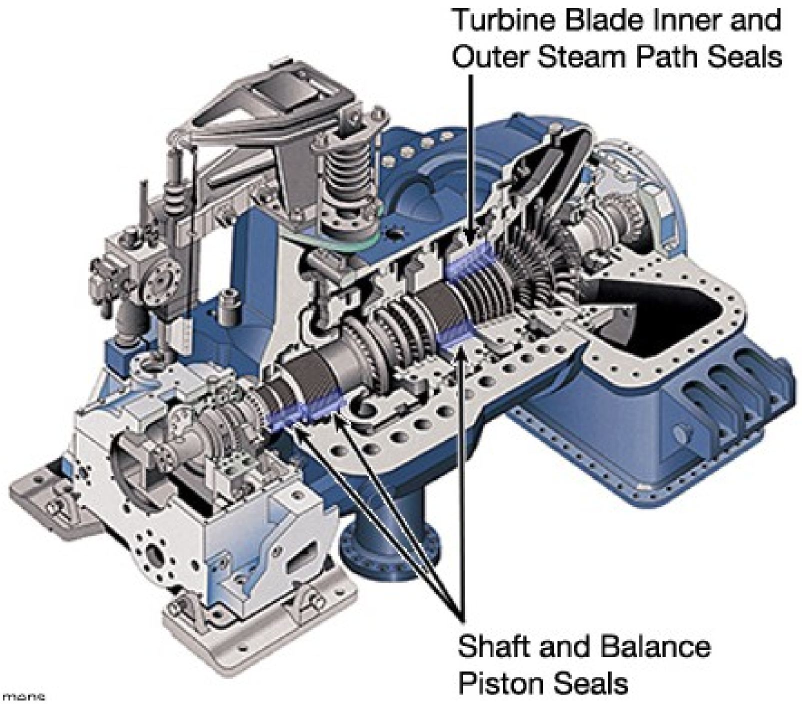
PRIME MOVERS

Prime Movers



3.0 Prime Movers

Definition: A device which produces useful power output is called a prime mover.
Classification:
Prime movers are classified as follows:

1. Electric Motors
2. Engines.
    a. External Combustion Engine. Ex. Steam Engine
    b. Internal Combustion Engine
        i) Petrol engine
        ii) Diesel engine
3. Turbines.
    c. Steam turbine
    d. Gas turbine
    e. Water turbine
    f. Wind turbine

3.3 Steam Turbine

A steam turbine is defined as a prime mover in which the heat energy of the steam is transformed into mechanical energy directly in the form of rotary motion. The heat energy of the steam is first converted into kinetic (velocity) energy which in turn is transformed into mechanical energy of rotation. A steam turbine is mainly used as an ideal prime mover to drive the electric generators in thermal power plants to generate electric power. They are also used to propel ships and to drive the uniform speed machines such as centrifugal gas compressors, textile and sugar industry machineries, etc.

Classification of Steam Turbines:

Steam turbines are classified based on the manner in which drop in pressure due to expansion of the steam that occurs either before it is passed on to the turbine wheel or on the turbine wheel itself and the nature of the resulting propelling force. Accordingly the steam turbines are classified as

