STEAM TURBINES & CONDENSERS

UNIT-II

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Steam Turbine

INTRODUCTION

The steam turbine is a prime-mover in which a part of energy of steam due to its high pressure & temperature, is converted in to mechanical energy. In turbine, gradual changes in the momentum of a fluid are utilized to produce rotation of the rotor blade wheel.

The steam turbine has got variety of uses as follows:-

For driving pumps,
For power generation
For Transport like in ship propellers
For driving compressor etc

After studying this chapter, we shall be able to under-stand, Basic principles of steam ~~types~~, turbines, types of steam turbines, their working, their analysis. compounding, advantages, condensers, their types etc.

Classification of Steam Turbines

1. The most important classification with respect to action of steam (rate of change of angular momentum of steam) is

(a) Impulse turbine
(b) Reaction turbine
(c) Mixed of impulse & reaction turbine

2. On the basis of direction of steam flow
(a) Axial
(b) Radial
(c) Tangential
(d) Mixed

3. On the basis of number of reduction stages
(a) Single-stage
(b) Multi-stage

4. On the basis of exhaust pressure
(a) Condensing
(b) Non-condensing

5. On the basis of inlet pressure
(a) Low pressure
(b) Medium pressure
(c) High Pressure

6. On the basis of application
(a) Stationary turbine
(b) Mobile turbine

7. On the basis of number of cylinders
(a) Single cylinder
(b) Multi-cylinder

Simple Impulse Turbine :-

This turbine consist of oriented nozzles & a rotary blades as shown in fig . The blades are attached over the wheel which in turn keyed to the shaft.

As the steam flows through the nozzle its pressure decreases, while volume & velocity increases. When this high velocity steam passes over the blades, the velocity of steam decreases & the pressure remains constant. Thus, the wheel rotated & kinetic energy of steam is converted in to mechanical energy. The example of this turbine is "De Laval turbine". The disadvantage of this turbine is, as all kinetic energy is to be absorbed by one ring of rotary blades (in single stage), so the velocity of rotary blade is too high (25000 to 30,000 rpm)
The disadvantage can be overcome by compounding of turbines.

REACTION TURBINE :- In reaction turbine.

the steam expands as it flows over blades which, therefore, act, as nozzles.

In a pure reaction turbine, high pressure & temperature steam is supplied to the nozzle in which steam expands. As there nozzle are fixed radially, over drum two or more in numbers as shown in fig moves due to reaction exerted by expansion of steam. Thus, the shaft over which nozzles are fixed moves in opposite direction to the direction of steam jet.

But present day, reaction turbines are the combination of impulse turbine & reaction turbine. The expansion of steam occurs with in both the stationary & moving blades. Thus the rotation, of the shaft or drum carrying the blades is the result of both impulse & reactive forces in the steam.

The function of fixed or stationary blades are same as the set of nozzles & also alter the direction of steam. When the steam expands over the fixed blades, there is increase in velocity & decrease in pressure. But the velocity decreases while passing over moving blades as steam imparts it energy to moving blades. There is small pressure drop in each stage, thus, number of stages in a reaction turbine is much greater than in an impulse turbine of same ~~[illegible]~~ capacity. After each stage, there is gradual increase in volume & decrease in pressure also, so the diameter of turbine must increase gradually after each stage,

Comparison of IMPULSE & REACTION TURBINE

S.No.	Impulse Turbine	Reaction Turbine
1.	The pressure drop (expansion) of fluid occurs only in nozzles, not ~~in~~ over moving blades.	1. The pressure drop of fluid occurs in fixed blades as well as in moving blades.
2.	The blades are of profile shape.	2. The blades are of aerofoil shape.
3.	The blade passage is of constant cross-sectional area as there is no expansion.	3. The blade passage is of variable cross-sectional area to allow expansion.

S.No.	Impulse Turbine	Reaction Turbine
4.	The relative velocity of steam remains constant or reduces slightly as the steam moves over blades	4. The relative velocity of steam increases as it expands while the steam glides over moving blades
5.	As the pressure drop is large, the number of stages required are less for same capacity. Hence less space needed per unit power	5. As there is small pressure drop in each stage, thus, number of stages required are much greater for same capacity. Hence more space needed per unit power.
6.	More frictional losses occurred as compared to leakage losses	6. More leakage losses occurred as compared to frictional losses.
7.	It is used for small power generation	7. It is used for medium & higher power generation
8.	The steam speed & blade speed is large	8. The blade speed & steam speed is small.
9.	Because of symmetrical shape of blades, they are easy to manufacture	9. Because of aerofoil shape, they are difficult to manufacture.

