... turbines are classified as follows :

1. **According to the head available**

Pelton turbine : high head turbine, head may be more than 250 m to as large 2000 m.

Francis turbine : Medium head turbine, head varying from 60 m to 250 m.

Kaplan turbine : low head turbine, head is less than 60 m.

2. **According to the discharge available**

Pelton turbine : small flow turbine ($Q = 0.1$ to $2\ m^3/s$)

Francis turbine : medium discharge turbine (0.5 to $5.0\ m^3/s$)

Kaplan turbine : high discharge turbine ($Q = 5$ to $200\ m^3/s$)

3. **According to the name of the originator**

Pelton (1880) : named after Lester Allen Pelton of California (USA).

Francis (1865) : named after James Bichens Francis.

Kaplan (1916) : named after Dr. Victor Kaplan.

Other turbines invented were

Impulse type : Poncelet (1825), Girard (1850) and Banki (1900)

Francis type : Forneyron (1827)

Kaplan type : Jonval (1837), Turgo (1930)

4. **According to the action of water**

Impulse turbine : Pelton turbine.

Reaction turbine : 1. Francis turbine
2. Kaplan and propeller turbines.

5. **According to the direction of flow of water in the runner**

Tangential flow turbine : Pelton turbine.

Radial flow turbine : no more in use.

Mixed flow turbines (radial at entry and axial at exit)—Francis turbine (modern turbines).

Axial flow turbines—Kaplan or Propeller turbines (flow is parallel to the axis of the turbine).

Tangential flow means the water jet strikes the wheel tangentially to the path of rotation.

Kaplan turbine has adjustable runner vanes and can be rotated about pivots fixed to the boss or hub. In propeller turbine, the runner blades are fixed.

6. **According to the disposition of the shaft**

In present time, the Pelton turbines usually have horizontal shafts whereas the Francis and the Kaplan turbines, especially the large units have vertical shafts.

7. According to the specific speed

For hydraulic turbines, the following classification is used.

Table 1 : Classification of hydraulic turbines on the basis of specific speed

Type of turbine	Specific speed (in S.I.)	Maximum hydraulic efficiency $\eta_{h\ max}$	Speed ration	Remarks
1. Pelton turbine (i) Single jet (H upto 2000 m) (ii) Multiple jet (H upto 1500 m)	8.5-30 30-51 sp. speed is low	0.89	0.43-0.48	Employed for heads greater than 250 m
2. Francis turbine (i) High head (upto 300 m) (ii) Medium head (50-150 m) (iii) Low head (30-60 m)	51-102 102-153 153-255 sp. speed is medium	0.93	0.6-0.9	Full load efficiency is high and part load efficiency lower than Pelton turbine
3. Kaplan and propeller turbines (4 to 60 m)	255-860 sp.speed is high	0.93	1.4-2.0	Part load efficiency of Kaplan turbine is high
4. Bulb or tubular turbines (head = 3 to 10 m)	860-1020 sp. speed is high	0.91	6-8	Used in tidal plants

2.3 Impulse Turbine – Pelton Wheel

Pelton wheel is a high head, low discharge, impulse turbine, tangential flow turbine, horizontal shaft turbine and low sepcific speed turbine. In such turbines, the potential energy is converted into kinetic energy when water flows through the nozzle installed at the end of the penstock. The high velocity jet when strikes the buckets mounted on a wheel, makes the wheel to rotate. Five important Pelton-turbine installations in India are given below :

The speed of the turbine depends on the rate of flow entering the turbine or the load on the turbine. The frequency and voltage of generation of power also depends to a great extent on the speed of rotation. Therefore, the main objective of governing of turbine is to maintain constant speed by controlling the flow without developing any water hammer pressure in the pipeline.

If the load on the turbine changes, the governor has to operate spear valve for controlling the flow rate and the deflector for pressure control in the pipeline of Pelton Turbine whereas the flow and pressure will be controlled by operating wicket gates and relief valve respectively in Francis Turbine. In Kaplan turbine, the flow rate is controlled by operating wicket gates and runner blades and the pressure in the pipeline is controlled by a relief valve.

