UNIVERSITÀ DI TRENTO

DIPARTIMENTO DI

INGEGNERIA INDUSTRIALE

Hydroelectric Power

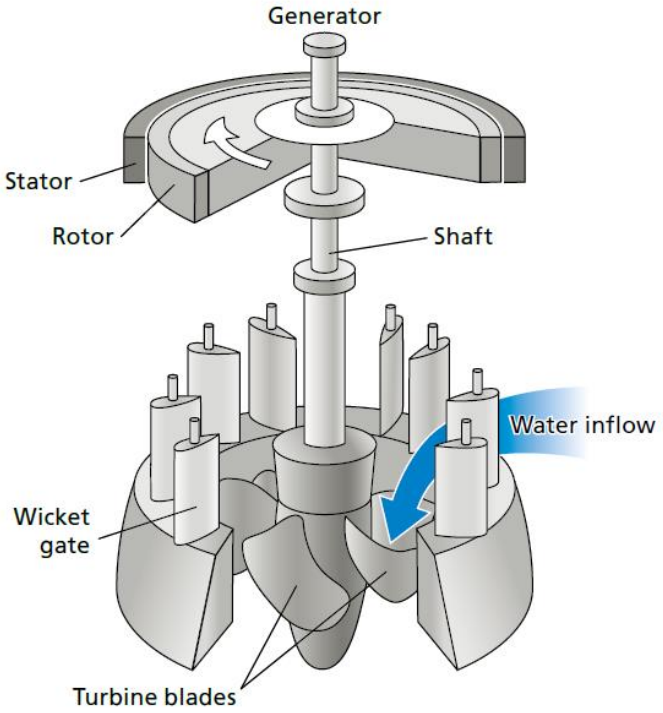
Renewable Energy Conversion Systems Course