COMPOUNDING OF STEAM TURBINES

In case of impulse turbine, all kinetic energy is to be absorbed by one ring of rotary blades i.e. in single stage, so the velocity of rotary blade is too high of the order of 25,000 - 30,000 rpm. It cannot be directly coupled with external equipment. Moreover, for power generation, we require 50 Hz i.e. 3000 rpm (In India). So, reduction in speed is required. The compounding

is the method for reducing the speed (r.p.m.) of turbine up to required one.
There are three methods of compounding.

1. Velocity compounding
2. Pressure Compounding
3. Pressure velocity Compounding.

1. Velocity Compounding :- In this turbine, velocity drop is arranged in many small drops through many rows of moving blades instead of single row of moving blades.

It consists of a nozzle or a set of nozzles & rows of moving blades attached to the rotor & rows of fixed blades known as guide blades attached to the casing. The function of these guide blades is to re-direct the steam flow without altering its velocity to the following next row moving blades where again work is done on them & steam leaves the turbine with a low velocity.

The steam from the boiler is passed through the nozzles where its expanding to condenser pressure, acquires very high velocity. This high velocity steam is then passed through a number of moving blades & then guide blades. A fall in velocity occurs every time, when the steam passes over a ring of moving blades. The steam thus leaves the turbine with a low velocity.

This method of compounding is used in Curtis Turbine.

Advantages :

1. Initial cost is low due to lower number of stages
2. Less space required
3. As most of pressure drop occurs in the nozzles, turbine casing is subjected to comparatively low pressure, hence it need not be strongly made.

Disadvantages:

1. The friction losses are high. Hence effiency is low.

2. Pressure Compounding :- In this turbine, the compounding is done for pressure of steam only i.e. to reduce the high rotational speed of turbine the whole expansion of steam is arranged in a number of steps by employing a number of simple impulse turbine in a series on the same shaft. Each of these simple impulse turbine consists of one set of nozzles & one row of moving blades is known as single stage of the turbine, & thus, this turbine consists of several stages. In this turbine, the whole pressure drop from inlet pressure to the condenser pressure split into a series of smaller pressure drops across several stages of impulse turbine, &, hence, it is known as pressure compounding.

This method of compounding is used in Rateau Turbine.

8.

Advantages:-

1. Friction losses are less as compared to velocity compounding method. Hence efficiency is high.
2. Efficiency also improves due to the ratio of blade velocity to steam velocity remains constant.

Disadvantages

1. The initial cost is high due to larger number of stages required.

3. Pressure-Velocity Compounding :- It is a combination of pressure compounding method & velocity compounding method. The total drop in steam pressure is carried out in two stages & the velocity obtained in each stage is also compounded. The arrangement of this compounding is as shown in fig.

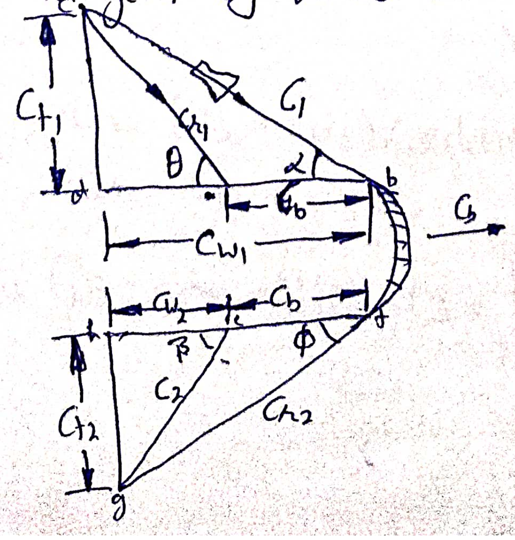
This method is used in Moore & Curtis turbine.

9: IMPULSE TURBINE

Velocity Diagram for Moving blade

The velocity of steam relative to the blades, work done on the blades, etc, can be easily found out from velocity diagram.