The governor employed for governing of the turbines should have the following characteristics :

1. The governor should be responsive to small changes in speed. It should, however, not move to extreme positions.
2. The governor should quickly stop the excessive increase of the speed of the turbine but it should not be so quick that water hammer occurs in the pipeline.
3. The governor should not oscillate.
4. When the load is steady, no periodic change in speed should take place.
5. It should have sufficient capacity to carry out the necessary function. For example, it should have capacity to exert enough force to open or close the wicket gates of a Francis turbine.

2.7.1 Governing of Impulse Turbines

Suppose the load on the Pelton turbine suddenly decreases. This will result in increase of the speed of turbine and the pendulum of the governor will go up. This will cause the main lever to push the pistons of the control valve down and also the bell crank lever. As the bell-crank lever comes down, it brings the deflector in front of the nozzle and a part of the jet is deflected away. This will reduce the speed of the wheel without causing water hammer in the supply penstock and the spear moves slowly to block the nozzle in proportion to the load on the turbine.

The forward motion of the spear moves the cam and the bell crank lever goes up. This makes the deflector to come to its normal position *i.e.*, it moves away from the jet. The entire process is reversed when the load increases on the turbine.

The operation is shown in fig. 4.

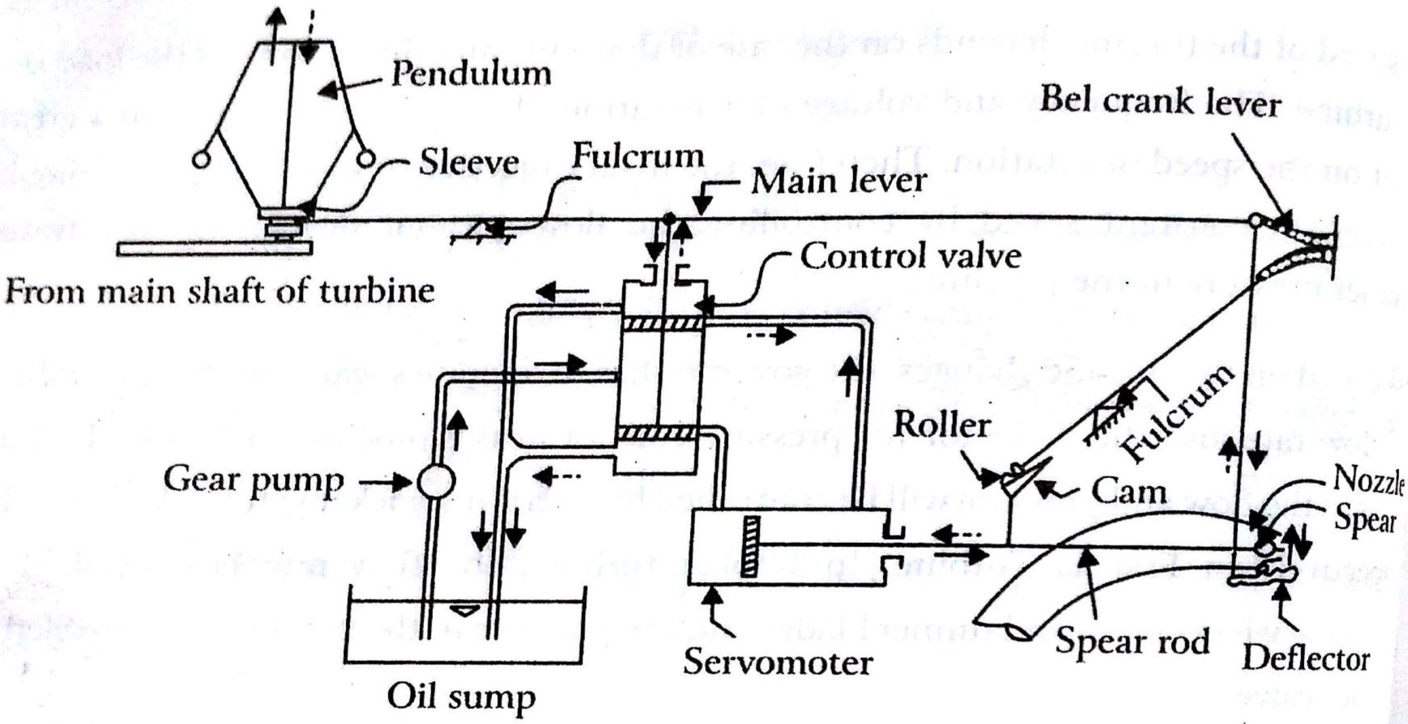

Fig. 4. Governing of impulse turbine

3.14 Cavitation in Turbines

It is a process in which the cavities or bubbles form, grow and collapse in high pressure zone in a flowing liquid when pressure falls to vapour pressure or below vapour pressure. The vapour or cavities form around a dust nuclei present in the liquid. Due to collapse of vapours, empty space is created. The liquid flows with a high velocity towards these spaces. This results in series of violent, irregular, spherical shock waves causing noise and vibrations. In this process, due to fatigue and indentations are formed or material is eaten away or pitting takes place.

The cavitation causes sudden drop in the output and efficiency. Hence an effort be made to avoid the occurrence of cavitation.

The cavitation may occur in reaction turbines at the following locations :