Lecture 2

Mattia Duranti

Academic Year 2024-2025

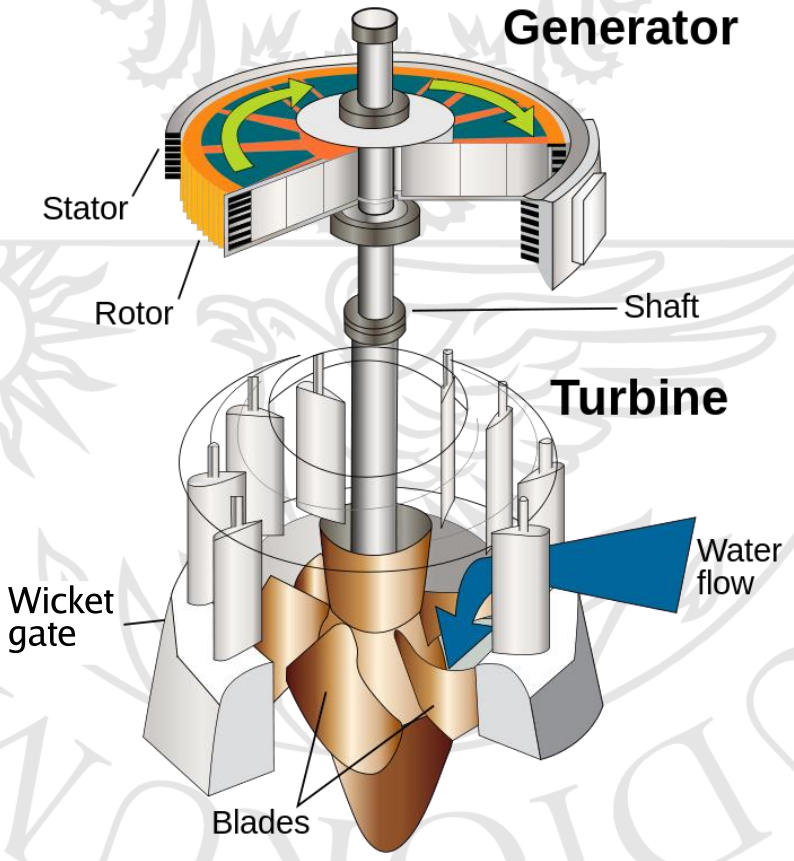
Hydroelectric Turbines



Hydraulic Turbines

What is a Hydraulic Turbine

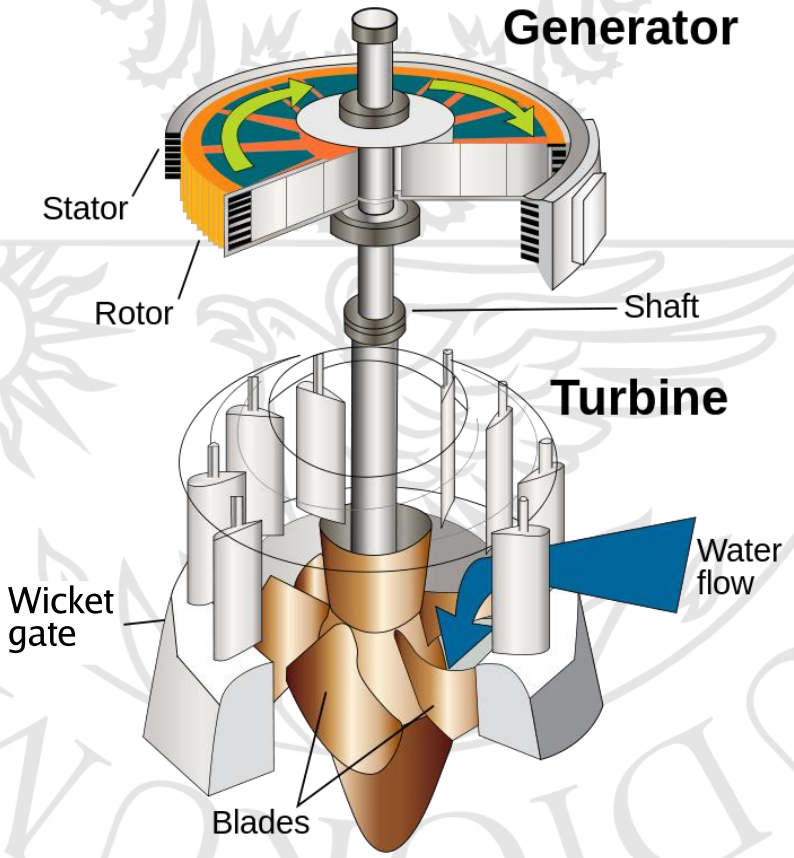
- Turbines are rotating dynamic fluid machines, which extract energy from a flowing fluid converting it into mechanical work
- Hydraulic turbines are turbomachines working with water, an incompressible fluid
- Two main parts:
  - Distributor (fixed)
  - Rotor (revolving)
- The first turbines were waterwheels and windmills
- In modern plants they are connected to an electrical generator



Hydraulic Turbines

Turbine Main Parts

- **Distributor**
  - Fixed with respect to the external structure
  - Controls the fluid direction and velocity before the fluid enters in the rotor
  - Different structure depending on the turbine
- **Rotor**
  - Rotating element composed by a shaft or a drum with blades connected
  - Receives water from the distributor
  - Fixed with respect to the generator rotor or connected to it through simple gears → fixed rotating speed