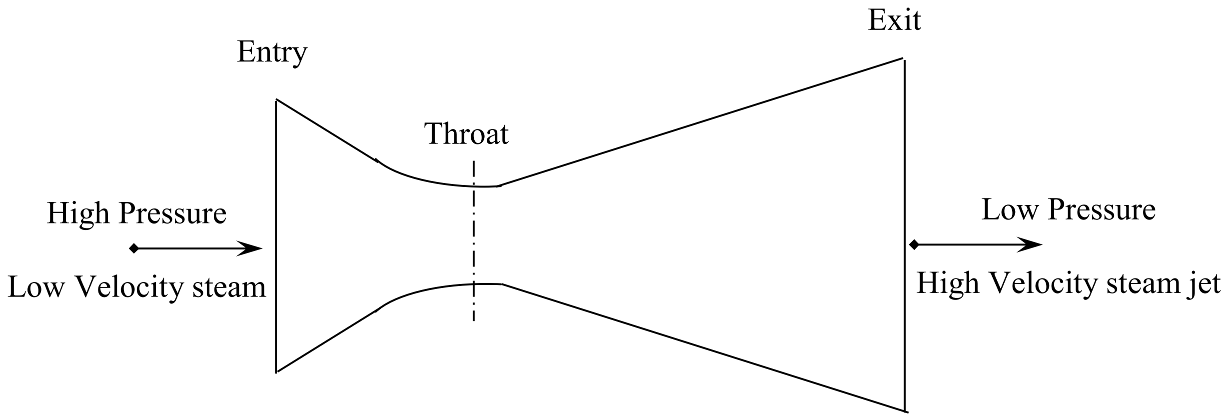
1. Impulse Turbine
2. Reaction Turbine

Impulse Turbine

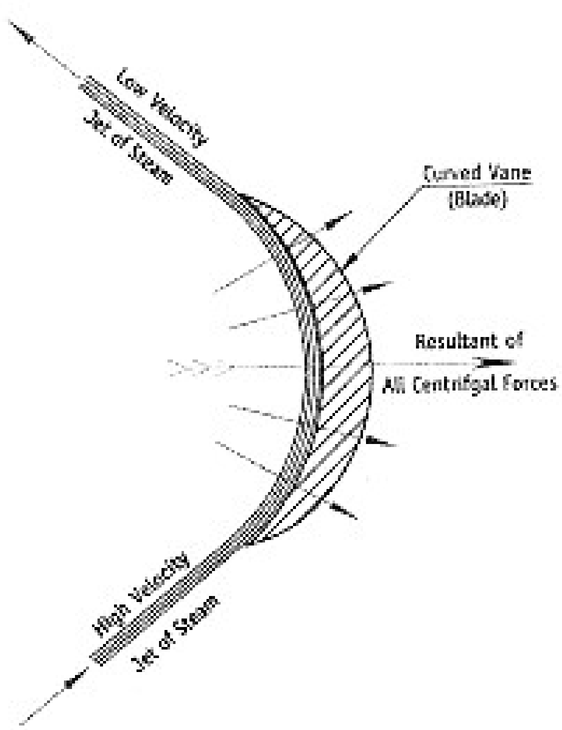
Propelling Force in an Impulse Turbine:

In an impulse turbine steam is made to fall in its pressure by expanding in a nozzle. Due to this fall in pressure, a certain amount of heat energy is converted into kinetic energy which sets the steam to flow with a greater velocity. The rapidly moving particles of the steam enter the rotating part of the turbine where it undergoes a *change* in the direction of motion which gives rise to *a change of momentum and therefore a force.* This constitutes the driving force of the turbine.

In an impulse turbine a high velocity jet of steam is produced by expanding a high pressure steam in a convergent – divergent nozzle as shown in figure below. The steam at high pressure and relatively low velocity enters the nozzle and as it passes between the entry and the throat, it expands to a low pressure. Due to this expansion in this portion of the nozzle the enthalpy of the steam is reduced. As there is no external work done and heat transfer in the nozzle, this *loss in the enthalpy of the steam must therefore be equal to the increase in the velocity (kinetic energy) of the steam.* Therefore a jet of steam at high velocity comes out of the throat section of the nozzle. The divergent portion of the nozzle beyond the throat is provided to complete any residual expansion without the lateral spreading of the high velocity jet of steam.

