UNIVERSITY OF THE EAST

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COLLEGE OF ENGINEERING

MECHANICAL ENGINEERING DEPARTMENT

"HYDRAULIC TURBINES"

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TERMINOLOGIES

Axial Flow   having the fluid or gas flowing parallel to the axis of flow.

Cavitation   Noise or vibration causing damage to the turbine blades as a results of bubbles that form in the water as it goes through the turbine which causes a loss in capacity, head loss, efficiency loss, and the cavity or bubble collapses when they pass into higher regions of pressure.

Flow Rate   the amount of fluid that flows in a given time.

Guide Vanes   it is the movable vanes, before the water reaches the runner, used to get maximum power extraction through the adjustment of angle of vanes.

Head   Vertical change in elevation, expressed in either feet or meters, between   the head water level and the tailwater level.

Head Water   The water level above the powerhouse or at the upstream face of   a dam.

High Head   Head greater than 25 meters

Impulsive Forc The force that two colliding bodies exert on one another acts only for a short time, giving a brief but strong push. This force is called an impulsive force.

Low Head Head of 20 meters or less.

Nozzle increase the velocity of fluid but reduces its pressure.

Penstock it is the pipeline used to carry water from the reservoir to the inlet nozzle.

Radial Flow having the working fluid flowing mainly along the radii of rotation

Runner The rotating part of the turbine that converts the energy of falling water into mechanical energy.

Servomechanism is an automatic device that uses error-sensing negative feedback to correct the performance of a mechanism and is defined by its function. It usually includes an in-built encoder

Spear or Needle Valve it is the governing mechanism of Pelton turbine used to regulate the amount of water flow from the nozzle.

Static Head Pressure of a fluid due to the head of fluid above some reference point.

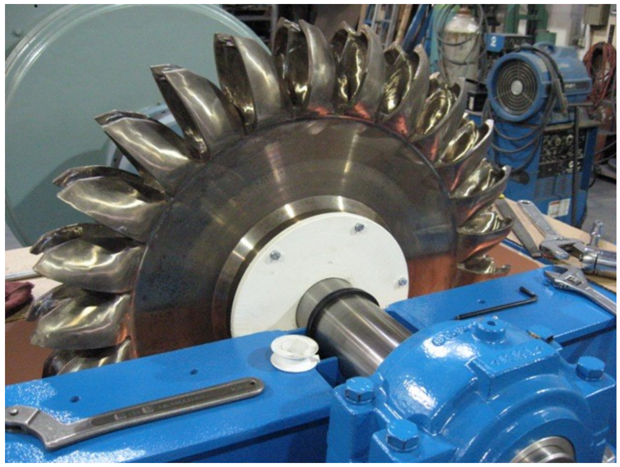
Stay Vanes The primary function of the guide or stay vanes is to convert the pressure energy of the fluid into the momentum energy. It also serves to direct the flow at design angles to the runner blades.

Tail Water The water level downstream of the powerhouse or dam.

Turbine Shaft	The function of the turbine shaft is to transfer the torque from the turbine runner to the generator shaft and rotor.
Velocity Head	the velocity of a fluid expressed in terms of the head or static pressurerequired to produce that velocity. It equals ρν/2 where ρ is the density of the fluid and ν is the velocity. In hydrology the density of water can be written 1/G where G is the gravitational constant
Water Jet	a stream of water forced out through a small aperture.
Wicket Gates	Adjustable elements that control the flow of water to the turbine passage.

INTRODUCTION

A **turbine**, is a rotary mechanical device that extracts energy from a fluid flow and converts it into useful work. A turbine is a turbomachine with at least one moving part called a rotor assembly, which is a shaft or drum with blades attached. Moving fluid acts on the blades so that they move and impart rotational energy to the rotor.