Hydraulic Turbines

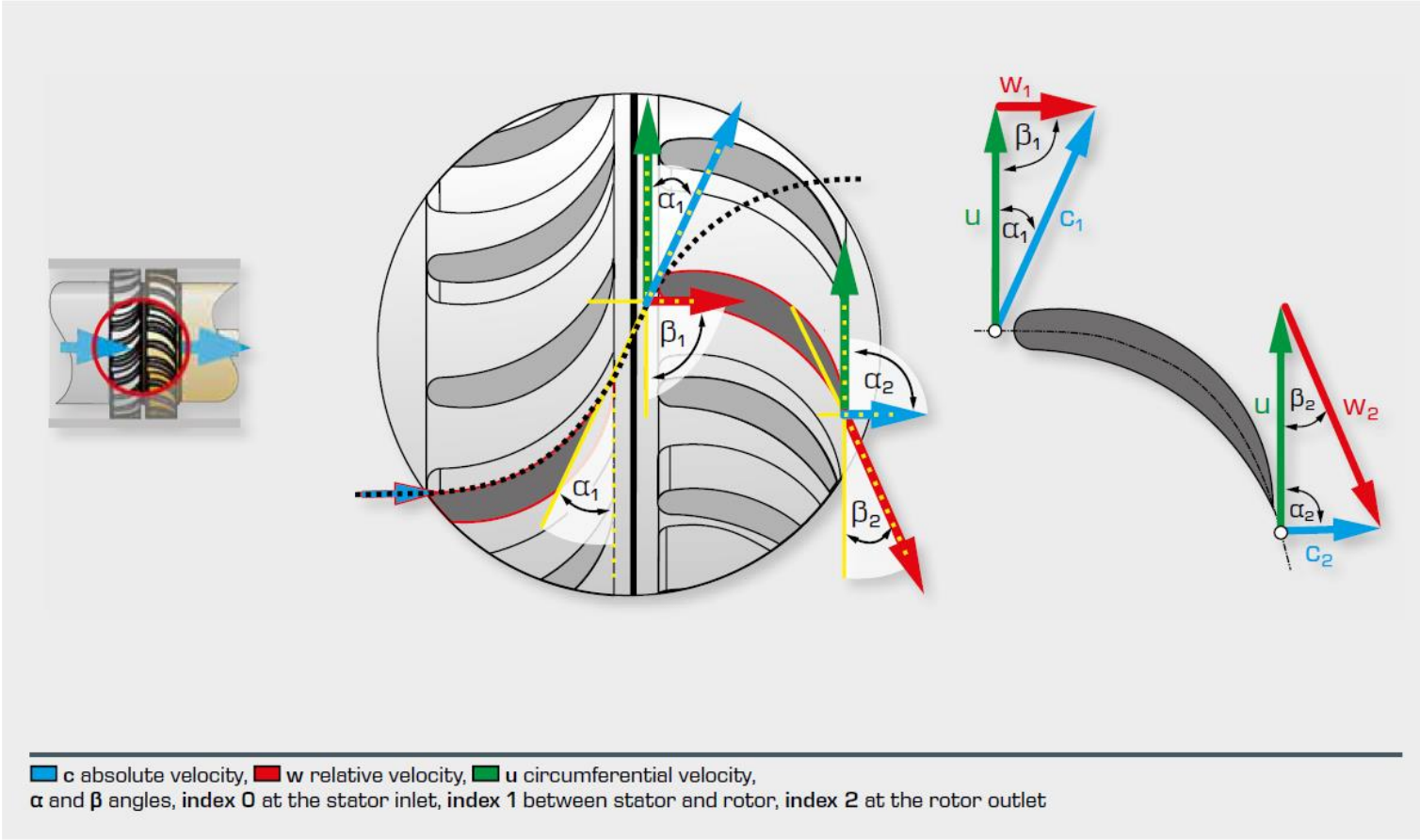
Features of Hydraulic Turbines

- No thermal energy, no fluid compression or expansion, mechanical energy conversion only
- Very high efficiency in nominal conditions
  - Up to 95-98% for very large turbines
  - In the range 70-90% for small turbines
- Very good performance with partial load (compared to other generation systems)
  - 60-70% for large turbines at one third of the rated power
  - 80-85% for Pelton and small turbines at 20% of the rated power
- Modern water turbines suffer little wear on turbine blades and almost no wear on the electric generator → Average service life of the electromechanical equipment is more than 60 years

Hydroelectric Plants Types

Triangles of Velocities

- c → Absolute velocity
- w → Relative velocity
- u → Rotor velocity

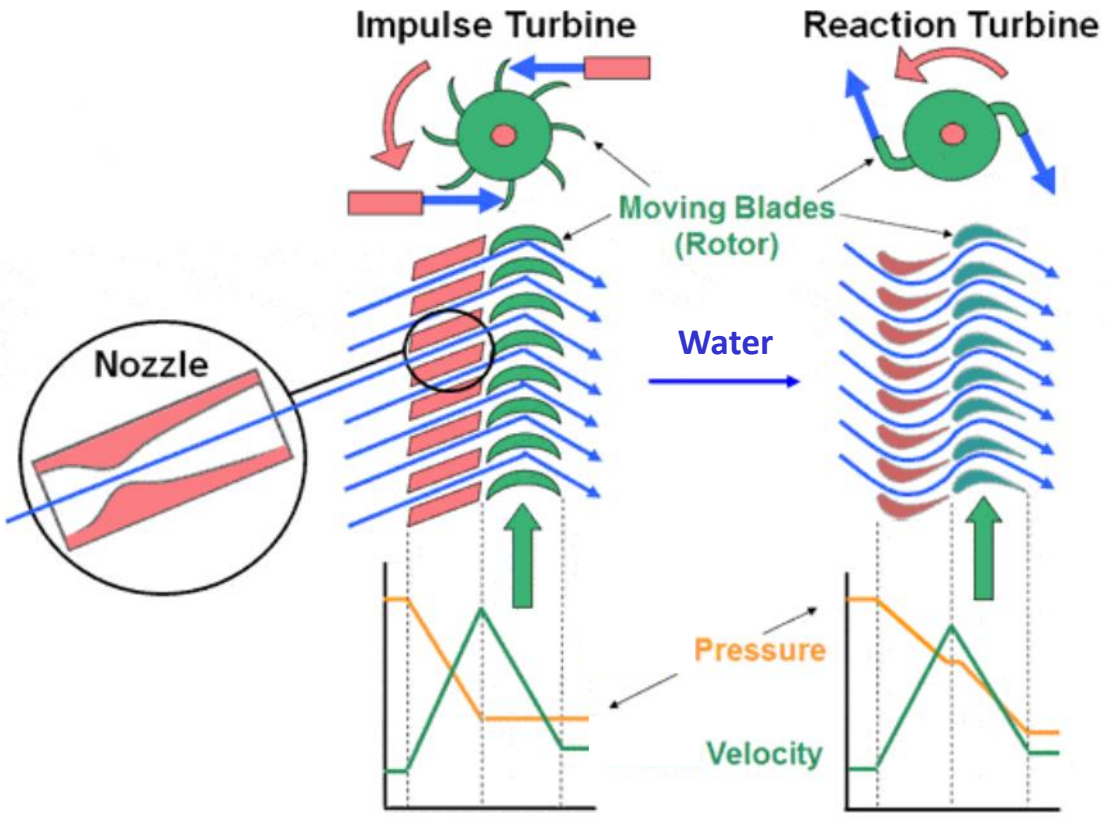


c absolute velocity, **w** relative velocity, **u** circumferential velocity,
α and **β** angles, **index 0** at the stator inlet, **index 1** between stator and rotor, **index 2** at the rotor outlet

