzle with a high pressure and relatively small velocity. As it flows through the nozzle, it expands to a lower pressure and in the process, the pressure falls and the velocity increases continuously from the entrance to the exit of the nozzle. Since the mass of steam passing through any section of the nozzle remains constant, the variation of steam pressure in the nozzle depends upon the velocity, specific volume and dryness fraction of steam.

A well designed nozzle converts the heat energy of steam into kinetic energy with a minimum loss. The smallest section of the nozzle is called throat.

Many engineering applications require a jet of high velocity steam and this objective is efficiently achieved with a nozzle.

6.12 TYPES OF NOZZLES

There are three types of steam nozzles :

1. Convergent nozzle,
2. Divergent nozzle,
3. Convergent divergent nozzle.

1. **Convergent nozzle :** *When the cross-sectional area of the nozzle decreases continuously from entrance to exit, it is called a convergent nozzle.* Fig 6.11 shows the convergent nozzle.

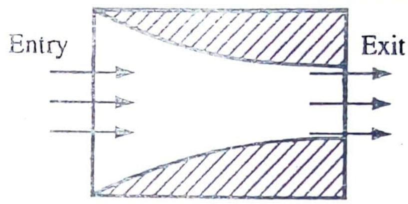


Fig. 6.11. Convergent Nozzle.

This type of nozzle is used when the back pressure is equal or more than the critical pressure ratio. It is also used for compressible fluids.

2. **Divergent nozzle :** *In this type of nozzle, the cross-sectional area of the nozzle increases continuously from entrance to exit as* shown in Fig. 6.12.

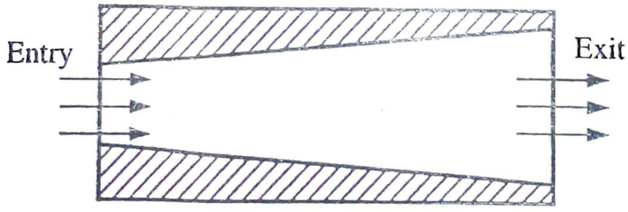


Fig. 6.12. Divergent Nozzle.

This nozzle is used where back pressure is less than critical pressure.

3. **Convergent divergent nozzle :** This type of nozzle mainly consists three parts :

(*a*) Convergent section, (*b*) Throat, (*c*) Divergent section.

A nozzle which converges to throat and then diverges afterwards is known as convergent-divergent nozzle. In this type of nozzle, the cross-section of the nozzle first tapers to a small section to allow for changes which occur due to changes in velocity, specific volume and dryness fraction. This section is known as convergent section. The smallest cross-section of nozzle is known as throat. The cross-section of the nozzle then diverges to large section. This section is known as divergent section. This type of nozzle is widely used these days in various types of steam turbines. A convergent-divergent nozzle is shown in Fig. 6.13.

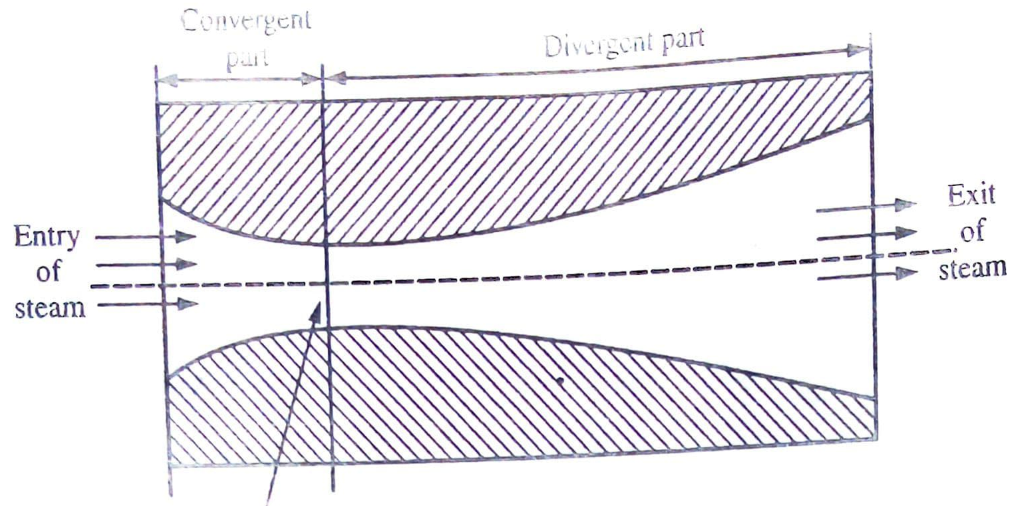


Fig. 6.13. Convergent-Divergent Nozzle.

6.13 APPLICATIONS OF STEAM NOZZLES

The various applications of steam nozzles are as follow :

(*i*) These are used to produce a high velocity jet of steam in steam turbines.

(*ii*) These are used to pump the feed water into boilers through injectors.

(*iii*) These are used to remove air from steam condensers by ejectors.

(*iv*) These are used to measure the flow of steam in steam flow measuring devices.

6.14 STEAM CONDENSER

A steam condenser is a closed vessel in which steam is condensed and heat released by steam is absorbed by water. The steam entering the condenser leaves it as a condensate and the temperature of cooling water passing through the condenser is higher at exit than at entry.

6.15 FUNCTIONS OF A STEAM CONDENSER

The steam condenser has the following two functions :

1. The steam condenser maintains a very low back pressure on the exhaust side of the piston of the steam engine or turbine. Steam expands to a greater extent which results in an increase in available heat energy for converting into mechanical work. The hatched area in fig. 6.14 (*i.e.* area 44'5'5) shows the increase in work obtained by fitting a condenser to a non-condensing engine. It is clear from the figure that the thermal efficiency of a condensing unit is higher than that of a non-condensing unit.

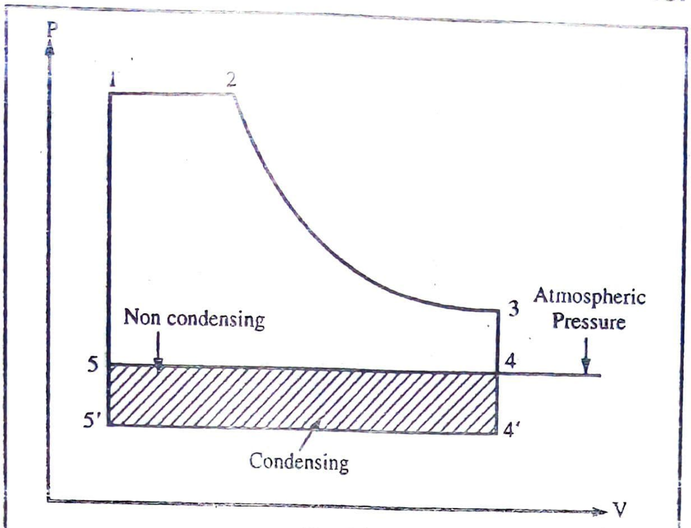


Fig. 6.14

2. It supplies pure feed water to the hot well, from where it is pumped back to the boiler. Hence, where sufficient quantity of pure water as feed water for a boiler is not available such as in marine practice, the use of condenser will prove to be of an immense use.

6 ELEMENTS OF A CONDENSING PLANT

Fig. 6.15 shows the essential elements which comprise a condensing unit :

1. **Condenser :** *It is a closed vessel in which steam is condensed.* The steam gives up heat energy to water during the process of condensation.
2. **Condensate Pump :** *A condensate pump is used to extract the condensed steam from the condenser and feed it to hot well.*

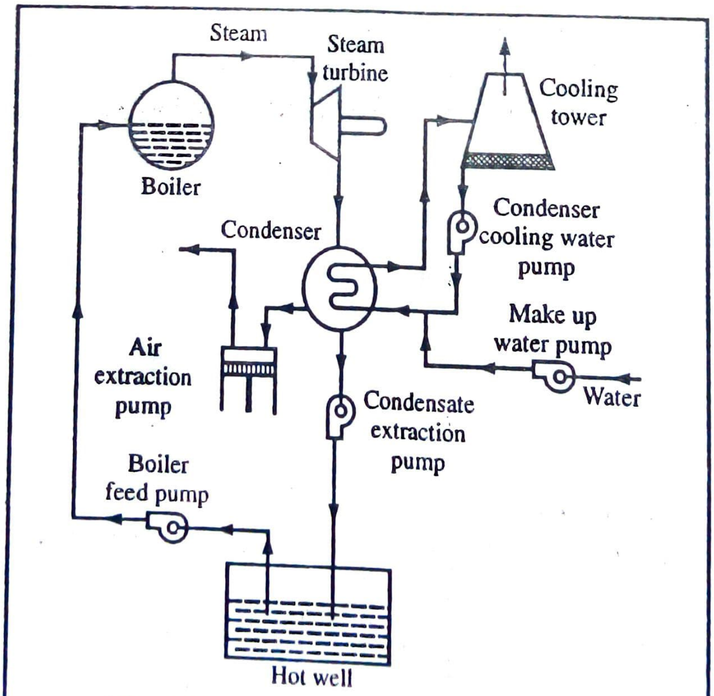


Fig. 6.15. Steam Condensing Plant.