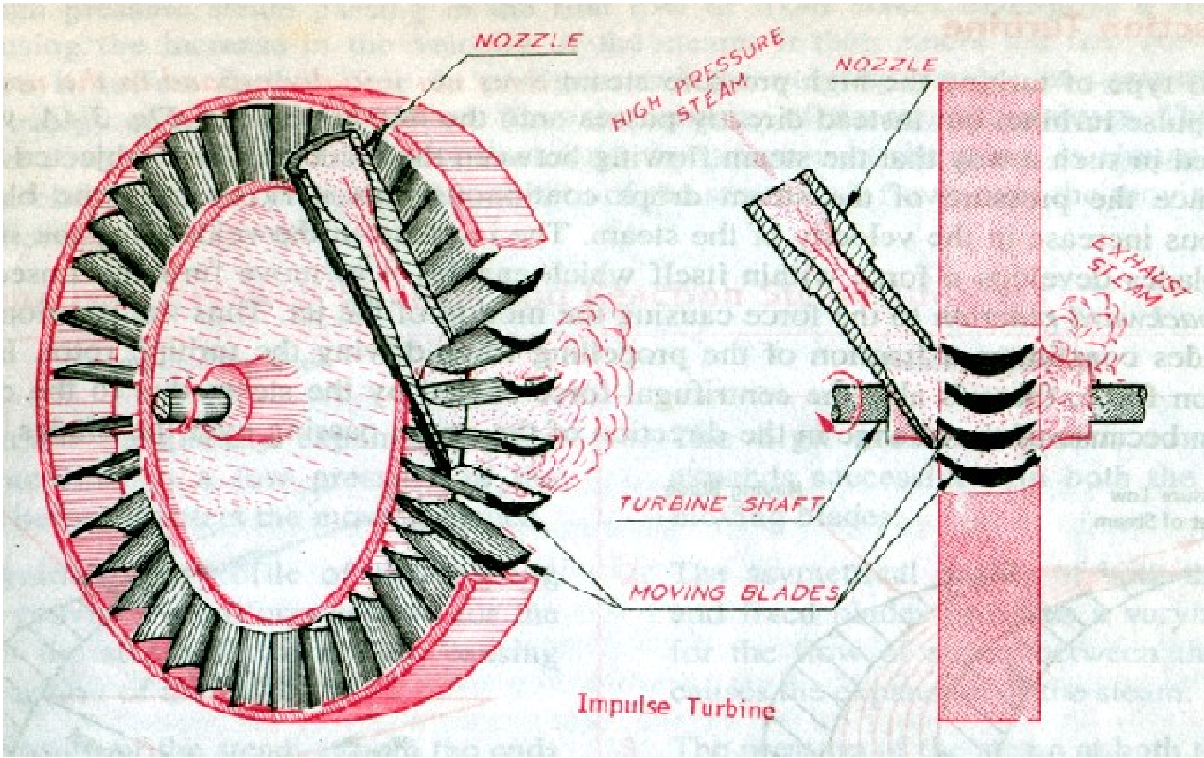


Expansion of Steam in Nozzle



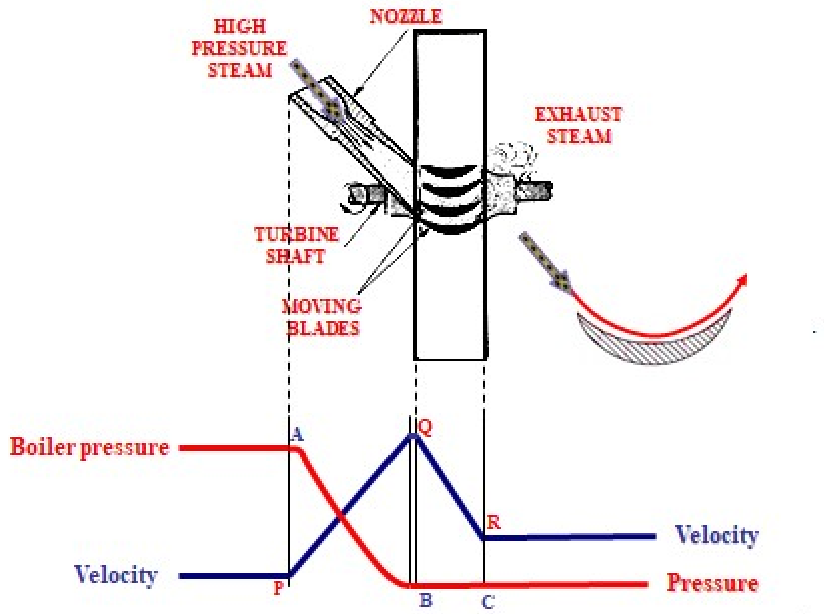
Propelling Forces in an Impulse Turbine

The high velocity jet of steam coming out of the nozzle is made to glide over a curved vane, called *blade.* The jet of steam gliding over the blade gets deflected in the circumferential direction. This causes the particles of steam to undergo a *change in the direction of motion* which gives rise to a *change of momentum* and therefore a *force,* which will be *centrifugal* in nature. The particles of steam exert centrifugal pressures all along their path on the curved surface of the blades as shown in figure above. The *resultant* of all these centrifugal forces acting on the entire curved surface of the blade causes it to move. When a number of such blades are fitted on the circumference of a revolving wheel called rotor as shown in the figure below they get exposed to the action of the steam jet in succession which in turn sets the *rotor* in continuous rotation.



Impuse Turbine

Pressure – Velocity changes in an Impulse Turbine:



Pressure – Velocity Changes in an Impulse Turbine

In an impulse turbines the steam is expanded from its high initial pressure to a lower pressure before it is delivered to the moving blades on the rotor. The pressure of the steam over the blades will be at a lower pressure. However, the velocity of the steam continuously decreases as it glides over the blades owing to the conversion of kinetic energy into mechanical energy of rotation. Thus in the impulse turbines the mechanical power is produced by the combined action of the resultant of the centrifugal pressures due the change of momentum and the effect of change of velocity of the steam as it glides over the blades.

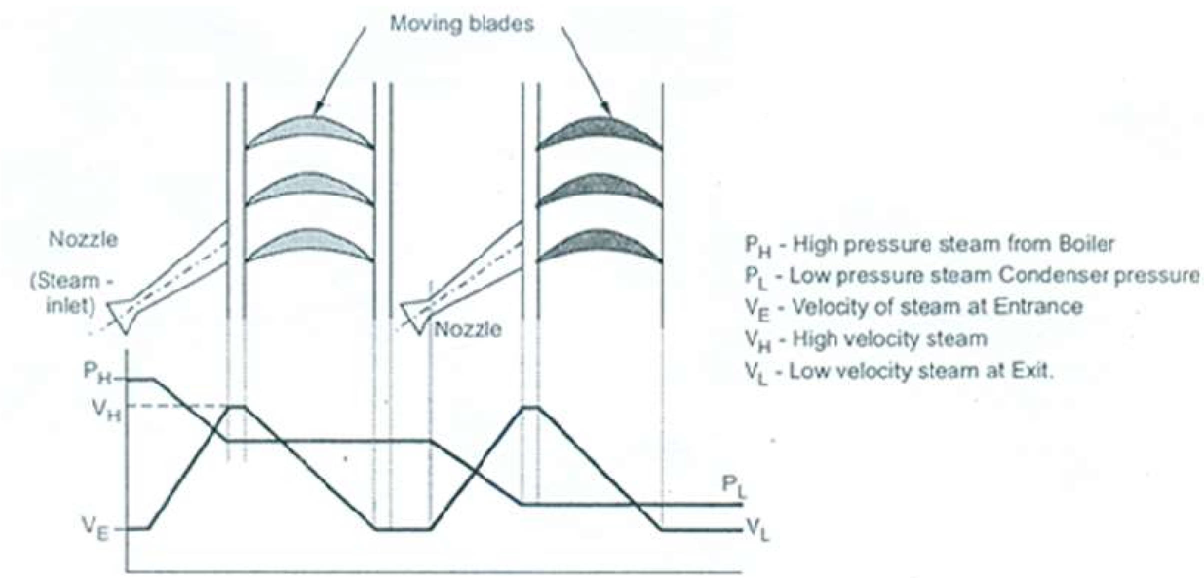
The above figure illustrates the pressure velocity changes in an impulse turbine. The upper portion shows the nozzle and the blades and the lower portion shows the variation of pressure and velocity of the steam as it flows through the nozzle and over the blades. Since the expansion of the steam takes place in the nozzle, the pressure drop is represented by AB. As there is no change in the pressure of the steam that is passing over the blades, this flow is represented by the horizontal line BC. Since the velocity of the steam in the nozzle increases due to the expansion of the steam, the increase in velocity of the steam is represented by PQ. As the blades absorb the kinetic energy of the steam as it flows over it, the velocity decreases. This is represented by QR.