Hydraulic Turbines

Turbine Types

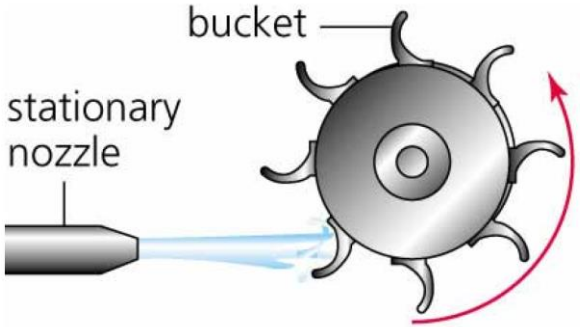
- **Impulse or Action Turbine**
  - ***The rotor works at ambient pressure***
  - The entire available energy is converted into kinetic energy in the distributor (nozzle)
- **Reaction Turbine**
  - ***The rotor works at non uniform pressure***
  - Part of the available energy is converted into kinetic energy in the distributor and the other part in the rotor
  - Must be encased to contain the water pressure or suction

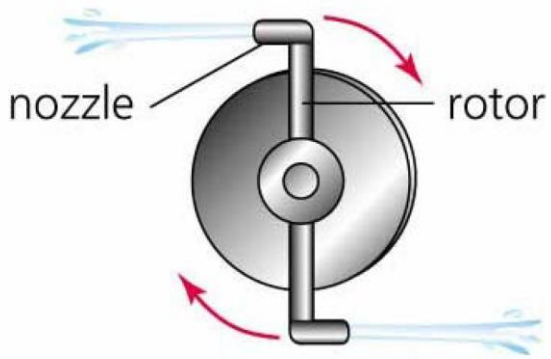


Hydraulic Turbines

Turbine Types

- **Impulse or Action Turbine**
  - The distributor (nozzle) creates a water jet increasing as much as possible the water velocity.
  - The jet impinges on the turbine's curved blade which changes the direction of the flow.
  - The resulting change in momentum (impulse) causes a force on the turbine blades.
- **Reaction Turbine**
  - The distributor steers and partially accelerates the water flow
  - The water flow changes pressure and velocity as it moves through the rotor
  - A continuous force on the blades is caused by the change in water momentum.