3. **Boiler feed Pump :** *It is used to pump the condensate from the hot well to the boiler.* This is done by increasing the pressure of condensate above the boiler pressure.
4. **Cooling Water Pump :** *It is a pump which circulates the cooling water through the condenser.*
5. **Hot Well :** *It is a sump between the condenser and boiler which receives condensate pumped by the condensate pump.*
6. **Air Extraction Pump :** *It is used to remove air and non-condensable gases from the condenser.*
7. **Cooling Tower :** *It is used for cooling the water which is discharged from the condenser.*
8. **Relief Valve :** *An atmospheric relief valve is used for relieving the pressure in the condenser when the condenser does not function properly.* The steam then escapes through the valve and engine operates as non-condensing.

6.17 CLASSIFICATION OF CONDENSERS

The steam condensers may be broadly classified into the following two types depending upon the way in which the cooling water cools the exhaust steam. These are :

1. Jet condensers or mixing type condensers,
2. Surface condensers or non-mixing type condensers.

1. Jet Condenser : *In this condenser, there is a direct contact between the steam and cooling water and the heat exchange is by way of direct conduction.* In this, the cooling water is usually sprayed into the exhaust steam to cause rapid condensation.

Jet condensers are seldom used in modern power stations because of loss of condensate and the high power of jet condenser pumps. Moreover, the condensate can not be used as feed water to the boiler as it is not free from salt. However, jet condensers may be used at places where water of good quality is available in adequate quantity. These condensers may be sub-divided into the following four classes :

(*i*) Parallel flow jet condenser,

(*ii*) Counter flow jet condenser,

(*iii*) Barometric jet condenser,

(*iv*) Ejector condenser.

(*i*) Parallel Flow Jet Condenser : *In this type, both the exhaust steam and cooling water find their entry at the top of the condenser and then flow downwards and condensate and water are finally collected at the bottom.*

The principle of this condenser is shown in fig. 6.16. The exhaust steam is condensed when it mixes up with water. The cooling water, air flow downwards and condensate are removed by two separate pumps known as air pump and condensate extraction pump.

The condensate pump delivers the condensate to the hot well as shown in fig. 6.16

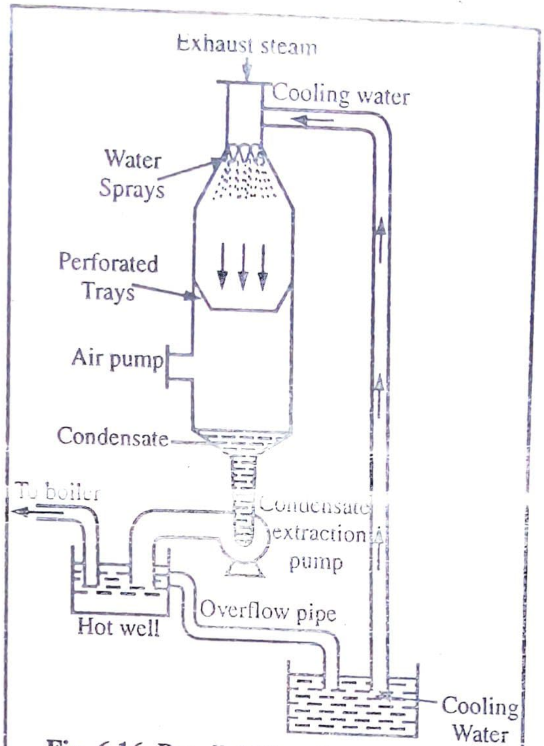


Fig. 6.16. Parallel Flow Jet Condenser.

(ii) Counter Flow Jet Condenser : *In this type, the steam and cooling water enter the condenser from opposite directions.* Generally, the exhaust steam travels in upward direction and meets the cooling water which flows downwards.

The principle of this condenser is shown in fig. 6.17. An air pump is used to create vacuum in the condenser shell. This draws the supply of cooling water, which falls through a large number of jets in perforated conical plate. The falling water is then collected in the trays from where it escapes in a second series of jets and meets the exhaust steam entering at the bottom. A condensate pump is used deliver condensate in to the hot well. This condenser is also known as low level jet condenser.

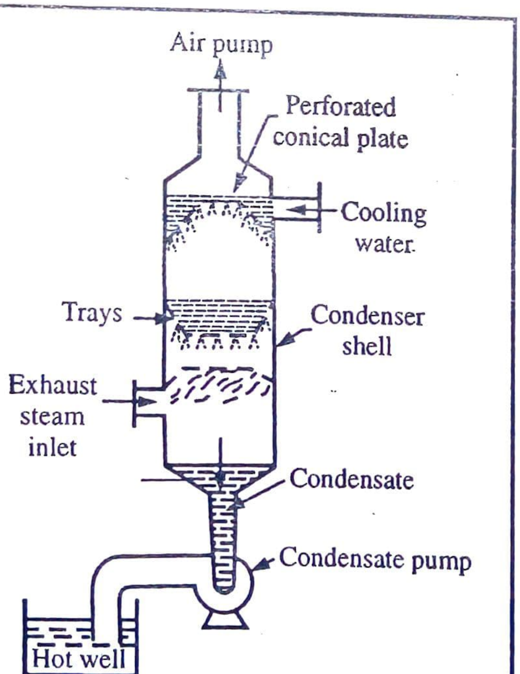


Fig. 6.17. Counter flow Jet Condenser.

***(iii)* Barometric Jet Condenser :** It is also known as high level jet condenser. It is similar to low level jet condenser except that a column of water in the tail pipe of about 10.36 m height forces the condensate to drain away by gravity in to hot well. A barometric jet condenser is shown in fig. 6.18. Theoretically, the height 'H' of the tail pipe is given by

H = (Atmospheric pressure–Condenser pressure) + Friction loss in tail pipe + Water velocity head.

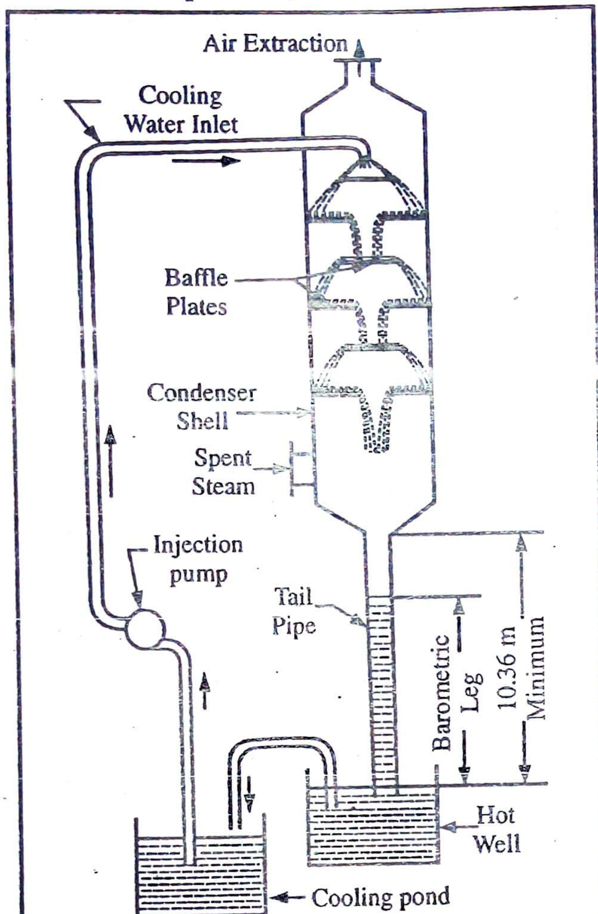


Fig. 6.18. Barometric Jet Condenser.

An injection pump is used to pump the cooling water into the condenser shell.

(iv) Ejector Condenser : Fig. 6.19 shows the schematic sketch of an ejector condenser. *In this type, mixing of exhaust steam and cooling water takes place in a series of combining cones and the kinetic energy of the steam is utilised to assist in draining the water from the condenser into the hot well against the pressure of atmosphere.*

The exhaust steam inlet is provided with a non-return value which does not allow water from hot well to rush back to the engine in case a failure of cooling water supply to condenser.

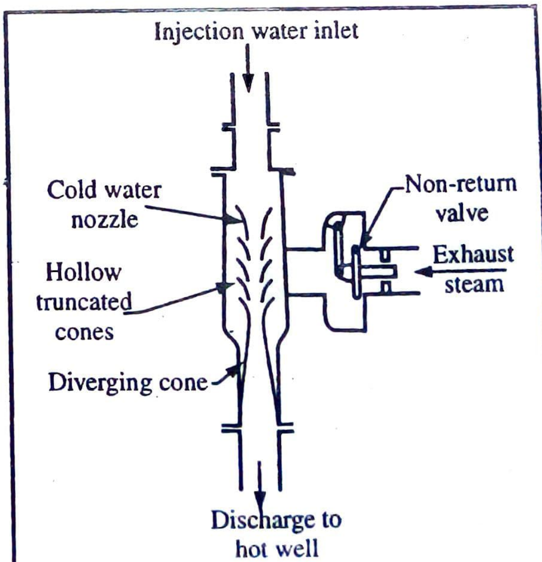


Fig. 6.19. Ejector Condenser.