1. At the exit of the convex side of the runner.
2. At the inlet of the draft-tube.

3.14.1 Cavitation Factor

It is defined as

$$\sigma = \frac{H_a - H_v - H_s}{H}$$

where H_a = atmospheric pressure head in m of water

H_v = vapour pressure head in m of water at given temperature.

H_s = suction head (or height of turbine outlet above tail race level in m)

H = working head of turbine.

The value of critical cavitation factor depends on the specific speed of the turbine as evident from the following empirical formulae :

For Francis Turbine : $\sigma_c = 0.625 \left(\frac{N_s}{380.78}\right)^2$ ...(3.

$$\sigma_c = 4.31 \times 10^{-6} N_s^2$$

For Propeller Turbine : $\sigma_c = 0.28 + \left[\frac{1}{7.5}\left(\frac{N_s}{380.78}\right)^3\right]$ ...(3.

$$= 0.28 + 2.415 \times 10^{-9} N_s^3$$ ...(3.

For Kaplan Turbine : σ_c = 1 1...

5.14.2 Methods to Avoid or Reduce Cavitation

The following methods are used to avoid or reduce cavitation in turbines :

1. The runner or turbine may be installed inside the tail race water or at minimum height above the tail race water.
2. Through model testing, the distribution of pressure along runner vanes may be obtained. This will enable to locate the region where pressure is minimum.This is the region where vapourisation is likely to occur.
3. The design of moving vanes should be such as will avoid the sharp corners or curvatures. Such design will result in the formation of eddies or vertices causing low pressure.
4. The proper selection of material may also reduce the chances of cavitation. It is found that cast iron, aluminium or welded steel are the least cavitation resistant. Cast aluminium bronze, Nickel and welded stainless steel are moderately resistant to cavitation. It is observed that stellite has high resistance to cavitation. It is suggested that bronze, stainless steel or alloy steel may be preferred than other materials. The cost of stellite is very high, therefore may not be used. By polishing the surface of cast steel runners and vanes with stainless steel may also reduce the chances of cavitation.
5. Temperature of water should be as less as physically possible as it will lower the vapour pressure and hence the chances of cavitation.
6. It is also advisable to make suitable arrangement to admit air at the region of low pressure. This will reduce the chances of cavitaion.
7. The proper selection of specific speed may also reduce the possibility of occurrence of cavitation.