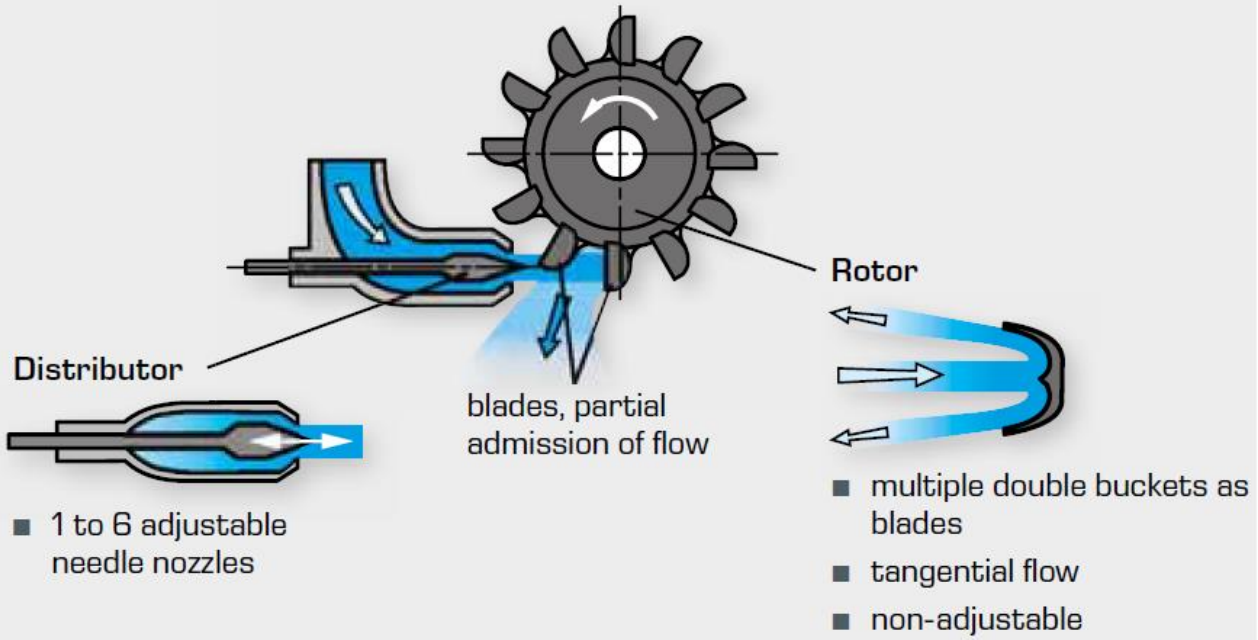




Hydraulic Turbines

Action or Impulse Turbines

Example – Pelton Turbine

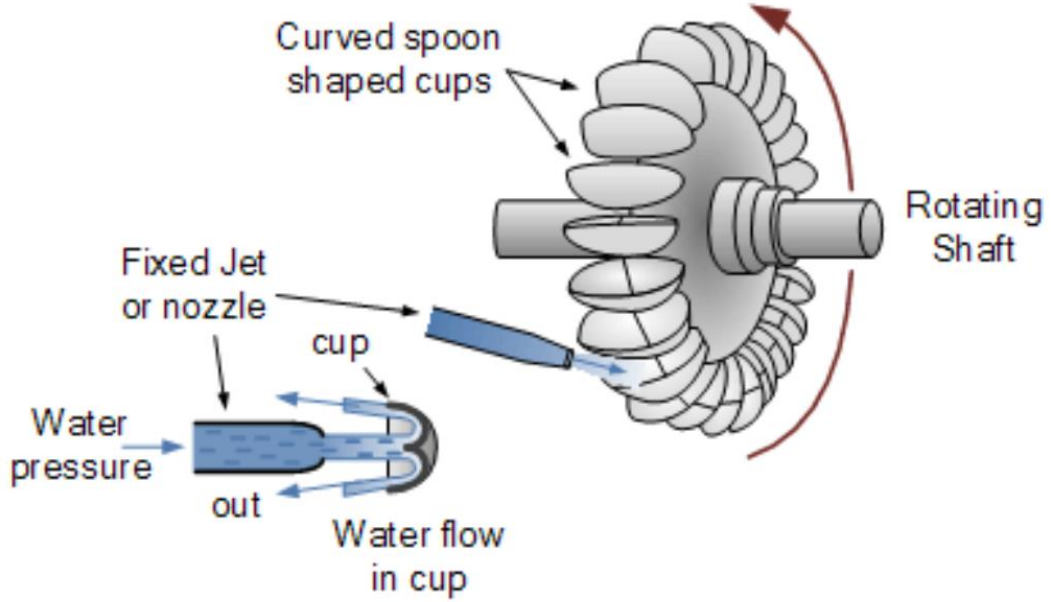


Rotor with double buckets as blades and needle nozzles

Hydraulic Turbines

Impulse Turbines

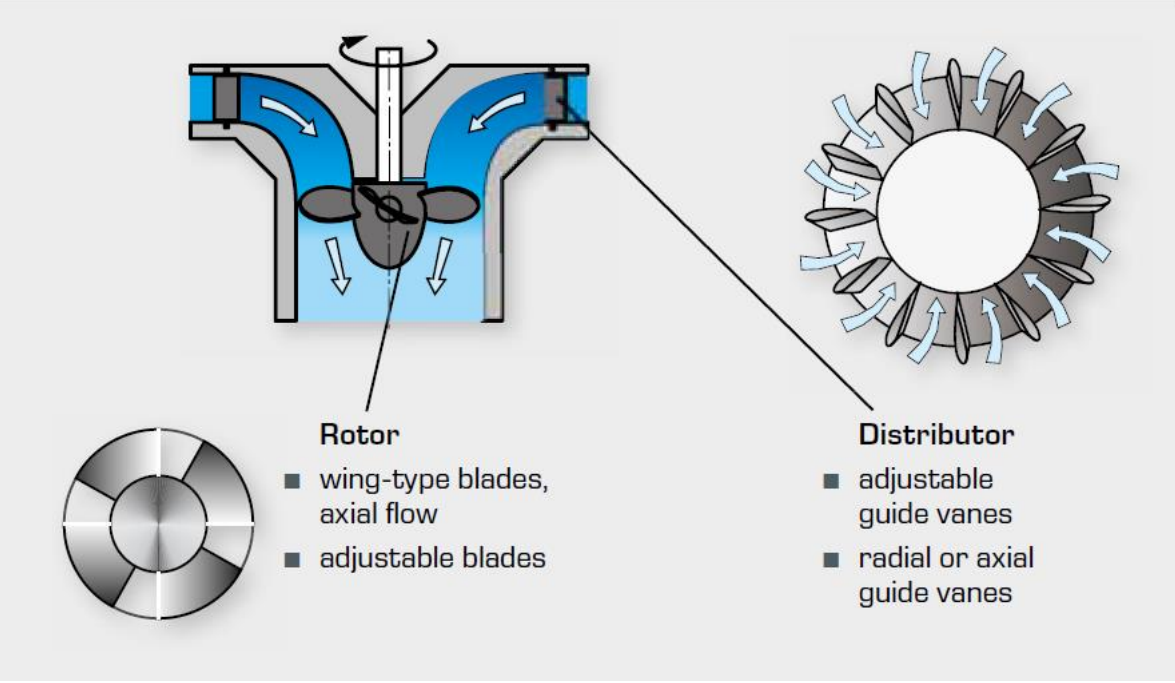
- In the rotor, inlet and outlet pressure are the same
  - The conversion in kinetic energy happens entirely in the distributor
  - All the kinetic energy is then converted into mechanical work at the rotor
- Degree of Reaction = 0
- Small-medium flow rates
- High heads (usually)
- Partial admission:
  - The working fluid interacts only with part of the blades at the same time