Source: http://www.dtlhydro.com/products.htm

Figure 1.1: **A photo of Hydraulic Turbine Propeller**

HISTORY

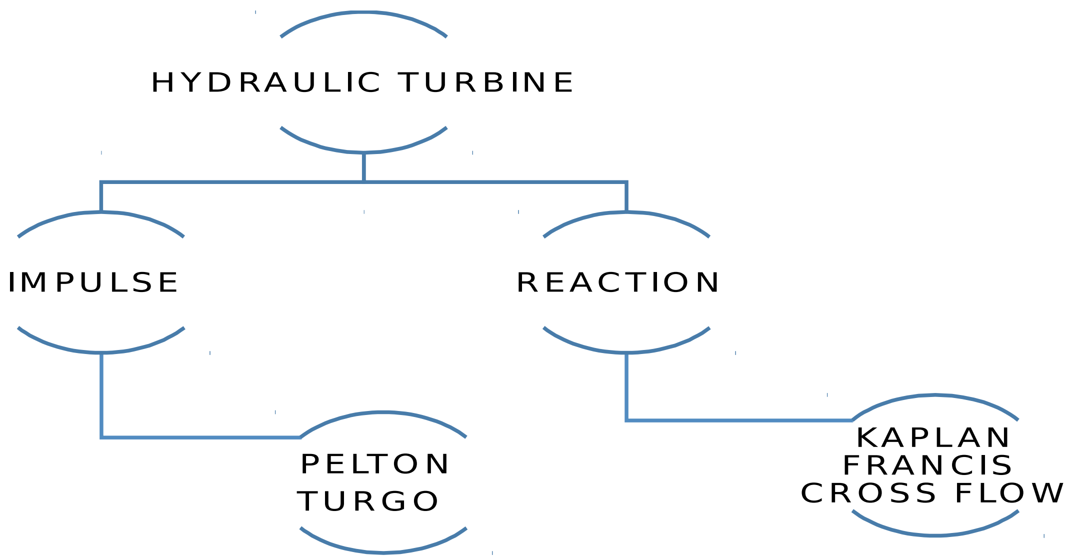
Early turbine examples are windmills and waterwheels. Gas, steam, and water turbines usually have a casing around the blades that contains and controls the working fluid. Credit for the invention of the steam turbine is given to British engineer Sir Charles Parson, for inventing the reaction turbine and to Swedish engineer Gustaf de Laval, for the invention of the impulse turbine. Modern steam turbines frequently employ both reaction and impulse in the same unit, typically varying the degree of reaction and impulse from the blade root to its periphery.

TYPES OF TURBINES

- Steam turbine
- Gas turbine
- Transonic turbine
- Contra-rotating turbine
- Statorless turbine
- Ceramic turbine

- Shrouded turbine
- Shroudless turbine
- Bladeless turbine
- Wind turbine

Types of Water/Hydraulic Turbines



IMPULSE HYDRAULIC TURBINE

In an impulse turbine the potential energy, or the head of water, is first converted into kinetic energy by discharging water through a carefully shaped nozzle. The jet, discharged into air, is directed onto curved buckets fixed on the periphery of the runner to extract the water energy and convert it to useful work.

PELTON WHEEL

The Pelton wheel is an impulse type water turbine. It was invented by Lester Allan Pelton in the 1870s. The Pelton wheel extracts energy from the impulse of moving water, as opposed to water's dead weight like the traditional overshot water wheel. Many variations of impulse turbines existed prior to Pelton's design, but they were less efficient than Pelton's design.

Water leaving those wheels typically still had high speed, carrying away much of the dynamic energy brought to the wheels. Pelton's paddle geometry was designed so that when the rim ran at half the speed of the water jet, the water left the wheel with very little speed; thus his design extracted almost all of the water's impulse energy which allowed for a very efficient turbine