Let C_b = Linear velocity of moving blade in m/s
C_1 = Absolute velocity of steam entering moving blades in m/s
C_{r_1} = Relative velocity of steam to moving blade at inlet.
C_{f_1} = Axial component of velocity of C_1 or velocity of flow at inlet.
C_{w_1} = Tangential component of velocity C_1 or velocity of whirl at inlet.
α = Nozzle angle
θ = Entrance angle of moving blade
C_2 = Absolute velocity of steam at outlet from moving blade
C_{r_2} = Relative velocity of steam to moving blade, at exit
C_{f_2} = Axial component of velocity C_2
C_{w_2} = Tangential component of velocity C_2
ϕ = Angle of blade at outlet
β = Angle of discharch which the steam makes with the tangent of wheel at exit of moving blade

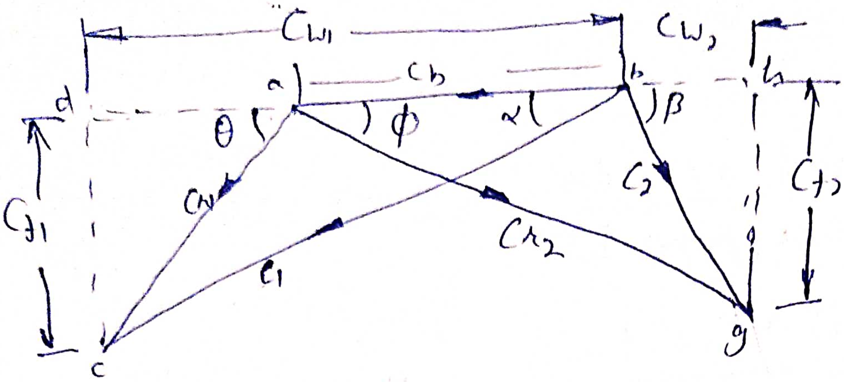


Speed ratio $\rho = \frac{C_b}{C_1}$

Blade velocity co-efficient,

$$K = \frac{C_{r_2}}{C_{r_1}}$$

To solve the problems on turbine, combine both the inlet & outlet velocity diagram on same base.



Work done on blade :- The effective component of steam jet which produces tangential force & causes the wheel to rotate is the velocity of whirl. So the work on the blade is done by this tangential force & may be found out from the change of momentum in the direction of motion. The velocity of flow is responsible for producing the axial thrust on the wheel.

Let m_s = steam flow through blades in kg/s

∴ Tangential force on the wheel

= mass of steam × acceleration

$= m_s (C_{w1} \pm C_{w2})$

Work done on blade /s = force × distance velocity

$= m_s (C_{w1} \pm C_{w2}) \times C_b$

{NOTE: If $\beta < 90$, then $(C_{w1} + C_{w2}) = C_w$ addition take place
If $\beta > 90°$, then $C_{w1} - C_{w2} = C_w$ }

Blade or Diagram efficiency = $\frac{\text{Work done on blade}}{\text{Energy supplied to the blade}}$

$\therefore$ Blade or diagram efficiency $= \dfrac{m_s (C_{w_1} \pm C_{w_2}) \times C_b}{\frac{m_s C_1^2}{2}}$

$$= \frac{2 C_{bl} (C_{w_1} \pm C_{w_2})}{C_1^2}$$

Now, Stage efficiency $= \dfrac{\text{Work done by blade}}{\text{Total energy supplied per stage}}$

$$= \frac{(C_{w_1} \pm C_{w_2}) \times C_b}{h_d}$$

where, h_d is heat drop in nozzle per kg of steam.

& Axial thrust on wheel = mass of steam flow/sec × change in axial component of velocity

$$= m_s (C_{f_1} - C_{f_2})$$

It is due to the difference between the axial component of velocity at entrance & exit.