2. Surface Condenser : *In a surface condenser, the exhaust steam and cooling water do not come into direct contact.* The steam to be condensed is made to flow over outside of a nest of tubes through which cooling water circulates. Most condensers are generally classified on the basis of direction of flow of condensate, the arrangement of the tubing and the position of the condensate extraction pump. The followings are the main classifications of surface condensers :

(*i*) Down Flow Type,

(*ii*) Central Flow Type,

(*iii*) Inverted flow Type,

(*iv*) Regenerative Type,

(*v*) Evaporative Type.

(*i*) **Down Flow Type :** Fig. 6.20 shows a down flow type of surface condenser. It consists of a shell which is generally of cylindrical shape, though other types may also be used. It also has cover plates at the ends furnished with number of parallel brass tubes. A baffle plate divides the water box into two sections.

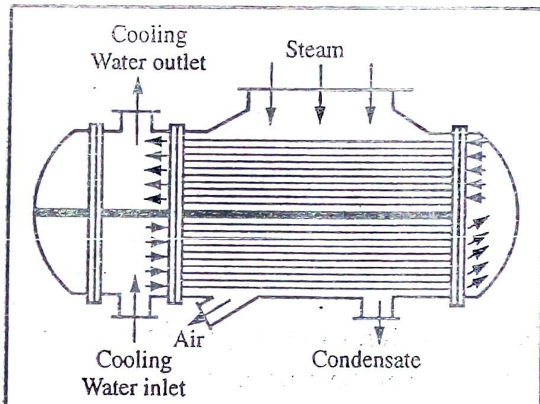


Fig. 6.20. Down Flow Surface Condenser (Longitudinal Section).

In this type, the exhaust steam enters at the top and flow downwards over the tubes due to force of gravity as well as suction of the extraction pump fitted at the bottom. The cooling water enters the shell at the lower half section and after travelling through the upper half section comes out of the outlet. The condensate is collected at the bottom and then pumped by the extraction pump. As the steam flows in a direction at right angle to the direction of flow of water, it is also called cross-surface condenser. A transverse section of the condenser is shown in fig. 6.21.

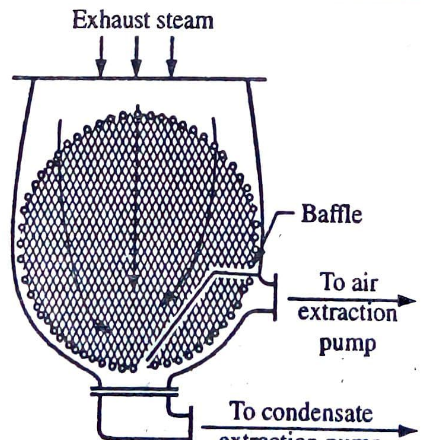


Fig. 6.21. Down Flow Surface Condenser (Transverse Section).

(ii) **Central Flow Type :** In this type of condenser, the suction pipe of the air extraction pump is located in the center of the tubes which results in radial flow of the steam. The central flow condenser is an improvement over the down flow type condenser as the steam is directed radially inwards by a volute casing around the tube nest. It, thus, gives an access to the whole periphery of the tubes. In this, the condensate is collected at the bottom and then pumped by the extraction pump as shown in fig. 6.22.

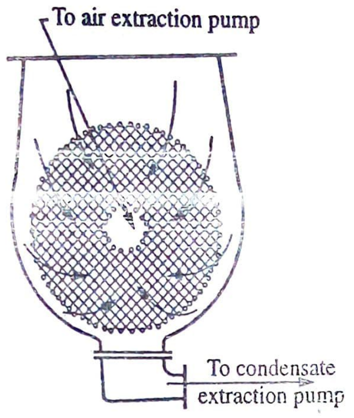


Fig. 6.22. Central Flow Surface Condenser.

(iii) **Inverted Flow Type :** In this type, the condenser has the air suction at the top. The steam after entering at the bottom rises up and then again flows down to the bottom of the condenser, by following a path near the outer surface of the condenser. The condensate extraction pump is at the bottom.

(iv) **Regenerative Type :** In this type, the condensate is heated by a regenerative method. The condensate after leaving the tube is passed through the exhaust steam from the engine or turbine. It raises its temperature for use as feed water for the boiler.

(v) **Evaporative Type :** In this type, the steam to be condensed enters a coiled finned pipe system as shown in fig. 6.23.

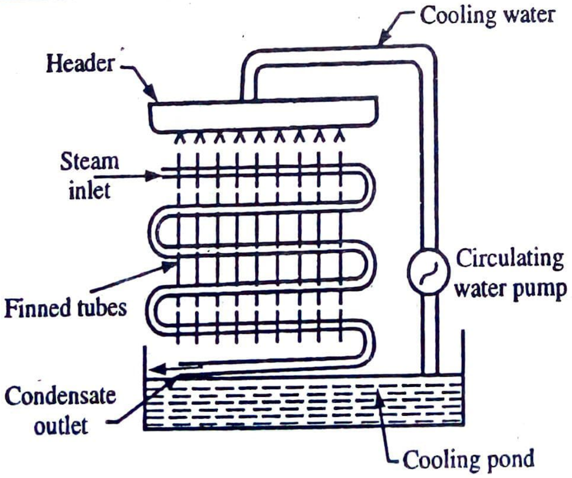


Fig. 6.23. Evaporative Condenser.

The water from a cooling pond is pumped by the circulating pump to a cooling header which is fitted with spray nozzles. When the cooling water falls over the finned tubes, it gets evaporated. The steam loses its heat both to the cooling water and the current of air circulating over the water film. The heated air moves upwards carrying along with it a portion of cooling water evaporated into vapour. The remainder of the cooling water falls into the cooling pond and the loss of water evaporated is replenished by the addition of a requisite quantity of cold make up water.

The arrangement is simple, cheap, does not require large quantity of cooling water and so needs a cooling pond of small capacity. The evaporating condensers are provided when the circulating water is to be used again and again.

6.18 COMPARISON OF JET AND SURFACE CONDENSERS

Jet Condensers	Surface Condensers
1. Low manufacturing cost.	1. High manufacturing cost.
2. Condensate is wasted.	2. Condensate is reused.
3. Cooling water and steam are mixed up.	3. Cooling water and steam are not mixed up.
4. The condensing plant is simple.	4. The condensing plant is complicated.
5. It is less suitable for high capacity plants due to low vacuum efficiency.	5. It is more suitable for high capacity plants due to high vacuum efficiency.
6. Its maintenance cost is low.	6. Its maintenance cost is high.
7. More power is required for air pump.	7. Less power is required for air pump.
8. It requires less quantity of circulating water.	8. It requires a large quantity of circulating water.
9. It requires small floor space.	9. It requires large floor space.
10. Lower up-keep.	10. Higher up-keep.
11. More power is required for water pumping.	11. Less power is required for water pumping.

6.19 COOLING WATER SUPPLY FOR CONDENSERS

When the supply of water for the water cooled condenser is inadequate and expensive, then the hot water coming from the condenser is repeatedly re-cooled and used again and again. The cooling of the water is done by the following means :

1. Cooling ponds,
2. Spray ponds,
3. Cooling towers.

The principle of cooling the water in spray ponds and cooling towers is similar to that of evaporative condenser *i.e.* the cooling is caused by means of evaporation. The amount of cooling depends upon the surface area exposed, time of exposure, air velocity and the wet bulb temperature of the atmospheric air.

1. Cooling Pond : It is the simplest system of removing heat from the cooling water. The effectiveness of this method depends upon very large surface area of the pond and for this reason, its use is restricted to small condensers only. The cooling ponds may be of following two types :

(*i*) Non-directed flow types,

(*ii*) Directed flow types.

(*i*) Non-directed Flow Types : Fig. 6.24 shows the principle of working of a non-directed flow type pond in which hot water from the condenser enters a trough and after flowing through it, is discharged into an open pond. The direction of flow of water is shown by arrow heads. This type of cooling pond is suitable for long and narrow lots.

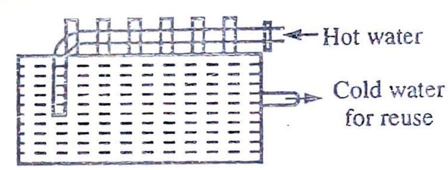


Fig. 6.24. Non-Directed Flow Cooling Pond.

(*ii*) Directed Flow Type : In this case, the tank is divided into a number of channels by providing baffle walls so as to direct the flow of hot water which is discharged into the pond. This, ensures thorough mixing of hot and cold water. The hot water from the condenser is discharged into the middle channel, which on reaching the far end divides into two currents being directed by the baffle walls so as to make it traverse the pond several times before uniting at the outlet point. A directed flow type of cooling pond is shown in fig. 6.25.

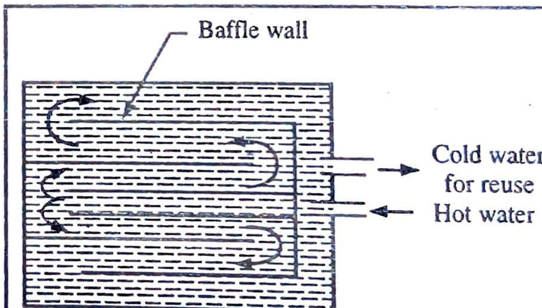


Fig. 6.25
Directed Flow Cooling Pond.