Hydraulic Turbines

Reaction Turbines

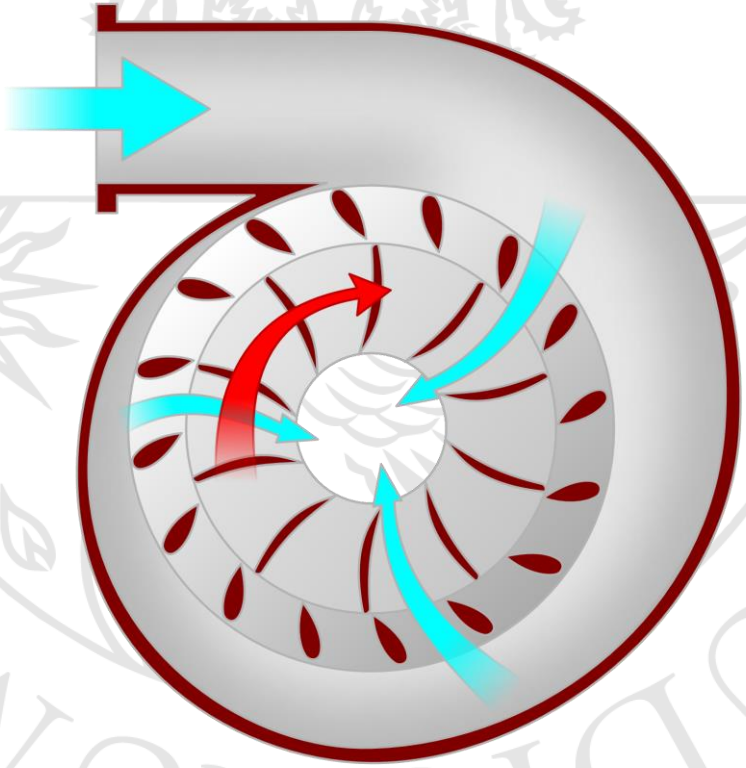
Example – Kaplan Turbine



Hydraulic Turbines

Reaction Turbines

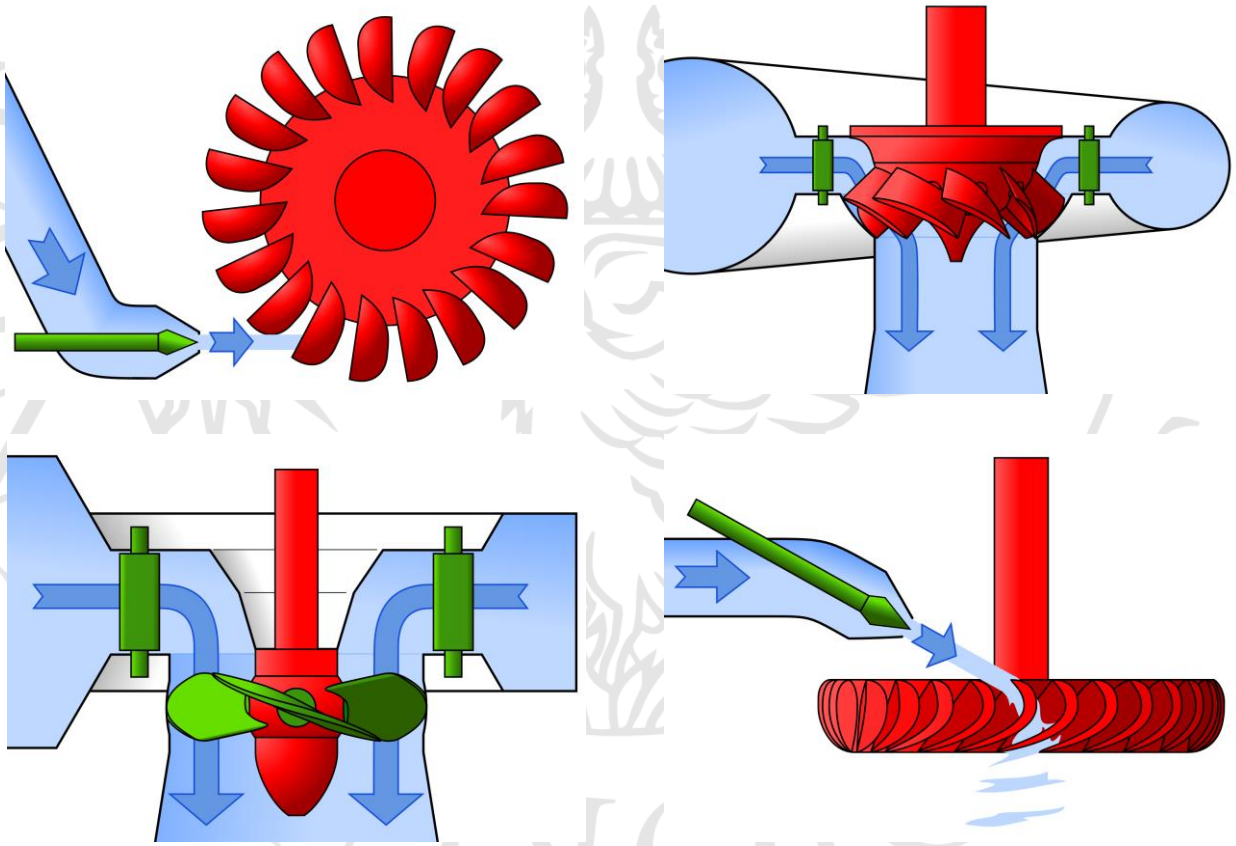
- In the rotor, inlet pressure is higher than outlet pressure
  - The conversion to kinetic energy happens both in the distributor and the rotor
  - All the kinetic energy is then converted into mechanical work at the rotor
- Degree of Reaction between 0 and 1
- High flow rates
- Medium to low heads (usually)
- Full admission flow:
  - The working fluid flows through the entire circumference of the rotors.