* Energy converted to heat by blade friction

$$= m_s (C_{r_1}^2 - C_{r_2}^2)$$

&

$$C_{r_2} = k\, C_{r_1}$$

where $k \rightarrow$ Blade velocity co-efficient

If neglect the friction

then

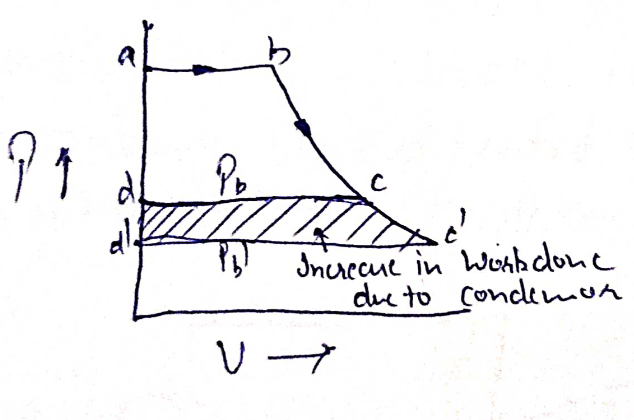
$$C_{r_2} = C_{r_1}$$

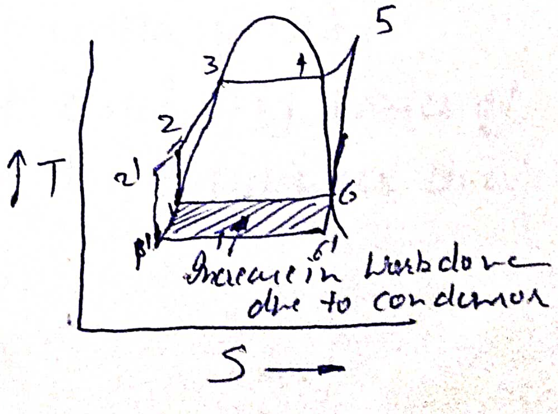
CONDENSERS

Condensers is defined as a closed vessel in which exhaust steam from steam turbine or engine is condensed by cooling water, & vaccum is maintained, resulting in an increase in workdone & efficiency of steam turbine plant & use of condensate as a feed water to the boiler.

FUNCTION OF A CONDENSER

1. It convert (condensed) exhaust steam from steam turbine or engine in to hot water.
2. It maintain a low back pressure or exhaust pressure on the exhaust side of the steam turbine or engine. So that, the steam expands to a greater extent which results in an increase in available heat energy for converting in to mechanical work. Hence, work done & efficiency of a turbine plant is increased.





Effect of using condenser on P-V & T-S diagram

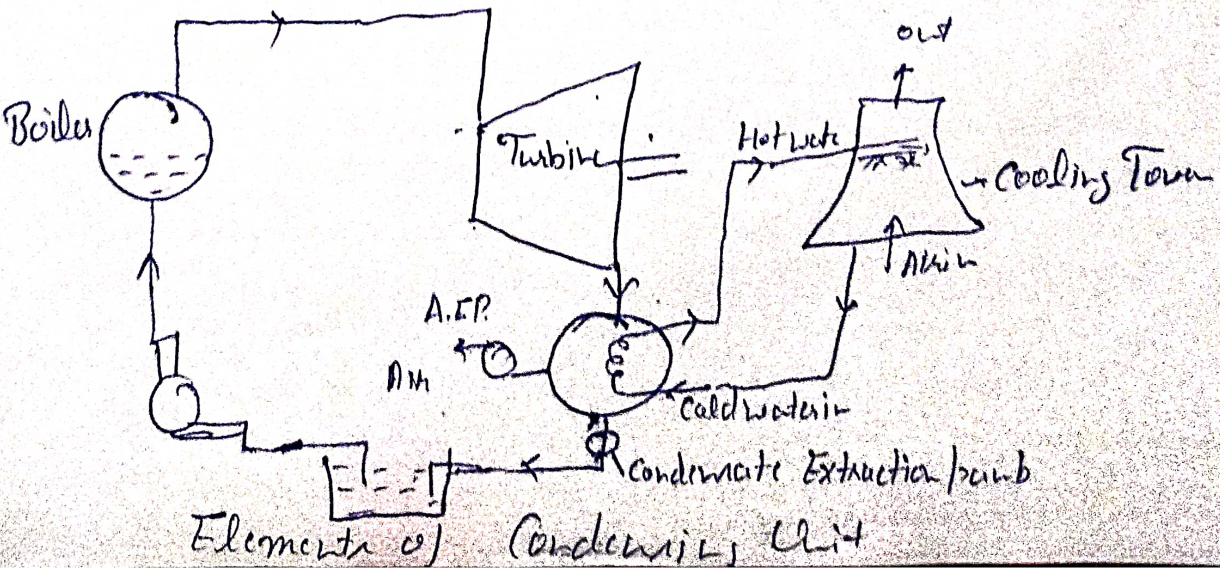
The area abcd shows the work done by non-condensing plant & the area abc'd' show the work done by condensing unit.