2. Spray Pond : A spray pond consists of a piping and spray nozzle arrangement suspended over an outdoor open pond or reservoir. It can cool large quantity of warm water. A single deck type spray pond is shown in fig. 6.26 in which all the spray nozzles are provided at the same level. In a double deck spray pond, the nozzles are provided at different levels.

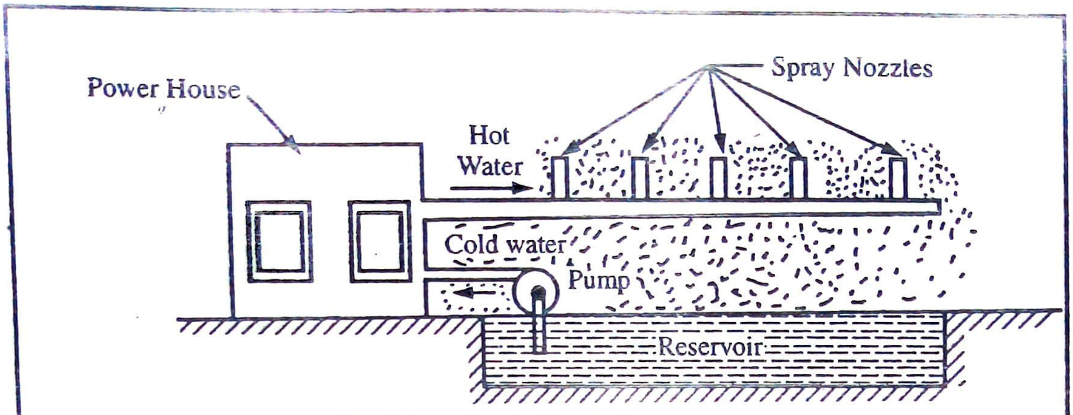


Fig. 6.26. Single Deck Spray Pond.

Hot water from the condenser is sprayed through the nozzles as shown in the fig. 6.26 to expose the maximum surface of water to the air. The air surrounding the falling water droplets from the spray nozzles causes some of the water droplets to evaporate, while the rest of the droplets drip down into the reservoir. The evaporating water absorbs latent heat of evaporation from the remaining water and thus cools it. The air also absorbs a small amount of sensible heat from the remainder water. The cooled water collects in the pond from where it is pumped to the condenser for recirculation.

The spray ponds require more floor area per kg of water than cooling towers. The spray ponds are always surrounded with wooden walls or louver fence to prevent the escape of water particles with the winds.

3. **Cooling Towers :** A cooling tower is an enclosed tower like structure through which atmospheric air circulates and by direct contact, cools large quantities of warm water from the condenser. A cooling lower occupies less floor space than the spray pond and cools the water to the wet-bulb temperature of air.

Cooling towers are used for big plants such as absorption refrigeration systems, steam jet refrigeration systems and centrifugal units of above 100 TR capacity.

The cooling towers are mainly divided into the following two groups :

1. Natural Draft Cooling Towers,
2. Mechanical Draft Cooling Towers.

When circulation of air through the tower is by natural convection, it is called a natural draft or atmospheric cooling tower. On the other hand, *when the circulation of air is brought about by the action of a fan or blower, it is called a mechanical draft cooling tower.* A mechanical draft cooling tower may either be a forced draft type if the fan or blower forces the air through the tower or it may be of induced draft type if the blower draws the air through the tower.

1. **Natural Draft Cooling Tower :** A natural draft or atmospheric spray type cooling tower is shown in fig. 6.27. It should be located in open space or on the roof of the building where the free movement of the air is available.

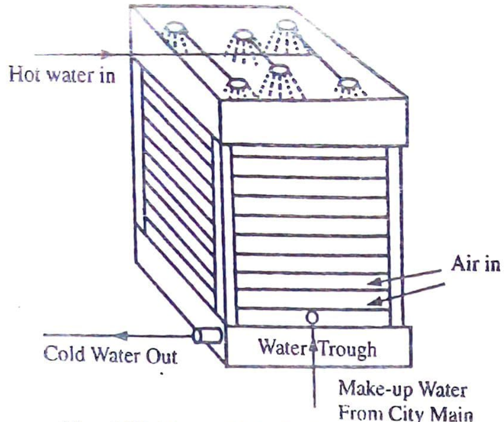


Fig. 6.27. Natural Draft Cooling Tower.

The warm water from the condenser is pumped to the top of the tower where it is sprayed down through the tower through a series of spray nozzles.

The atmospheric air circulates in the tower by natural convection. As in case of spray ponds, the cooling of water is caused by the evaporation of water. Some water droplets evaporate by absorbing latent heat of evaporation and thus cool the remaining water. Air also absorbs some sensible heat from water. The cooled water is collected at the bottom and is recirculated through the condenser.

Some natural draft towers contain decking, usually of redwood, to increase the wetted surface in the tower and to break up the water into droplets.

2. Mechanical Draft Cooling Tower : Mechanical draft cooling towers are smaller in size than the natural draft cooling tower of the same capacity because of large volume of forced air. The cooling capacity can be controlled by controlling the forced air supply. These can be located inside the building as these do not depend upon atmospheric air. But they require additional power for operating the fans and maintenance cost is more. These cooling towers are of two type *i.e.*, forced draft type and induced draft type.

A. Forced Draft Cooling Tower : A forced draft cooling tower is shown in fig. 6.28.

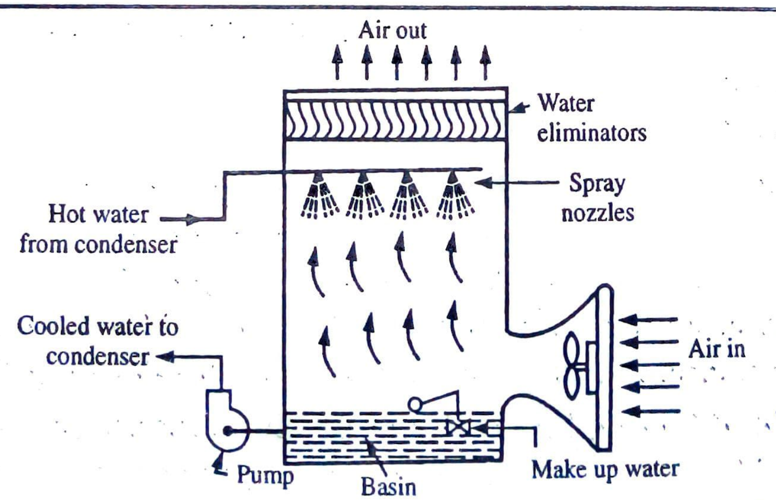


Fig. 6.28. Forced Draft Cooling Tower.

A fan forces the air through the tower. Warm water coming from the condenser is sprayed at the top of tower through spray nozzles. The warm water is cooled by means of evaporation as in case of natural draft cooling towers and spray ponds. The water eliminators provided near the exit restrict the water particles escaping with the air. Cooled water collects in the basin and is recirculated in the condenser.

B. Induced Draft Cooling Tower : An induced draft cooling tower is shown in fig. 6.29.

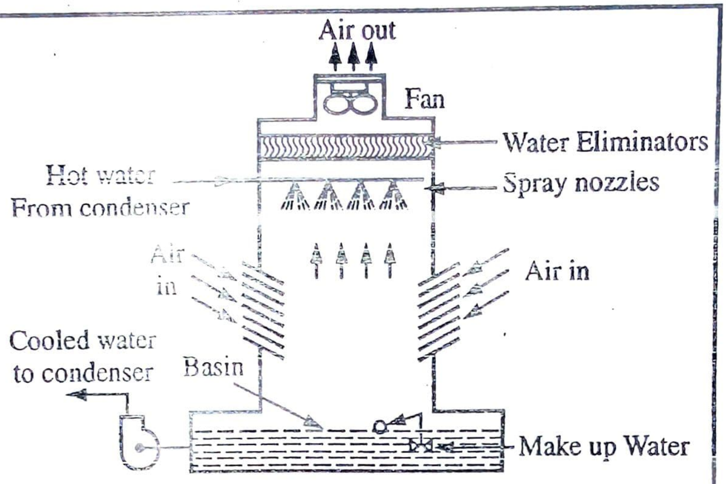


Fig. 6.29. Induced Draft Cooling Tower.

The induced draft cooling tower is similar to the forced draft cooling tower with the exception that in this case, the fans are located at the top instead of at the bottom. These fans suck the air upward through the tower and discharge to outside atmosphere.

EXERCISES

A. MULTIPLE CHOICE QUESTIONS :

1. **De-laval turbine is a :**
   (*a*) Impulse turbine. (*b*) Reaction turbine.
   (*c*) Both (*a*) and (*b*) turbine. (*d*) Neither (*a*) nor (*b*).
2. **The compounding of turbines is done in order to :**
   (*a*) reduce speed of rotor. (*b*) improve efficiency.
   (*c*) reduce exit losses. (*d*) All of the above.
3. **The purpose of governing in steam turbines is to :**
   (*a*) reduce the effective heat drop.
   (*b*) reheat the steam and improve its quality.
   (*c*) completely balance against end thrust.
   (*d*) maintain the speed of the turbine.