Compounding of Impulse Steam Turbines:

For maximum efficiency the entire pressure energy of the steam must be completely converted into kinetic energy. If the entire expansion of the steam from high pressure to low pressure takes place in a single set of nozzles, the turbine rotor rotates at a very high speed, which poses number of technical difficulties such as increase in vibrations, quick overheating of bearings, impossibility of direct coupling to other machines (generators), difficulty in lubrication etc. Therefore the expansion of the steam is performed in several stages so as to reduce the rotor speed. Hence utilization of the high pressure energy of the steam by expanding it in successive stages is called compounding. The concept of compounding applies to a impulse turbine. The different methods of compounding are

1. Pressure Compounding.
2. Velocity Compounding.
3. Pressure – Velocity Compounding.

1. Pressure Compounding:

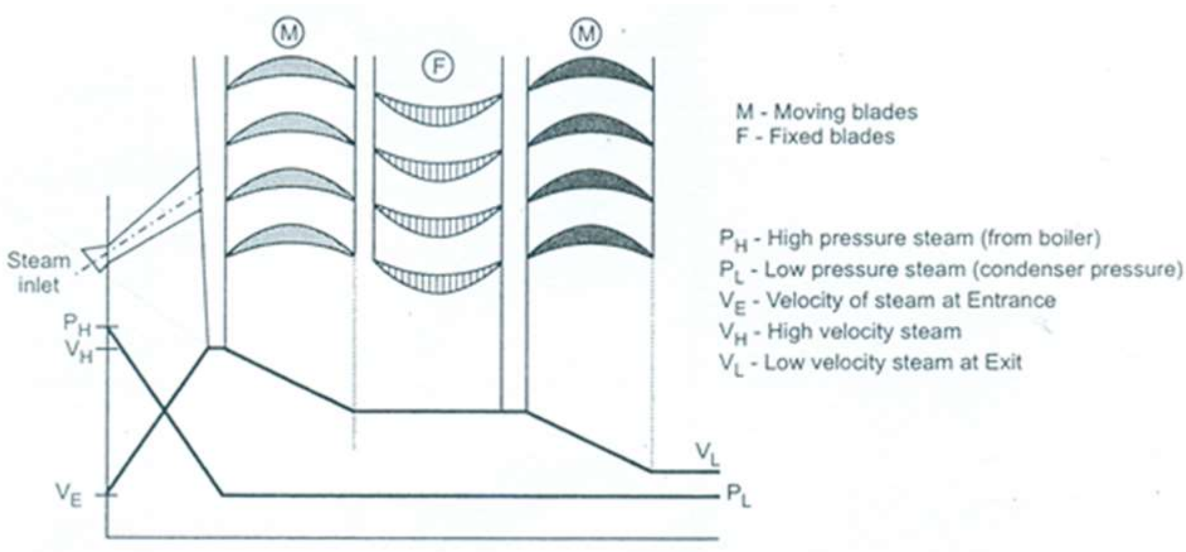


Pressure Compounded Impulse Steam Turbine

Pressure compounded steam turbine comprises alternate rows of fixed nozzles and moving blades arranged in series. Each set comprising one row of fixed nozzles and one row of moving blades is called a stage. The high pressure steam expands in the nozzles of the first stage with a small pressure drop leading to conversion of a small fraction of pressure energy into kinetic energy. The steam with this small amount of kinetic energy then enters the moving blades of first stage where it undergoes a change of momentum and gives up all its kinetic energy which is absorbed by the rotating wheel. The steam from the first stage then enters the second stage where further drop in pressure occurs leading to simultaneous increase in kinetic energy which is immediately absorbed by the wheel. The process continues in the remaining stages until the steam pressure reduces to the exhaust pressure or condenser pressure.

The pressure compounded steam turbine facilitates transformation of a small portion of pressure energy into kinetic energy in each stage. Hence steam velocity is much lower which reduces the rotational speed of the turbine.