Advantages of Condenser unit

1. The work done & efficiency of the plant increase due to increased available heat drop.
2. The condensate is collected in a hot-well from where it is pumped back to boiler as feed water. Recovering gives the boiler, pure & hot feed water.
3. Supplying hot water to boiler reduces thermal strain.

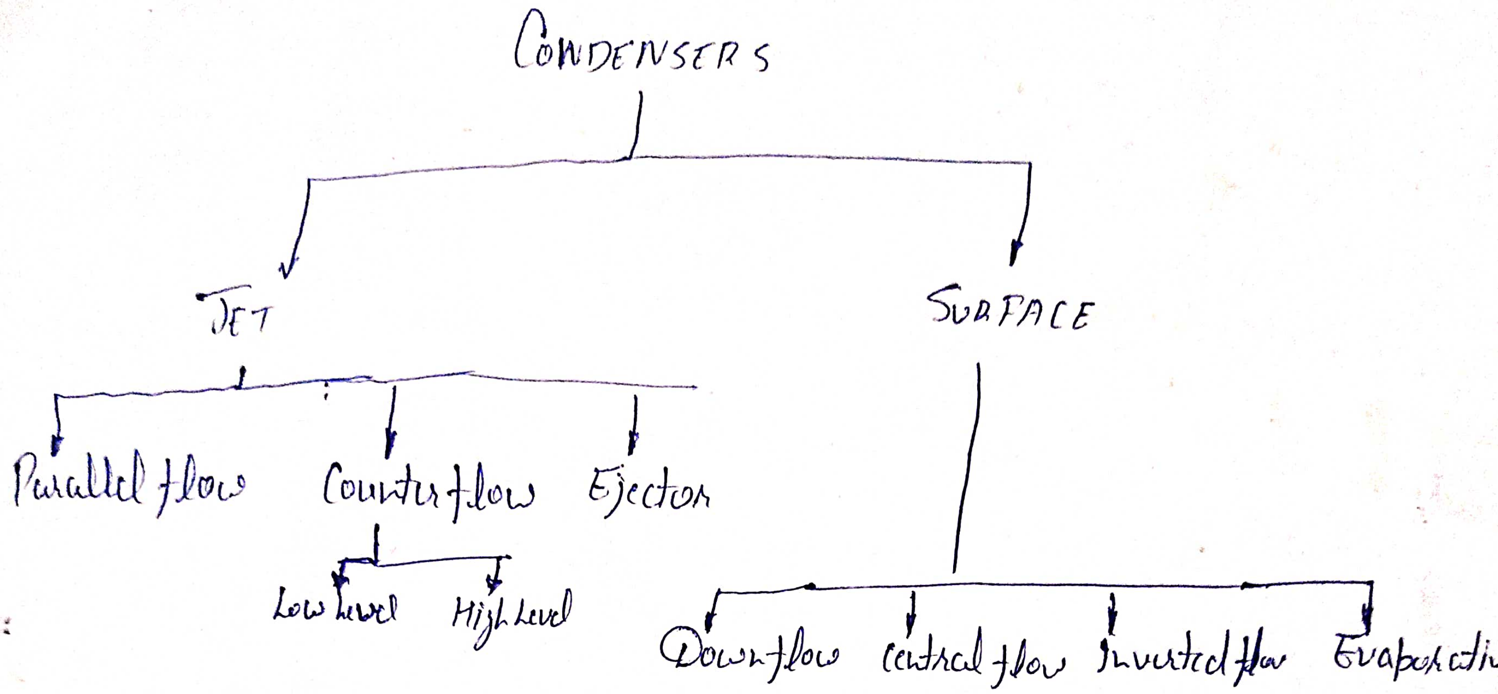
Elements of a steam Condensing plant

1. A Condenser (To condense the steam)
2. A dry air pump whose purpose is to remove air & other non-condensable gases from condenser.
3. A condensate extraction pump, which extract the condensed steam collected in the hot-well of the condenser.
4. Supply of cooling (or injection) water
5. Hot well where the condensate can be discharged & from which the boiler feed water is taken.
6. A cooling tower to recool the circulating water of the condenser which is heated in the condenser due to condensation of steam.



Elements of Condensing Unit

Classification Of Condensers



Jet Condensers: The exhaust steam & water come in direct contact with each other & temperature of condensate is the same as that of cooling water leaving the condenser.

Surface Condensers. There is no direct contact between the steam to be condensed & the cooling water, there is a wall interposed between them through which heat is transferred by conduction & convection.