Chapter

7

GAS TURBINES AND JET PROPULSION

7.1 INTRODUCTION

A gas turbine is a rotary machine which is similar in principle to a steam turbine. It obtains its power by utilizing the energy of a jet of burnt gases, the velocity of the jet being absorbed as it flows over several rings of moving blades which are fixed to a common shaft. The gas turbine requires an air compressor which is usually driven by its own shaft and this absorbs a considerable proportion of the power produced and thus lowers the overall efficiency.

Gas turbines have been constructed to work on the following fuels : Coal gas, furnace gas, oil and pulverized coal.

7.2 CLASSIFICATION OF GAS TURBINES

The gas turbines are classified into two main types :

1. Constant pressure gas turbine,
2. Constant volume gas turbine.

1. Constant Pressure Gas Turbine : The constant pressure gas turbine is further classified as :

(*a*) Closed cycle constant pressure gas turbine,

(*b*) Open cycle constant pressure gas turbine.

(*a*) Closed Cycle Constant Pressure Gas Turbine : It works on Joule or Brayton cycle. The following assumptions are made for the analysis of ideal gas turbine cycle :

(*i*) The processes of compression and expansion are reversible and adiabatic in nature.

(*ii*) The kinetic energy of the working fluid remains unchanged between the inlet and outlet of each component.

(*iii*) There is no pressure loss in the inlet and outlet passages and combustion chamber.

(*iv*) The working fluid has same composition throughout the cycle and could be treated as ideal gas with constant specific heats.

(*v*) The heat exchanger, if used, should be counter flow with 100% efficiency.

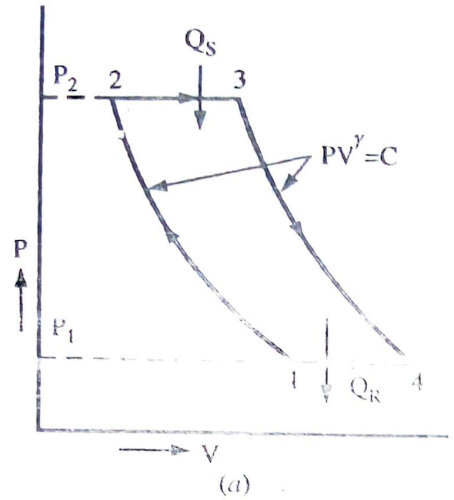
This cycle consists of four processes. The cycle is shown on a P-V chart and a T-S chart in fig. 7.1. This is the ideal cycle for closed cycle gas turbine unit (see fig. 7.2). The working substance is air which flows in a steady manner during the cycle.

The sequence of the processes is as follows :

Process (1 – 2) : Reversible adiabatic compression, Process (2 – 3) : Constant pressure heat addition,

Process (3 – 4) : Reversible adiabatic expansion,

Process (4 – 1) : Constant pressure heat rejection.



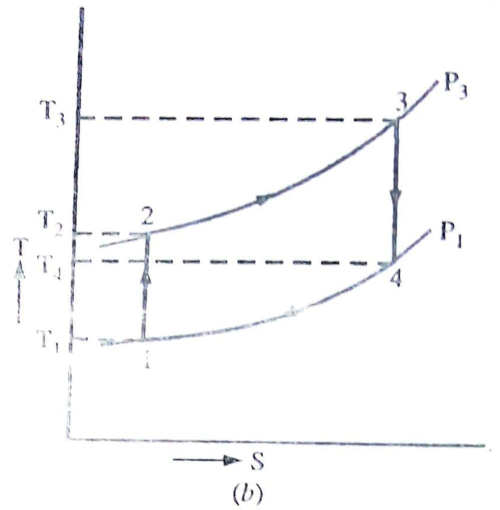


Fig. 7.1. Brayton Cycle.

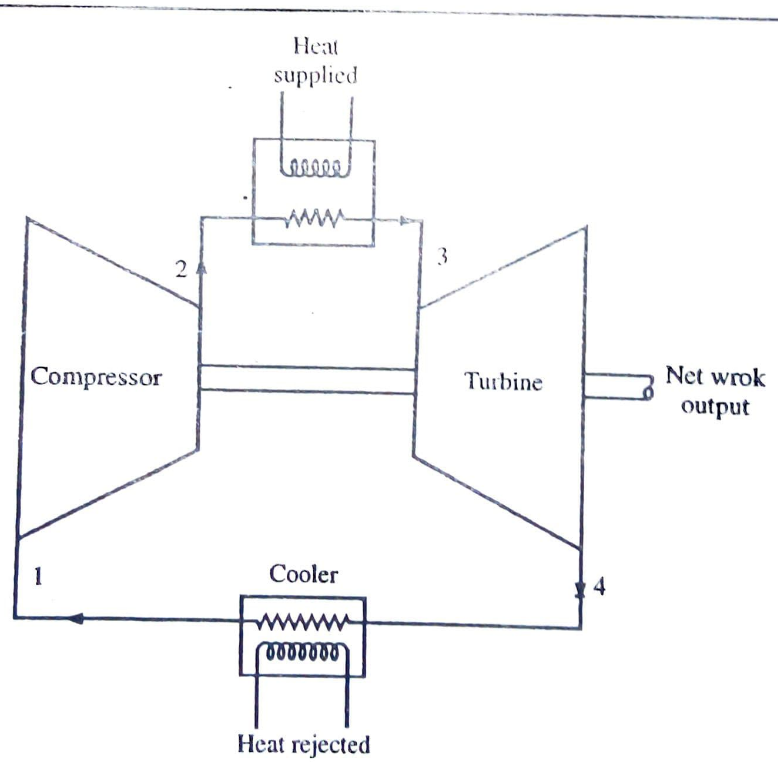


Fig. 7.2. Closed Cycle Gas Turbine Unit.

(*b*) Open Cycle Constant Pressure Gas Turbine : The basic principle of working of this gas turbine is not very much different from that of the I.C. engines. The air is compressed in the compressor, heated by the combustion process to raise its pressure and temperature, expanded in turbine and finally the expanded products of combustion are rejected through the exhaust.

The most basic gas turbine unit operates on an open cycle in which a rotary compressor and a turbine are mounted on a common shaft as shown in fig. 7.3.

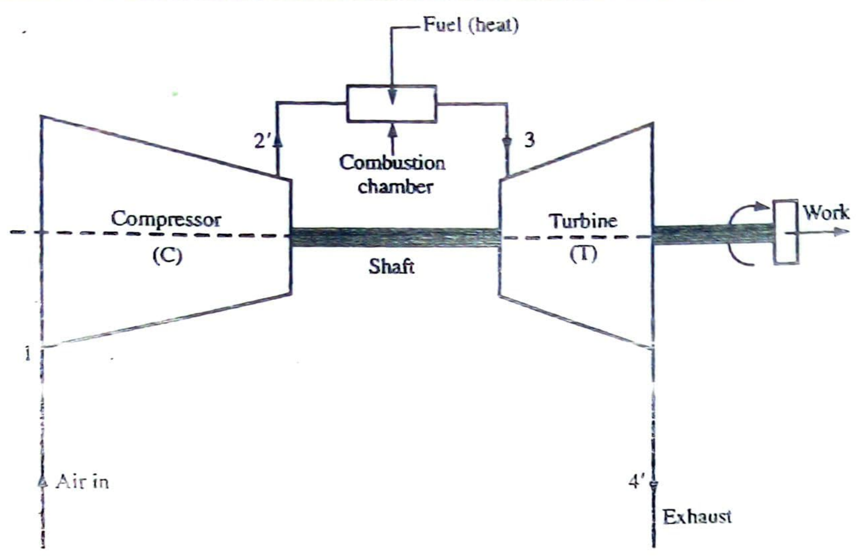


Fig. 7.3. Open Cycle Gas Turbine.

Air is drawn in the compressor and after compression, passes to a combustion chamber. In the combustion chamber, the heat is supplied by the fuel sprayed into the air stream. Then the resulting hot gases are allowed to expand through a turbine. After passing through the turbine, the gases are rejected into atmosphere. In this arrangement, the shaft of compressor is coupled with shaft of turbine and in order to achieve net work output from the unit, the turbine must develop more gross work output than the work required to drive the compressor and to overcome mechanical losses in the drive.

If pressure loss in the combustion chamber is neglected, this cycle may be drawn on a T-S diagram as shown in fig. 7.4.

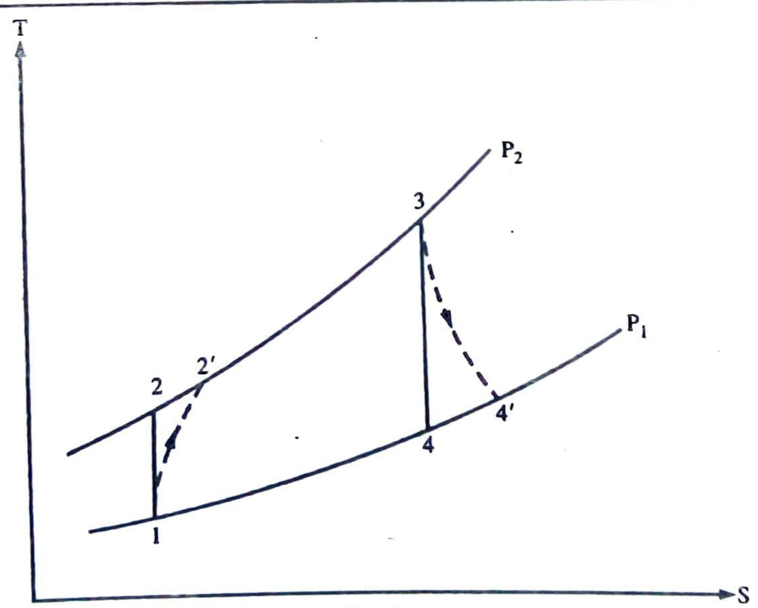


Fig. 7.4.