2. Velocity Compounding



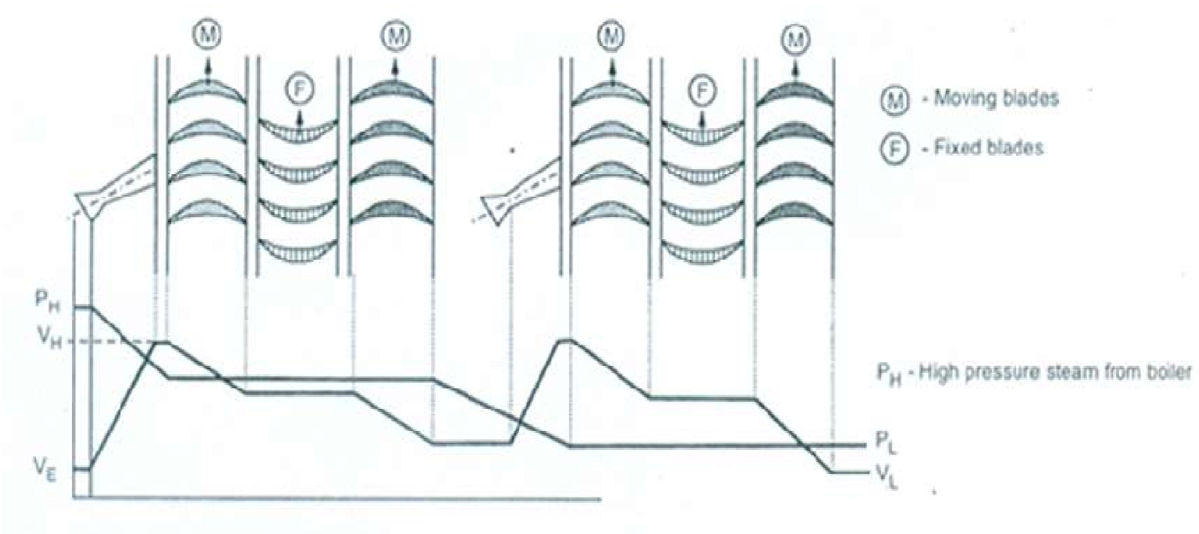
Velocity Compounded Impulse Steam Turbine

Velocity compounded steam turbine comprise of one set of nozzles and two or more rows of moving blades arranged in series. In between two rows of moving blades one set of fixed blades are suitably arranged. These fixed blades are fitted to the casing and therefore do not rotate. They guide the steam from one row of moving blade to the next.

The steam entirely expands in the nozzle from an initial high pressure down to a lower exhaust pressure or condenser pressure. The high velocity jet of steam flowing out of the nozzle enters the first row of moving blades where it undergoes a change of momentum and gives up only a fraction of its kinetic energy to the wheel and issues out from the first set of moving blades with a fairly high velocity. It then enters the first row of fixed blades which redirects it to the second row of moving blades. As it passes over second row of moving blades it undergoes change in momentum for the second time and gives up that fraction of its kinetic energy to the wheel. If required the process continues in the remaining stages where it gives up the remaining kinetic energy and finally leaves the last row of moving blades with little residual velocity.

Since in this type of turbine kinetic energy is absorbed by different rows of moving blades, the speed of the wheel will be relatively less as compared to the turbine having only one row of moving blades.

3. Pressure – Velocity Compounding:

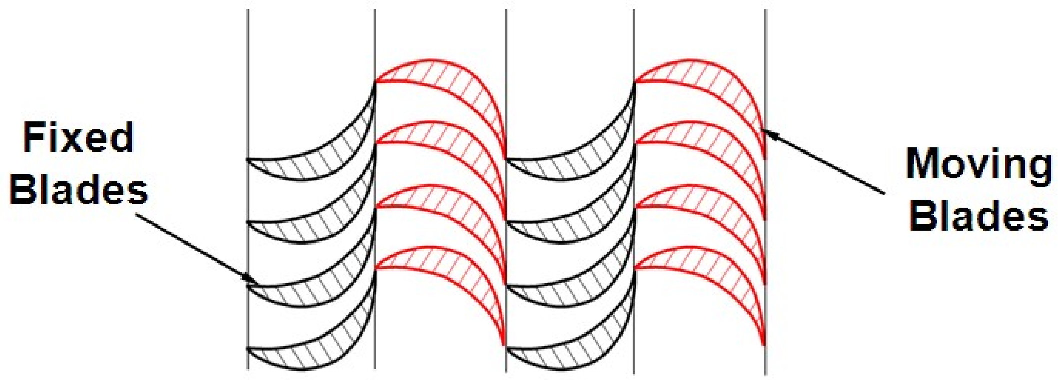


Pressure - Velocity Compounded Impulse Steam Turbine

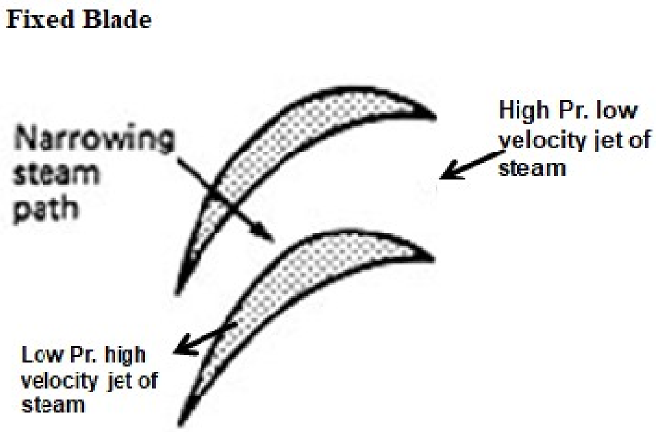
As the name suggests this is a combination of pressure compounding and velocity compounding. Here the pressure drop is split into two or more stages and the kinetic energy gained in each step is also absorbed in stages. Figure above represents a two stage pressure velocity compounded turbine. The first pressure drop occurs in the first set of nozzles and the resulting gain in kinetic energy is absorbed successively in two rows of moving blades before the second pressure drop occurs in the second set of nozzles. The kinetic energy gained due to the second pressure drop in the second set of nozzles is absorbed successively in the next two rows of moving blades. The fixed blades fitted in between two rows of moving blades guide the steam from one row to the next.