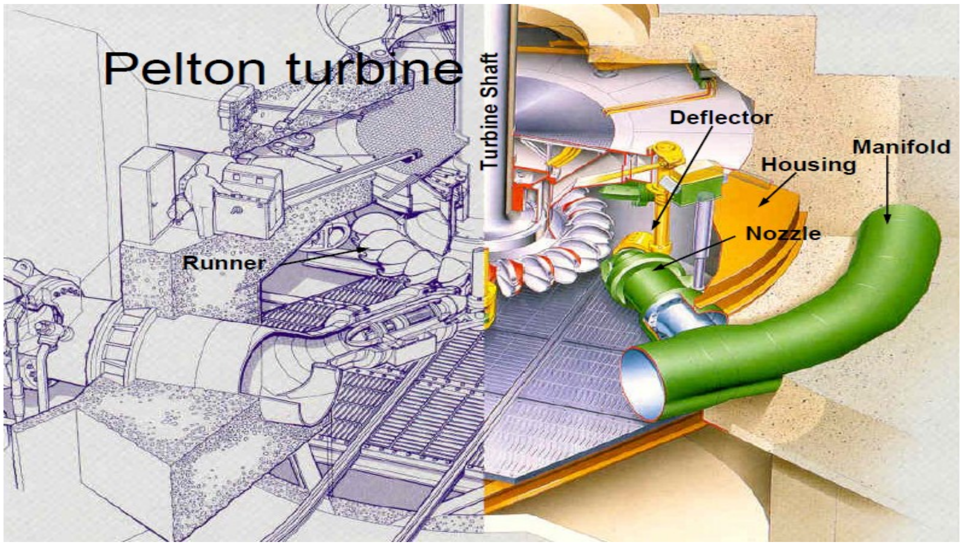


Figure 1.2: **shows a photo of the parts of the Pelton Turbine**

TURGO TURBINE

Turgo turbine is an impulse water turbine designed for medium head applications. Operational Turgo Turbines achieve efficiencies of about 87%. In factory and lab tests Turgo Turbines perform with efficiencies of up to 90%. It works with net heads between 15 and 300 m. Developed in 1919 by Gilkes as a modification of the Pelton wheel, the Turgo has some advantages over Francis and Pelton designs for certain applications. First, the runner is less expensive to make than a Pelton wheel. Second, it doesn't need an airtight housing like the Francis. Third, it has higher specific speed and can handle a greater flow than the same diameter Pelton wheel, leading to reduced generator and installation cost.

Turgos operate in a head range where the Francis and Pelton overlap. While many large Turgo installations exist, they are also popular for small hydro where low cost is very important. Like all turbines with nozzles, blockage by debris must be prevented for effective operation.

Figure 1.3: **shows a photo of an actual running Turgo Turbine**

REACTION TURBINES

In a reaction turbine, forces driving the rotor are achieved by the reaction of an accelerating water flow in the runner while the pressure drops. The reaction principle can be observed in a rotary lawn sprinkler where the emerging jet drives the rotor in the opposite direction. Due to the great variety of possible runner designs, reaction turbines can be used over a much larger range of heads and flow rates than impulse turbines.

KAPLAN TURBINE

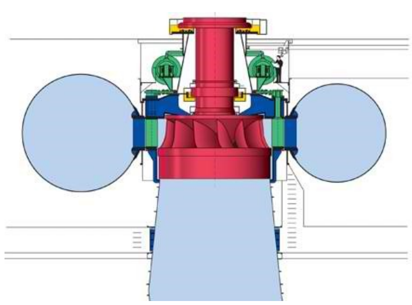
The Kaplan turbine is an inward flow reaction turbine, which means that the working fluid changes pressure as it moves through the turbine and gives up its energy. Power is recovered from both the hydrostatic head and from the kinetic energy of the flowing water. The design combines features of radial and axial turbines.

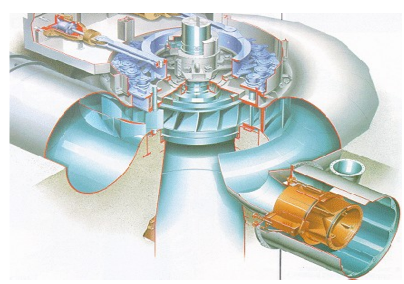
The inlet is a scroll-shaped tube that wraps around the turbine's wicket gate. Water is directed tangentially through the wicket gate and spirals on to a propeller shaped runner, causing it to spin.

Figure 1.4: **shows a photo of an actual Kaplan Turbine**

FRANCIS TURBINE

The Francis turbine is a type of water turbine that was developed by James B. Francis in Lowell, Massachusetts. It is an inward-flow reaction that combines radial and axial flow concepts. Francis turbines are the most common water turbine in use today.





(***(c)***

(***(d)***

Figure 1.5: **figure (c) and (d) shows a photo of a Francis Turbine Layout and an actual insides of a Francis turbine, respectively.**

CROSS-FLOW TURBINE

A cross-flow turbine, Bánki-Michell turbine, or Ossberger turbine is a water turbine developed by the Australian Anthony Michell, the Hungarian Donát Bánki and the German Fritz Ossberger. Michell obtained patents for his turbine design in 1903, and the manufacturing company Weymouth made it for many years. Ossberger's first patent was granted in 1933 ("Free Jet Turbine" 1922, Imperial Patent No. 361593 and the "Cross Flow Turbine" 1933, Imperial Patent No. 615445), and he manufactured this turbine as a standard product. Today, the company founded by Ossberger is the leading manufacturer of this type of turbine.