Hydraulic Turbines

Turbine Classifications

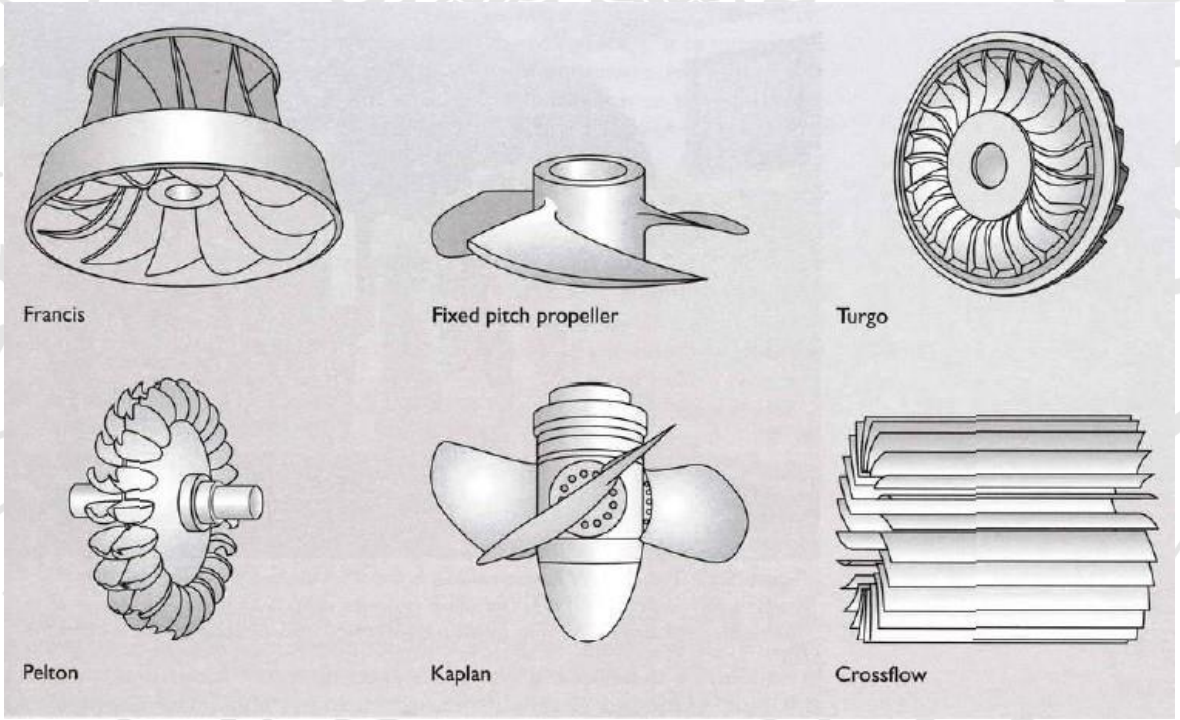
- Direction of Water Flow
  - Axial Turbines
  - Radial Turbines
  - Diagonal Turbines
  - Tangential Flow
- Shaft direction
  - Vertical shaft
  - Horizontal shaft
- Regulation
  - Single regulated (distributor only)
  - Double regulated (distributor and rotor)



Hydraulic Turbines

Impulse and Reaction Turbines

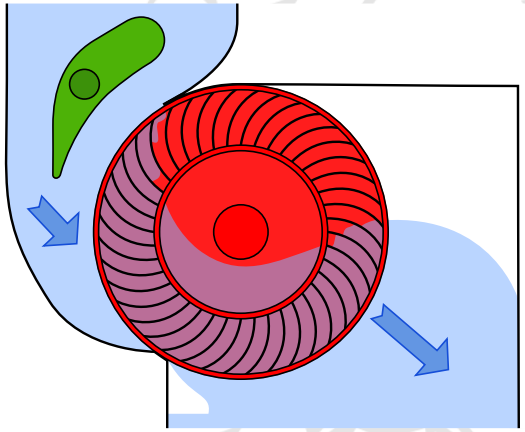
- Impulse Turbines
  - Crossflow
  - Turgo
  - Pelton
- Reaction Turbines
  - Francis
  - Kaplan
  - Others (Kaplan variants)