Line 1 – 2′ : Irreversible adiabatic compression,

Line 2′ – 3 : Constant pressure heat addition in the combustion chamber,

Line 3 – 4′ : Irreversible adiabatic expansion,

Line 1 – 2 : Ideal isentropic compression,

Line 3 – 4 : Ideal isentropic expansion.

2. **Constant Volume Gas Turbine :** The constant volume gas turbine is shown in fig. 7.5.

A, B = Valves,
C = Compressor,
D = Combustion chamber,
P = Fuel pump,
S = Spark plug,
T = Turbine.

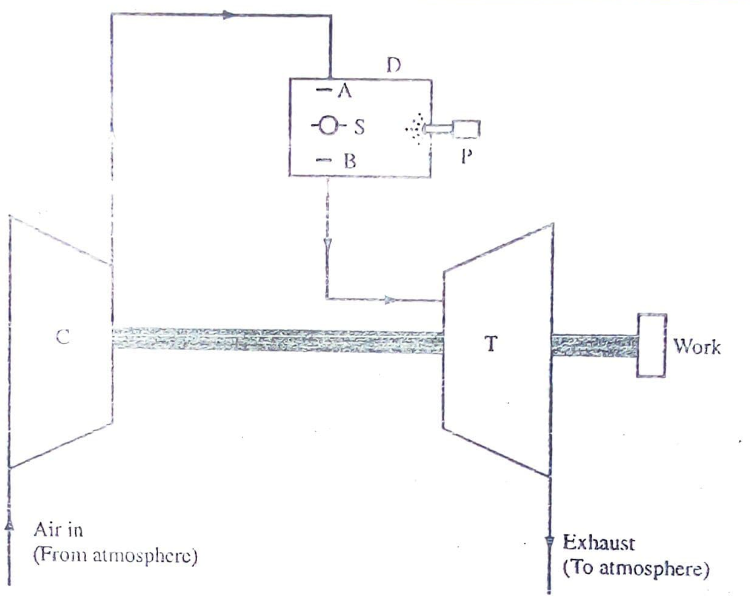


Fig. 7.5. Constant Volume Gas Turbine.

This type of turbine works on Atkinson cycle.

In this turbine, the compressed air from an air compressor 'C' is admitted into the combustion chamber 'D' through the valve 'A'. When the valve A is closed, the fuel is admitted into the combustion chamber by means of a fuel pump 'P'. Then the mixture is ignited by means of a spark plug 'S'. The combustion taken place at constant volume with increase of pressure. The valve 'B' opens and the hot gases flow to the turbine T and finally, they are discharged into atmosphere. The energy of the hot gases is thereby converted into mechanical energy. For continuous running of the turbine, these operations are repeated. The major disadvantage of this turbine is that the pressure difference and velocities of hot gases are not constant, so the turbine speed fluctuates.

7.2.1 Advantages of Closed Cycle Gas Turbine Over Open Cycle Gas Turbine

1. Reduced size.
2. Improved part-load efficiency.
3. No contamination.
4. Use of inexpensive fuel like coal is possible.
5. The filteration of incoming air is eliminated in closed cycle.

7.2.2 Disadvantages of Closed Cycle Gas Turbine Over Open Cycle Gas Turbine

1. Cooling water is required to pre-cool the turbine exhaust before it enters the compressor.
2. This system is more complex and costly.
3. A heavy and large air heater is required.
4. The response of the power plant to the changing load conditions is very poor.

7.3 APPLICATIONS AND LIMITATIONS OF GAS TURBINES

Applications : Gas turbines are used for many applications. However, some of its important applications are :

1. Military applications *e.g.* power generation in tanks.
2. Aviation and marine fields.
3. Power generation.
4. Turbo charging of diesel power plants.
5. Generation of power at peak load plants.
6. Power generation for transport applications.
7. In Steel, Oil and Chemical Industries.

Limitations :

1. Non-reversibility.
2. They are not self starting.
3. The life of the unit is comparatively shorter.
4. The unit gives more noise than other power producing units.
5. Overall efficiency of the plant is low.
6. Higher-rotor speed.

7.4 COMPARISON OF GAS TURBINES WITH RECIPROCATING I.C. ENGINES

S. No.	Gas Turbines	Reciprocating I.C. Engines
1.	It requires lesser number of sliding parts.	1. It has large number of sliding parts.
2.	The mechanical efficiency is quite high (95 %).	2. The mechanical efficiency is low (85%).
3.	The ignition and the lubrication systems are simple.	3. The ignition and the lubrication systems are complicated.
4.	It is more reliable as fire danger is less.	4. It is less reliable as fire danger is more.

S. No.	Gas Turbines		Reciprocating I.C. Engines
5.	It is very suitable for air crafts.	5.	It is less suitable for air crafts.
6.	The starting is not simple.	6.	The starting is simple.
7.	It can be driven at a very high speed.	7.	It is cannot be driven at a very high speed.
8.	It requires no cooling water.	8.	It requires cooling water.
9.	The balancing of a gas turbine is perfect.	9.	The balancing of a reciprocating I.C. engine is not perfect.
10.	The weight of gas turbine per kw of power developed is less.	10.	The weight of I.C. engine per kw of power developed is more.
11.	The cheaper fuels such as paraffin type, residue oil can be used.	11.	The costlier fuels of special grade are used.
12.	It has low pressure ratio.	12.	It has high pressure ratio.
13.	No flywheel is required.	13.	Flywheel is required.
14.	Its installation and running cost is less.	14.	The installation and running cost is more.
15.	The exhaust gases are less polluting.	15.	The exhaust gases are more polluting.

7.5 JET PROPULSION

Propulsion means 'moving forward'. The jet propulsion engine is a type of I.C. engine. In this engine, hot gases are produced by the combustion of fuel in the combustion chamber. These gases are made to discharge with very high velocity through a nozzle which produce a thrust. This thrust called propulsive force acts in a direction opposite to direction of flow of hot gases. Due to this propulsive force, the vehicle moves in the forward direction.

It should be noted that oxygen is required to burn the fuel in all the jet propulsion engines. The atmospheric air is quite suitable for this purpose, but at high altitudes where there is no air, the propulsive unit takes required amount of oxygen from a substance called oxygen carrier or oxidant.

7.6 CLASSIFICATION OF PROPULSION SYSTEMS

The propulsion systems may be classified as follow :

1. Air stream jet engines or Air-breathing engines :
   (*a*) Steady combustion system : Continuous air flow
   (*i*) Ram jet (*ii*) Turbo-jet (*iii*) Turbo-prop
   (*b*) Intermittent combustion system : Intermittent flow
   (*i*) Pulse jet or flying bomb.

2. Self contained rocket engines or Non-air breathing engines:

   (*i*) Liquid propellent (*ii*) Solid propellent.

In air stream jet engines, the oxygen required for the combustion of fuel is taken from the surrounding atmosphere whereas in a rocket engine, the fuel and the oxidiser are contained in the body of the unit which is to be propelled.