Figure 1.6: **shows a photo of an actual cross-flow turbine runner**

PARTS OF A CROSS-FLOW TURBINE

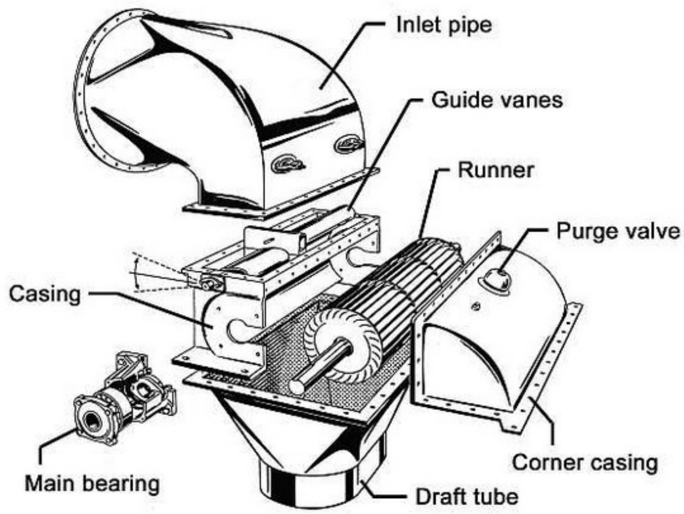


Figure 1.7: **shows the parts of the cross-flow turbine**

OPERATION OF HYDRAULIC TURBINE

IMPULSE TURBINE

PELTON WHEEL

Pelton wheels are the preferred turbine for hydro-power, when the available water source has relatively high hydraulic head at low flow rates, where the Pelton wheel is most efficient. Thus, more power can be extracted from a water source with high-pressure and low-flow than from a source with low-pressure and high-flow, even when the two flows theoretically contain the same power.

Also a comparable amount of pipe material is required for each of the two sources, one requiring a long thin pipe, and the other a short wide pipe. Pelton wheels are made in all sizes. There exist multi-ton Pelton wheels mounted on vertical oil pad bearings in hydroelectric plants. The largest units can be up to 200 megawatts. The smallest Pelton wheels are only a few inches across, and can be used to tap power from mountain streams having flows of a few gallons per minute.

Some of these systems use household plumbing fixtures for water delivery. These small units are recommended for use with 30 feet (9.1 m) or more of head, in order to generate significant power levels. Depending on water flow and design, Pelton wheels operate best with heads from 49–5,905 feet (14.9–1,799.8 m), although there is no theoretical limit.

TURGO TURBINE

The Turgo turbine is an impulse type turbine; water does not change pressure as it moves through the turbine blades. The water's potential energy is converted to kinetic energy with a nozzle. The high speed water jet is then directed on the turbine blades which deflect and reverse the flow. The resulting impulse spins the turbine runner, imparting energy to the turbine shaft. Water exits with very little energy. Turgo runners are extremely efficient

A Turgo runner looks like a Pelton runner split in half. For the same power, the Turgo runner is one half the diameter of the Pelton runner, and so twice the specific speed. The Turgo can handle a greater water flow than the Pelton because exiting water doesn't interfere with adjacent buckets.

The specific speed of Turgo runners is between the Francis and Pelton. Single or multiple nozzles can be used. Increasing the number of jets increases the specific speed of the runner by the square root of the number of jets (four jets yield twice the specific speed of one jet on the same turbine).

REACTION TURBINE

KAPLAN TURBINE

The Kaplan turbine is an inward flow reaction turbine, which means that the working fluid changes pressure as it moves through the turbine and gives up its energy. Power is recovered from both the hydrostatic head and from the kinetic energy of the flowing water. The design combines features of radial and axial turbines.

The inlet is a scroll-shaped tube that wraps around the turbine's wicket gate. Water is directed tangentially through the wicket gate and spirals on to a propeller shaped runner, causing it to spin. The outlet is a specially shaped draft tube that helps decelerate the water and recover kinetic energy.

The turbine does not need to be at the lowest point of water flow as long as the draft tube remains full of water. A higher turbine location, however, increases the suction that is imparted on the turbine blades by the draft tube. The resulting pressure drop may lead to cavitation.

Variable geometry of the wicket gate and turbine blades allow efficient operation for a range of flow conditions. Kaplan turbine efficiencies are typically over 90%, but may be lower in very low head applications. Current areas of research include CFD driven efficiency improvements and new designs that raise survival rates of fish passing through.

FRANCIS TURBINE

The Francis turbine is a type of reaction turbine, a category of turbine in which the working fluid comes to the turbine under immense pressure and the energy is extracted by the turbine blades from the working fluid. A part of the energy is given up by the fluid because of pressure changes occurring in the blades of the turbine, quantified by the expression of Degree of reaction, while the remaining part of the energy is extracted by the volute casing of the turbine.