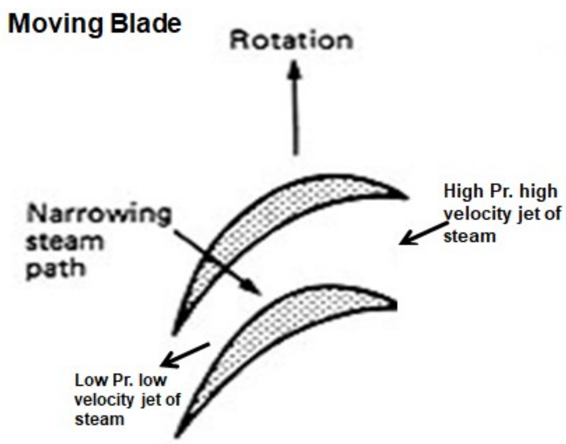
Reaction Turbine

Propelling Force in an Reaction Turbine:



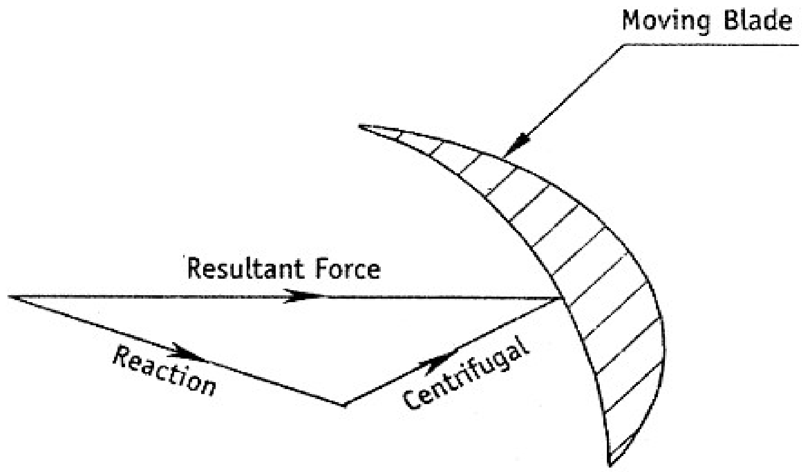
Arrangement of Blades in a Reaction Turbine





In a reaction turbine the high pressure steam does not initially expand in the nozzle as in the case of impulse turbine, but instead directly passes onto a set of fixed blades and moving blades, whose shapes are designed in such a way that the steam flowing between the blades will be subjected to the nozzle effect. Hence the pressure of the steam drops continuously as it flows over the blades.

First the fixed blades which are fitted to the casing convert a portion of the pressure energy into kinetic energy leading to a simultaneous increase in the velocity of the steam. The increase in the velocity of the steam flowing over the moving blades develops a force within itself which enables it to move further, consequently there will be a backward reaction to the force causing the motion of the jet. This reaction force acting on the blades constitutes a fraction of the propelling force driving the turbine rotor. In addition to this reaction force, there is also a centrifugal force exerted by the steam due to the change in the momentum because of the change in the direction of the steam passing over the blades, which reduces the velocity of the steam. Thus the net force acting on the moving blades of a reaction turbine is the vector sum of the centrifugal and the reaction forces as shown in the force diagram below.



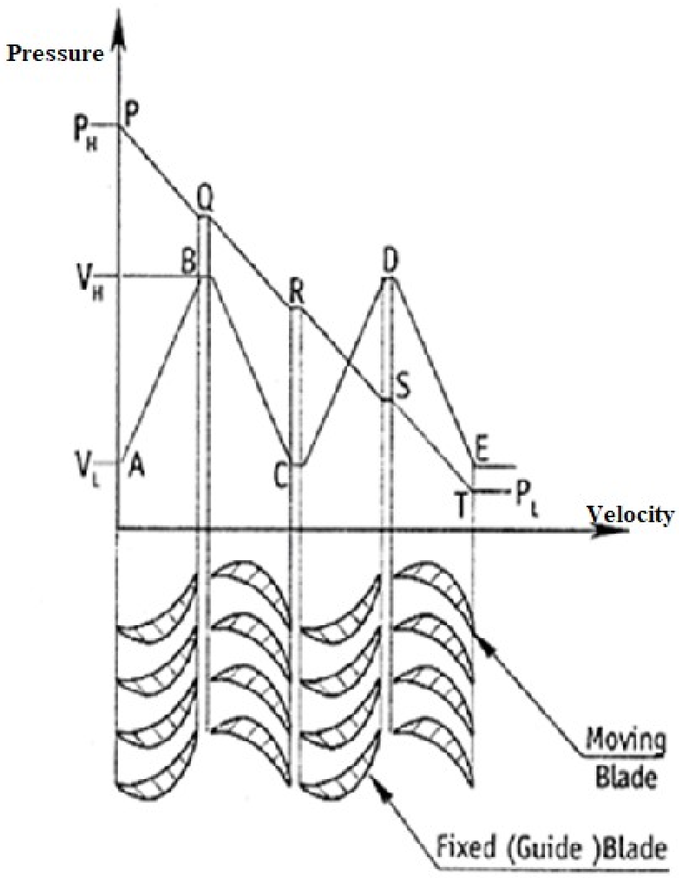
Force diagram

Reaction force: This force is due to the backward reaction to the force causing the motion of the jet.