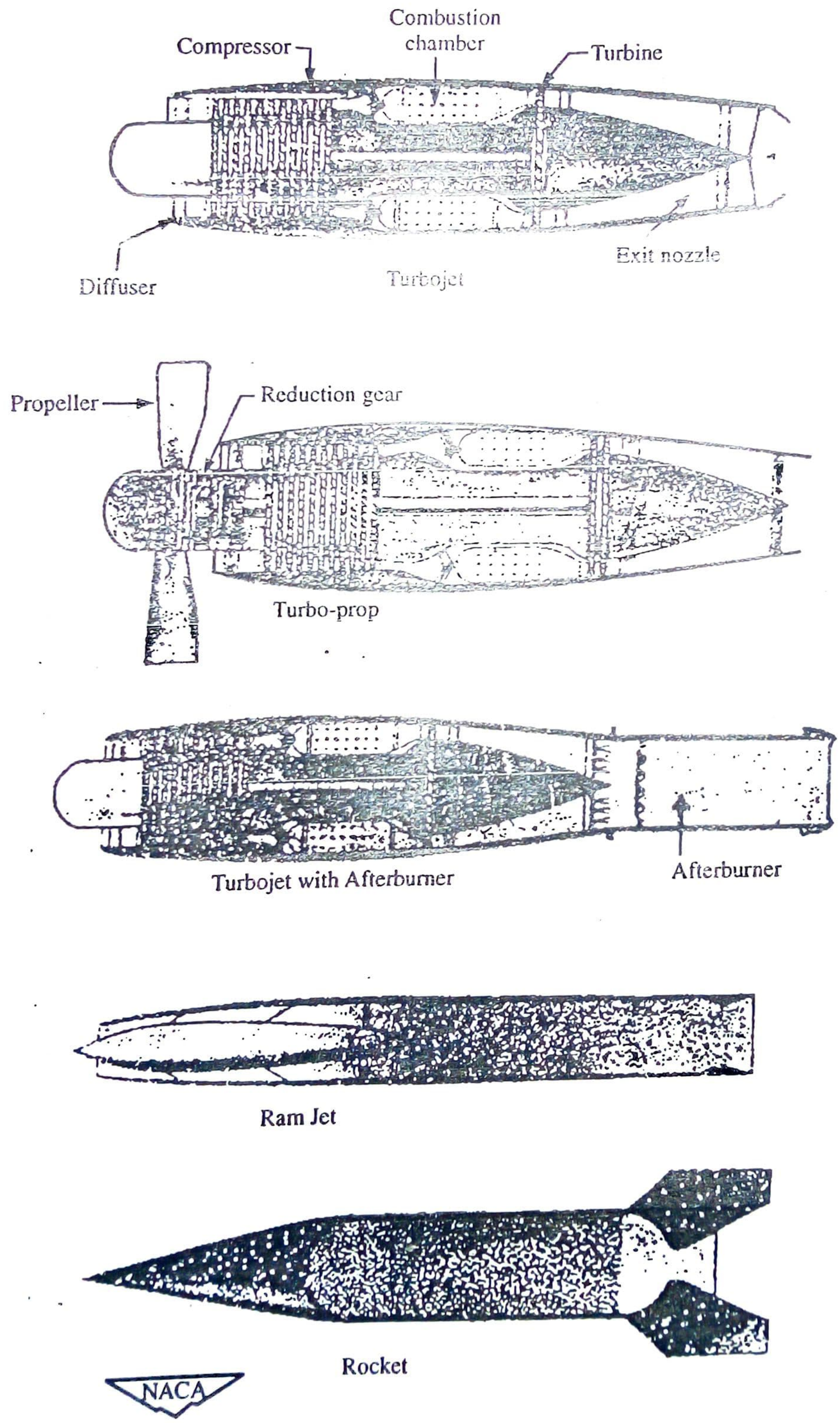


Fig. 7.6. Schematic Diagrams of Jet Propulsion Engines.

7.7 PRINCIPLE OF OPERATION OF RAM-JET ENGINE

Ram jet is also called athodyd (aero-thermo-dynamic ducts), Lorin tube or "flying stovepipe." The ram jet is the simplest of all the propulsive devices. There is neither a compressor nor a turbine in it. It consists of three main components namely diffuser, combustion chamber and the exhaust nozzle. Fig. 7.7 shows a schematic diagram of a ram jet engine.

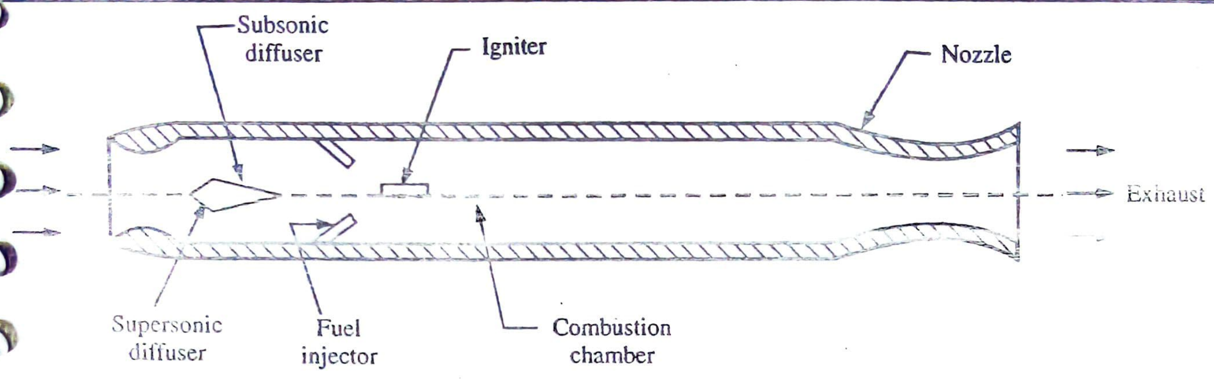


Fig. 7.7. Schematic Diagram of Ram-Jet Propulsion Unit.

The diffuser system has two parts : (*i*) Supersonic diffuser and (*ii*) Subsonic diffuser. The air enters the ram jet unit with supersonic speed and is slowed down to sonic speed in the supersonic diffuser. Consequently the pressure increases in the supersonic diffuser and the formation of shock wave occurs. The pressure of air is further increased in the subsonic diffuser which increases the temperature of the air. The fuel is then injected through injection nozzles into the combustion chamber. The fuel air mixture is then ignited by means of a spark plug and temperature of the order of 2000 K is attained. The hot gases formed in the combustion chamber pass through the exhaust nozzle and are discharged to the atmosphere in the form of high velocity. The gases leaving the nozzle provide forward thrust to the unit. The best performance of ram jet engine is obtained at flight speed of 1700 kmph to 2000 kmph.

7.7.1 Advantages of Ram-Jet Engines

Followings are the few advantages of ramjet engines :

1. Light in weight.
2. No moving parts.
3. Wide variety of fuels may be used.

7.7.2 Disadvantages of Ram-Jet Engines

The main disadvantages of ram jet engines are :

1. It cannot be started of its own from rest. It has to be accelerated to a certain flight velocity with some other device.

2. The fuel consumption is high.
3. The designing of diffuser is difficult.

7.7.3 Applications

The ram jet engines are used to fly at supersonic speeds (1.5 to 2 Mach number).

7.8 PRINCIPLE OF OPERATION OF TURBO-JET ENGINES

The arrangement of turbo-jet engine is shown in fig. 7.8. A gas turbine plant for turbo-jet is also shown in fig. 7.9.

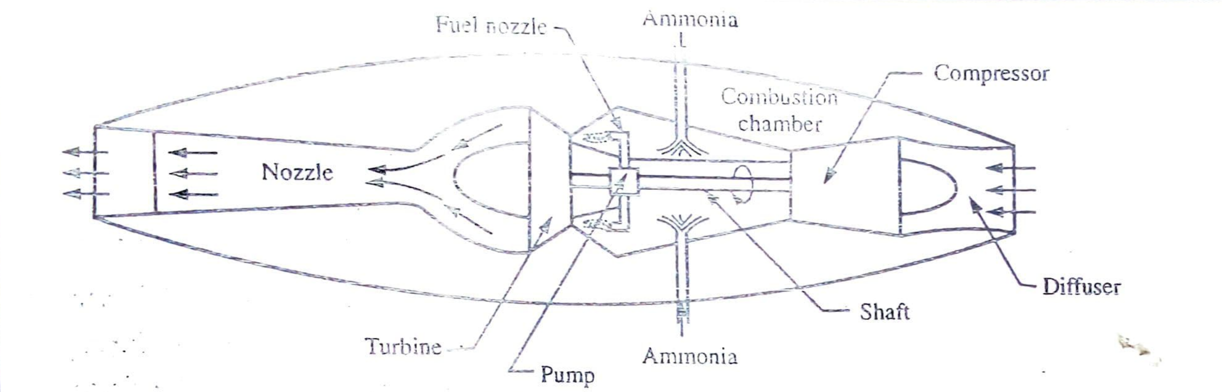


Fig. 7.8. Turbojet Engine.

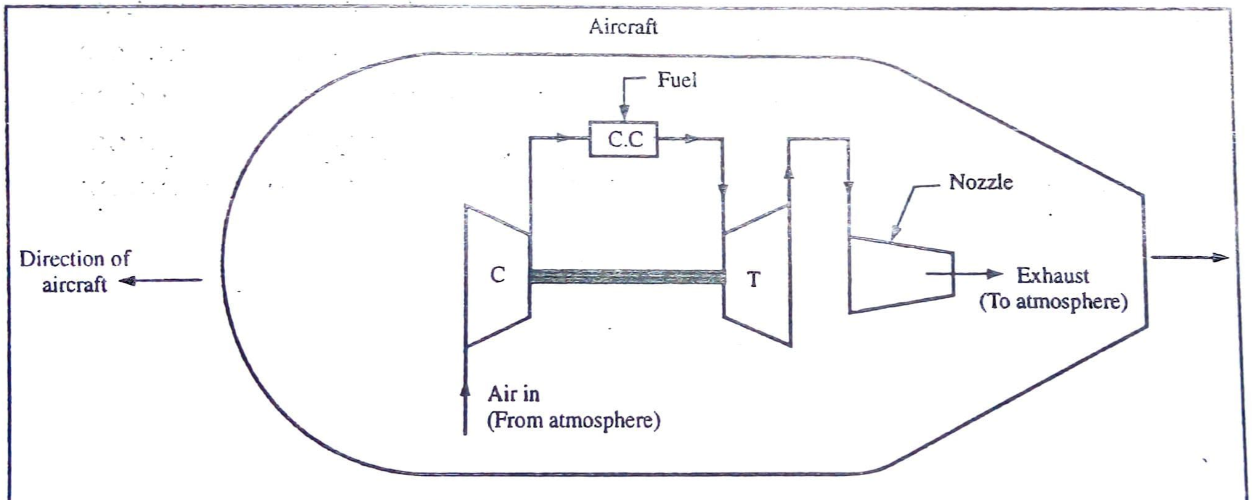


Fig. 7.9. Gas Turbine Plant For Turbo-Jet.