Table 18.1. Comparison between Impulse and Reaction Turbines

S. No.	Aspects	Impulse turbine	Reaction turbines
1.	*Conversion of fluid energy*	The available fluid energy is converted into K.E. by a nozzle.	The energy of the fluid is partly transformed into K.E. before it (fluid) enters the runner of the turbine.
2.	*Changes in pressure and velocity*	The pressure remains same (atmospheric) throughout the action of water on the runner.	After entering the runner with an excess pressure, water undergoes changes both in velocity and pressure while passing through the runner.
3.	*Admittance of water over the wheel*	Water may be allowed to enter a part or whole of the wheel circumference.	Water is admitted over the circumference of the wheel.
4.	*Water-tight causing*	Required	Not necessary.
5.	*Extent to which the water fills the wheel/turbine*	The wheel/turbine does not run full and air has a free access to the buckets.	Water completely fills all the passages between the blades and while flowing between inlet and outlet sections does work on the blades.
6.	*Installation of unit*	Always installed above the tail race. No draft tube is used.	Unit may be installed above or below the tail race-use of a draft tube is made.
7.	*Relative velocity of water*	Either remaining constant or reduces slightly due to friction.	Due to continuous drop in pressure during flow through the blade, the relative velocity increases.
8.	*Flow regulation*	— By means of a needle valve fitted into the nozzle. — Impossible without loss.	— By means of a guide-vane assembly. — Always accompanied by loss.

S.No.	Aspects	Inward flow reaction turbine	Outward flow reaction turbine
1.	*Entry of water*	Water enters at the outer periphery, flows inward and towards the centre of the turbine and discharges at the outer periphery.	Water enters at the inner periphery flows outward and discharges at the outer periphery.
2.	*Centrifugal head imparted*	Negative (negative centrifugal head reduces the relative velocity of water at the outlet).	Positive (Positive centrifugal head increases the relative velocity of water at the outlet).
3.	*Discharge*	Does not increase.	The discharge increases.
4.	*Speed control*	Easy and effective.	Very difficult.
5.	*Tendency of the wheel to race*	Nil. The turbine adjusts the speed by itself.	If the turbine speed increases the wheel tends to race; the turbine cannot adjust the speed by itself.
6.	*Suitability*	Quite suitable for medium high heads; best suitable for large outputs and units.	Quite suitable for low or medium heads.
7.	*Application*	For power projects.	Practically obsolete.

of vanes should be either one more or one less than the number of guide vanes.

18·4·1·4. Advantages and disadvantages of a Francis turbine over a Pelton wheel

Advantages :

The Francis turbine claims the following *advantages* over Pelton wheel :

1. In Francis turbine the variation in the operating head can be more easily controlled.
2. In Francis turbine the ratio of maximum and minimum operating heads can be even two.
3. The operating head can be utilized even when the variation in the tail water level is relatively large when compared to the total head.
4. The mechanical efficiency of Pelton wheel decreases faster with wear than Francis turbine.
5. The size of the runner, generator and power house required is small and economical if the Francis turbine is used instead of Pelton wheel for same power generation.

Disadvantages/Drawbacks :

As compared with Pelton wheel, the Francis turbine has the following *drawbacks/ shortcomings* :

1. Water which is not clean can cause very rapid wear in high head Francis turbine.
2. The overhaul and inspection is much more difficult comparatively,
3. Cavitation is an ever-present danger.
4. The water hammer effect is more troublesome with Francis turbine.
5. If Francis turbine is run below 50 percent head for a long period it will not only lose its efficiency but also the cavitation danger will become more serious.

Differences between Francis Turbine and Kaplan Turbine :

S.No.	Aspects	Francis turbine	Kaplan turbine
1.	*Type of turbine*	Radially inward or mixed flow.	Partially axial flow.
2.	*Disposition of shaft*	Horizontal or vertical	Only vertical.
3.	*Adjustability of runner vanes*	Runner vanes are *not* adjustable.	Runner vanes are adjustable.
4.	*Number of vanes*	Large, 16 to 24 blades	Small 3 to 8 blades
5.	*Resistance to be overcome*	Large, (owing to large number of vanes and greater area of contact with water)	Less (owing to fewer number of vanes and less wetted area)
6.	*Head*	Medium (60 m to 250 m)	Low (up to 30 m)
7.	*Flow rate*	Medium	Large
8.	*Specific speed*	50-250	250-850
9.	*Type of governor*	Ordinary	Heavy duty