At the exit, water acts on the spinning cup-shaped runner features, leaving at low velocity and low swirl with very little kinetic or potential energy left. The turbine's exit tube is shaped to help decelerate the water flow and recover the pressure.

CROSS-FLOW TURBINE

The turbine consists of a cylindrical water wheel or runner with a horizontal shaft, composed of numerous blades (up to 37), arranged radially and tangentially. The blade's edges are sharpened to reduce resistance to the flow of water. A blade is made in a part-circular cross-section (pipe cut over its whole length). The ends of the blades are welded to disks to form a cage like a hamster cage and are sometimes called "squirrel cage turbines"; instead of the bars, the turbine has trough-shaped steel blades.

The water flows first from the outside of the turbine to its inside. The regulating unit, shaped like a vane or tongue, varies the cross-section of the flow. The water jet is directed towards the cylindrical runner by nozzle. The water enters the runner at an angle of about 45/120 degrees, transmitting some of the water's kinetic energy to the active cylindrical blades.

The regulating device controls the flow based on the power needed, and the available water. The ratio is that (0–100%) of the water is admitted to 0-100%×30/4 blades. Water admission to the two nozzles is throttled by two shaped guide vanes. These divide and direct the flow so that the water enters the runner smoothly for any width of opening. The guide vanes should seal to the edges of the turbine casing so that when the water is low, they can shut off the water supply. The guide vanes therefore act as the valves between the penstock and turbine. Both guide vanes can be set by control levers, to which an automatic or manual control may be connected.

APPLICATION

The selection of the best turbine for any particular hydro site depends on the site characteristics, the dominant ones being the head and flow available. Selection also depends on the desired running speed of the generator or other device loading the turbine. Other considerations such as whether the turbine is expected to produce power under part-flow conditions, also play an important role in the selection. All turbines have a power-speed characteristic. They will tend to run most efficiently at a particular speed, head and flow combination.

Table 1.1: **Application of Hydraulic Turbines based on heads**

	High Head	**Medium Head**	**Low Head**
Impulse	Pelton Turgo	cross-flow Turgo	Cross-flow
Reaction		Francis	Kaplan

Table 1.1 shows the turbine design speed is largely determined by the head under which it operates. Turbines can be classified as high head,

medium head or low head machines. Turbines are also divided by their principle way of operating and can be either impulse or reaction turbines.

IMPULSE TURBINES

Impulse turbines are generally more suitable for micro-hydro applications compared with reaction turbines because they have the following advantages:

- Greater tolerance of sand and other particles in the water
- Better access to working parts
- No pressure seals around the shaft
- Easier to fabricate and maintain
- Better part flow efficiency

REACTION TURBINE

The reaction turbines considered here are the Francis turbine and the propeller turbine. A special case of the propeller turbine is the Kaplan. In all these cases, specific speed is high, i.e. reaction turbines rotate faster than impulse turbines given the same head and flow conditions.

This has the very important consequences in that a reaction turbine can often be coupled directly to an alternator without requiring a speed-increasing drive system. Some manufacturers make combined turbine-generator sets of this sort. Significant cost savings are made in eliminating the drive and the maintenance of the hydro unit is very much simpler. The Francis turbine is suitable for medium heads, while the propeller is more suitable for low heads.

ADVANTAGE AND DISADVANTAGES

Hydraulic Turbines has advantage and disadvantages for certain generation of electricity. These will be briefly discussed below based on application;

PELTON TURBINE

- Pelton wheel turbine is an impulse turbine
- It operates on high head and low discharge.
- It has tangential flow which means that it can have either axial flow or radial flow.
- Pelton wheel turbine is very easy to assemble.
- There is no cavitation because water jet strikes only a specific portion of the runner.
- It has fewer parts as compared to Francis turbine which has both fixed vanes and guided vanes.
- Its overall efficiency is high.
- In this turbine, whole process of water jet striking and leaving to the runner takes place at atmospheric pressure.
- The major disadvantage of impulse turbines is that they are mostly unsuitable for low-head sites because of their low specific speeds too great an increase in speed would be required of the transmission to enable coupling to a standard alternator.

TURGO TURBINE

- The runner is less expensive to make than a Pelton wheel.
- It doesn't need an airtight housing like the Francis turbine.
- It has higher specific speed and can handle a greater flow than the same diameter Pelton wheel, leading to reduced generator and installation cost.
- The disadvantage of turgo tubine is that, it has Less efficiency compared to Pelton, Kaplan and Francis Turbine.

- The flow rate of water is not adjustable.