Centrifugal force: This is the force exerted by the steam due to the change in momentum because of the change in direction of the steam while passing over the blades.

Resultant force: This is the vector sum of Reaction force and Centrifugal force

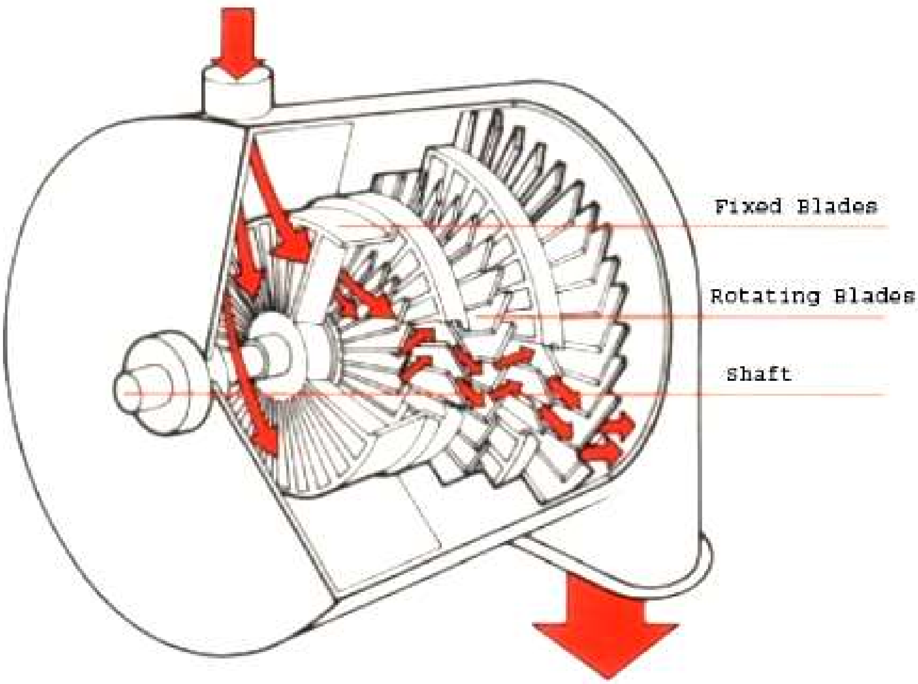
<u>Pressure Velocity Changes in a Reaction Turbine:</u>



Pressure – Velocity changes in Reaction turbine

The reaction turbine consists of a number of rows of moving blades fitted on the different rotors keyed to the turbine shaft with alternate rings of fixed blades rigidly fixed to the casing of the turbine. Both the fixed and moving blades are designed in the shape of the nozzles. Therefore the expansion of the steam takes place both in the fixed and the moving blades. The fixed blade rings between the two moving blade rotors enables to deflect and guide the steam to enter from one row of moving blades to the next.

The changes in the pressure and velocity of the steam as it flows over the fixed and moving blades are shown in the figure above. The high pressure steam passing through the first row of fixed blades undergoes a small drop in pressure causing an increase in the velocity of the steam. It then enters the first row of moving blades where it suffers further drop in pressure and the velocity energy is converted into the mechanical energy of rotation of the rotor. Thus the velocity of the steam decreases. This Continues in further rows of fixed and moving blades till the pressure of the steam is almost completely reduced.

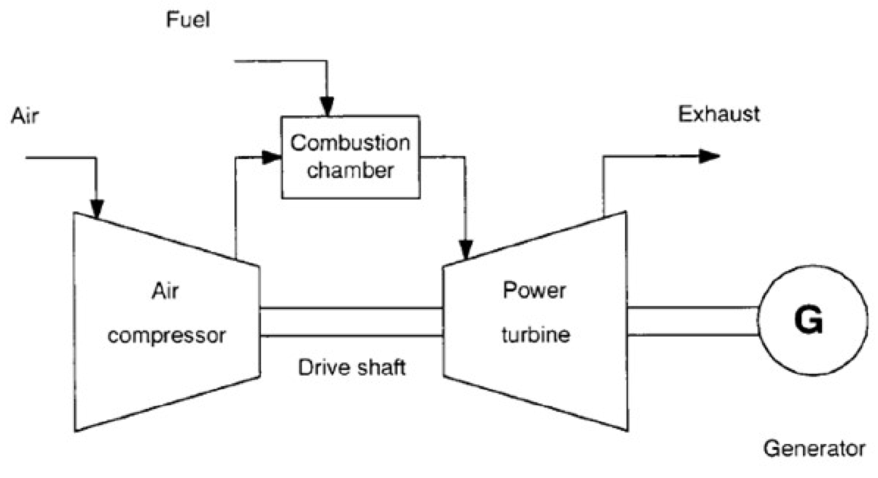


Reaction Turbine

Comparison of Impulse and Reaction Steam Turbine

Impulse Turbine	Reaction Turbine
1. Steam completely expands from a high pressure to low pressure in the nozzle before it enters the moving blades.	The high pressure steam continuously expands successively in both the fixed and moving blades.
2. The symmetrical profile of the moving blades provides a uniform section for the *flow* of the steam between them causing no expansion of the steam.	The asymmetrical profile of both the moving and fixed blades provides a varying section for the flow of steam between them which causes the expansion of the steam.
3. The pressure of the steam at both the ends of the moving blades and as well as while passing over them remains constant.	The pressure of the steam at both the ends of the fixed and moving blades and as well as while passing over them are different.
4. Because of the large drop in pressure in the nozzle, the steam speed and as well as the rotor speeds are high.	Due to the smaller pressure drop over both fixed and moving blades, both the steam speed and the rotor speed are relatively low.
5. Because of the larger pressure drop in the nozzle and less number of stages, size of the impulse turbine for the same power output is comparatively small.	Because of the smaller pressure drop in every stage, and more number of stages, size of the reaction turbine for the same power output is large.
6. Occupies less space per unit power.	Occupies more space for the unit power.