Turbojet engine consists of the following major parts :

1. Air compressor (Axial flow type rotary compressor),
2. Combustion chamber,
3. Turbine,
4. Nozzle.

At the entrance, a diffuser is used, which slows down the air velocity and part of the kinetic energy of the air stream is converted into pressure. This type of compression is called ram compression. After this, air is further compressed of 3 to 4 bar in a rotary compressor. Then this compressed air enters the combustion chamber where fuel is added. The combustion of fuel takes place at sensibly constant pressure and subsequently temperature rises rapidly. The hot gases then enters the gas turbine where partial expansion takes place. The power produced is just sufficient to drive the compressor, fuel pump and other auxiliaries. The gases coming out of turbine at a higher pressure are expanded in the nozzle producing a high velocity jet which gives the forward motion to the air-craft by the jet reaction.

7.8.1 Advantages of Turbo-Jet Engines

The followings are the advantages of turbo-jet engines :

1. Very less engine vibrations.
2. Power supply is smooth and uninterrupted.
3. Higher speed (more than 3000 kmph) is possible.
4. Smaller frontal area.
5. Rate of climb is higher.
6. Radio interference is much less.
7. Requirement of major overhauls is less frequent.

7.8.2 Disadvantages of Turbo-jet Engines

1. Less efficient.
2. More noisy (than a reciprocating engine).
3. Materials used are quite expensive.
4. Inefficient below 550 kmph.

7.8.3 Applications of Turbo-jet Engine

The turbo-jet unit is best suited to air-craft travelling at near sonic velocities of about 800 kmph as it gives higher propulsion efficiency at high speeds.

7.9 ROCKET ENGINE

The rocket engines are mostly used to take the vehicle outside the earth's atmosphere to launch on other planets. The chief purpose of the rocket engine is to deliver thrust in a given direction for a given period of time. The rocket engine differs from other types of jet propulsion in the manner that it does not require any outside material like air for oxidation. The fuel and oxidizer both are stored in the rocket. Therefore, the rocket can function in vacuum also and is only device capable of space flight.

7.9.1 Classification of Rocket Engines

The rockets may be classified as follow :

1. According to the type of propellants :
   (*i*) Liquid propellant rocket,
   (*ii*) Solid propellant rocket.
2. According to the number of motors :
   (*i*) Single-stage rocket,
   (*ii*) Multi-stage rocket.

7.9.2 Requirements of Rocket Propellant

A rocket engine does not use the surrounding air as oxidiser. The fuel and the oxidiser are carried into the body of the unit which is to be propelled. The two substances together are usually called the propellant.

The requirements of an ideal rocket propellant are :

1. High heat value.
2. Highest possible density so that it occupies less space.
3. Low toxicity and corrosiveness.
4. Reliable and smooth ignition.

7.10 PRINCIPLE OF WORKING ROCKET ENGINES

(*a*) Principle and Working of Liquid Propellant Rocket Engine

A liquid propellant rocket engine uses liquid oxygen and hydrocarbon fuel. The elements of a liquid propellant rocket engine are shown in fig. 7.10.

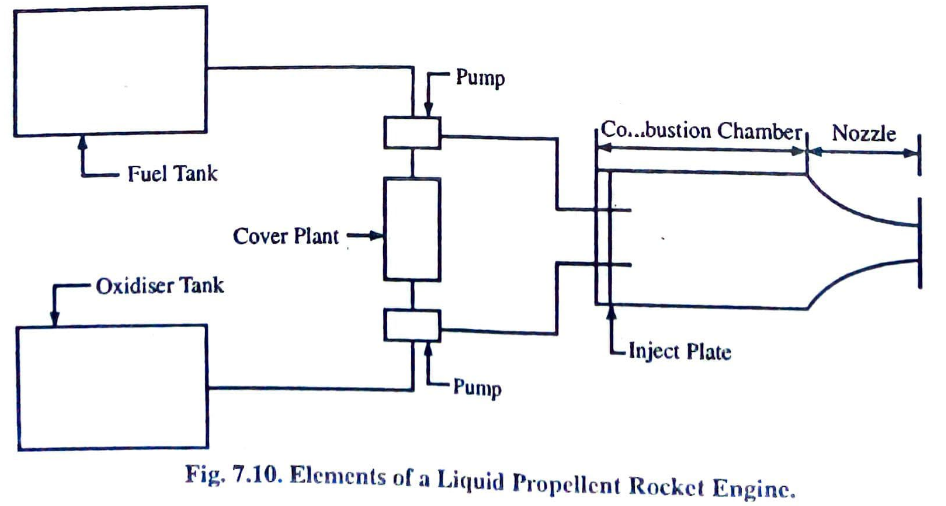


Fig. 7.10. Elements of a Liquid Propellent Rocket Engine.

The propellants at a low pressure are contained in the supply tanks *i.e.* fuel tank and oxidiser tank. When large quantity of propellants are needed to produce high thrust for larger duration, the propellants are pressurised by the pumps which are operated by a turbine. The turbine may be a steam turbine where steam is raised by the action of catalyst on hydrogen peroxide or a gas turbine where working medium formed by the fuel and the oxidiser is delivered to the turbine unit. However, in cases where only a small amount of propellant is needed, it is advantageous to pressurise the propellants by means of stored high pressure gases.

The pressurised propellants are then delivered to the combustion chamber where constant pressure combustion occurs. The hot combustion products then undergo reversible adiabatic expansion down to atmospheric pressure in a nozzle. The reaction to high velocity jet gives the propulsive force. Quite often the liquid propellant is circulated around the walls of the combustion chamber and nozzle and it provides the necessary cooling effect.

(b) Principle and Working of Solid Propellant Rocket Engine

The components of a solid propellant rocket engine using restricted burning and unrestricted burning are shown in Fig. 7.11.

In solid propellant rockets, the fuel and the oxygen are mixed and formed into a solid grain which is placed in the combustion chamber. Thus there is no fuel supply system.

In the restricted burning rocket engine, the burning of the propellant is restricted so that it burns in one direction only. The restricted burning also called the cigarette burning which can be accomplished by pouring the charge when liquid, so that on solidification it fits the chamber tight. Restricted burning rockets are preferred when the unit is required to deliver a small thrust for a relatively longer duration.

In the unrestricted burning, the entire charge is free to burn on all surfaces at the same time. Such rockets are used where it is desirable to develop large thrust for a short duration *i.e.* in launching rockets.

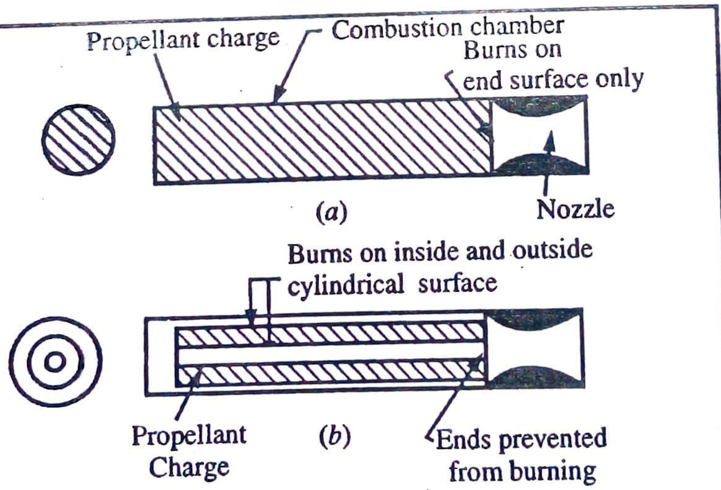


Fig. 7.11. Elements of a Solid Propellant Rocket Engine.

The combustion chamber of a solid propellant rocket has to be large enough to store the entire propellant and also strong enough to withstand the sufficiently high combustion pressures. Again, the propellant being solid cannot be used to cool the combustion chamber and the nozzle and there is danger of overheating. As such, these rockets are suitable for producing thrusts only for shorter durations.

7.10.1 Applications of Rockets

1. Launching satellites.
2. Used in long range missiles.
3. Lethal weapons.
4. For spaceships.
5. Long range artillery satellites.
6. For research work.
7. Firework display and signalling.

7.11 FUEL/PROPELLANT USED IN JET PROPULSION

The fuel used in jet propulsion must contain a balanced source of chemical energy for converting into heat energy. A liquid propellant engine uses liquid oxygen and hydrocarbon fuels like gasoline, kerosene etc. At atmospheric pressure and temperature at sea-level, these fuels are available in liquid form and therefore, need not to be refrigerated.

Fuel/propellant used in jet propulsion should have the following characteristics :

(*i*) It should have a high heat value.

(*ii*) It should have highest possible density so that it occupies less space.

(*iii*) it should have low toxicity and corrosiveness.

(*iv*) It should be reliable and its ignition should be smooth.

(*v*) It should have high boiling point at low pressure.

(*vi*) Its characteristics should not change with the change in atmospheric conditions.

EXERCISES

A. MULTIPLE CHOICE QUESTIONS :

1. Gas turbine works on

(*a*) Otto cycle. (*b*) Diesel cycle.

(*c*) Dual cycle. (*d*) Brayton cycle.

2. Turbo propelled engine resembles in construction to :

(*a*) Steam engine. (*b*) Diesel engine.

(*b*) Turbojet engine. (*d*) None of the above.