Gas Turbine

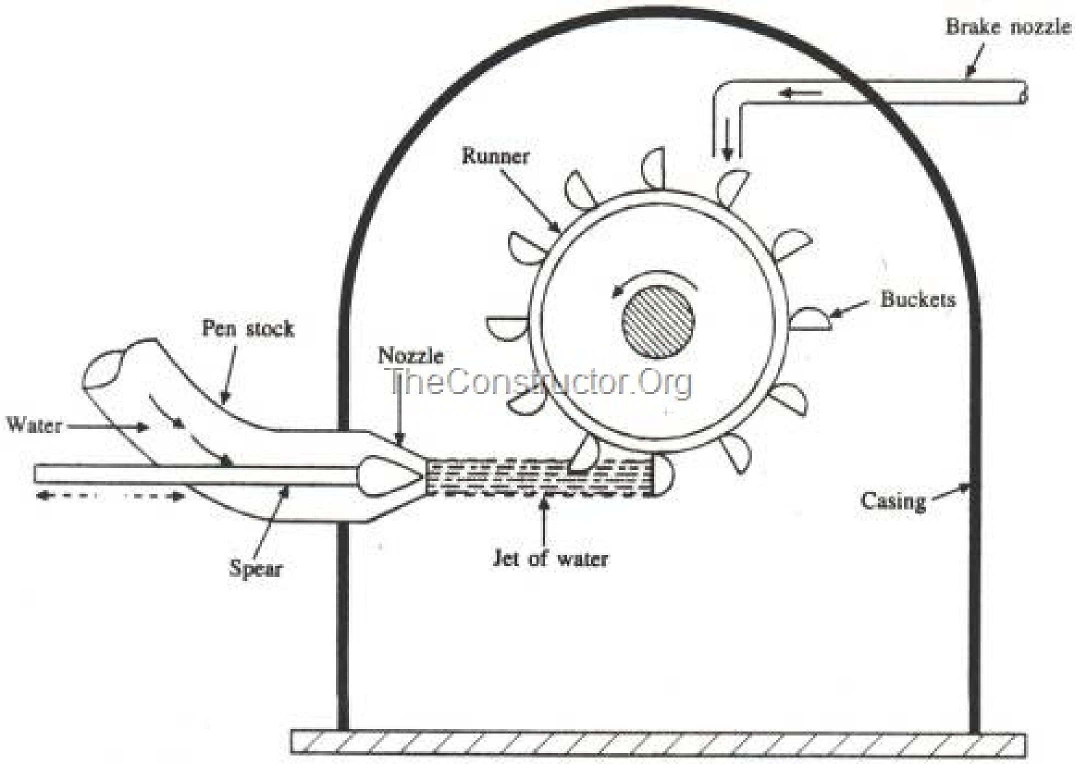


Flow diagram of a Gas Turbine.

The gas turbine comprises a compressor, combustion chamber and a turbine. Both the compressor and the turbine are coupled or mounted on the same shaft. The atmospheric air is drawn into the compressor and compressed to high pressures. The high pressure and relatively high temperature air flows into the combustion chamber where heat is added to the air by the combustion of the fuel in the combustion chamber. The high pressure, high temperature gases are then passed to the turbine, where it expands to lower pressure thereby driving the turbine shaft producing the mechanical energy of rotation. The exhaust gases from the turbine are let out to the atmosphere and the working fluid is replaced in every cycle. Part of the power produced in the turbine is used to run the compressor and the rest is available to run the generator.

Water Turbine (Pelton Wheel)

Pelton wheel is an impulse turbine used mainly in high head hydroelectric plants. Here first the potential energy of water contained in a dam built across a river is converted into kinetic energy using long tubes called penstocks and the kinetic energy is then converted into mechanical energy in the form of rotation in the Pelton Wheel. It is as shown below.



Pelton Wheel

The water from a high head source is supplied to the nozzle which is provided with a needle, through the long tubes known as penstocks. The function of the needle is to regulate the flow of water through nozzle depending upon the loading conditions. When the needle is pushed forward into the nozzle it reduces area of the jet as a result the quantity of water through the jet is reduced. Similarly if the spear is pushed back it increases the area of nozzle and discharge increases. The movement of spear is regulated by hand or by automatic governing arrangement. The jet of water issuing out of the nozzle at high velocity impinges on the buckets known as Pelton cups which are fitted on the runner. The impulse force of the jet striking on the Pelton cups causes the runner to rotate thereby converting the velocity energy into mechanical energy.

Whenever the turbine has to be brought to rest the nozzle is completely closed. But the runner of Pelton wheel goes on revolving due to inertia. To bring the runner to rest in short time, a brake nozzle is provided in such a way that it will direct the jet of water on the back of the buckets. It acts as a brake thereby reducing the speed of the runner.

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