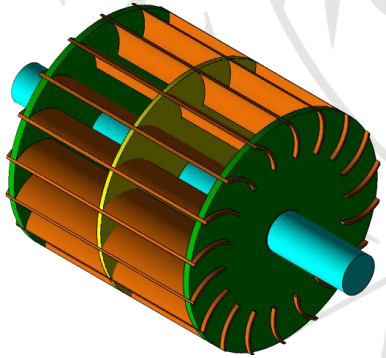


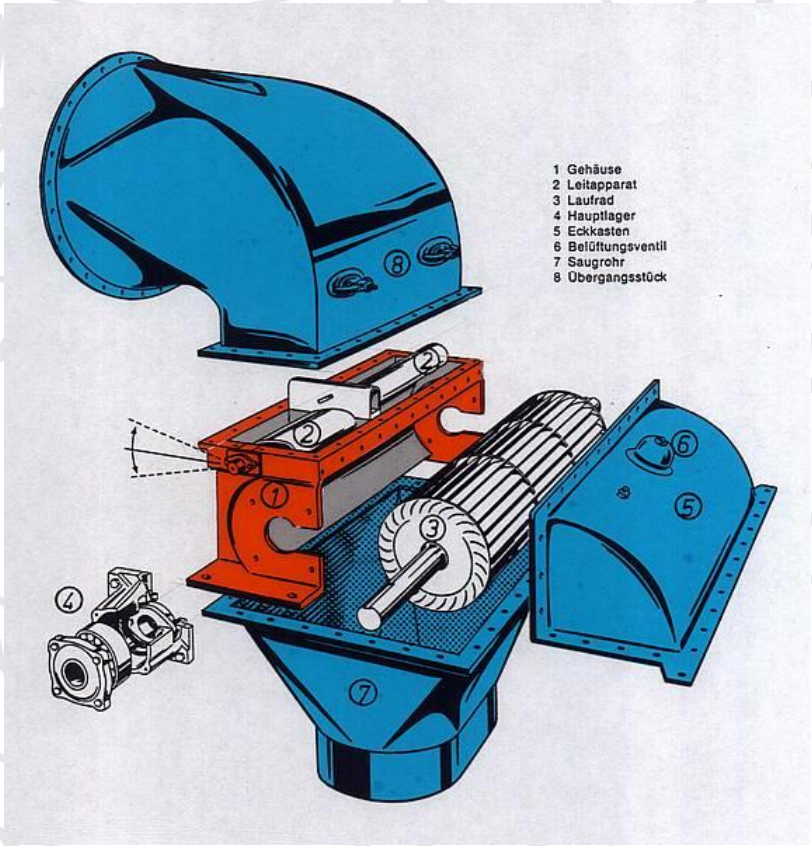
Impulse Turbines

Crossflow

- Tangential flow - Horizontal shaft
- The water passes two times across the rotor
- Low speed, low heads
- Acceptable efficiency, 70-85%
- Flat efficiency curve down to 15% of nominal power)
- Used for small and mini plants



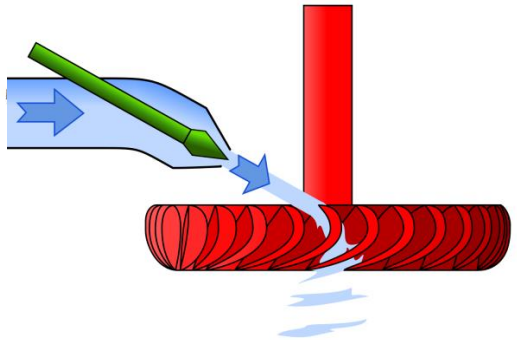


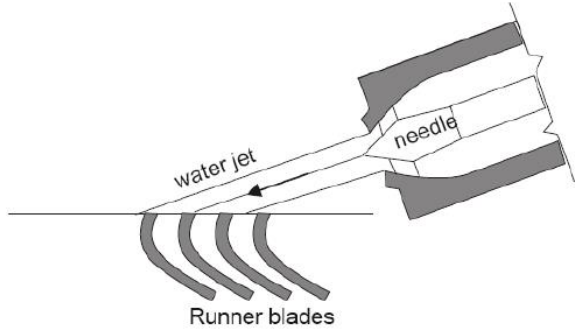


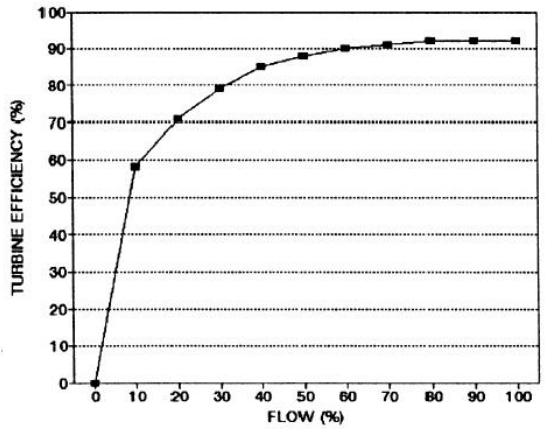
Impulse Turbines

Turgo

- Diagonal flow - Vertical shaft
- The water crosscuts the rotor from the top
- High speed, medium heads
- High efficiency, up to 90%
- Efficiency curve lowers at around 40% of nominal power
- Used for both large and small plants



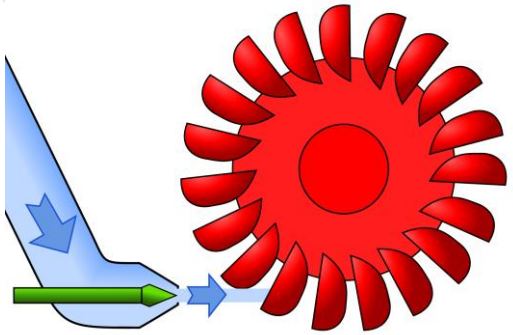


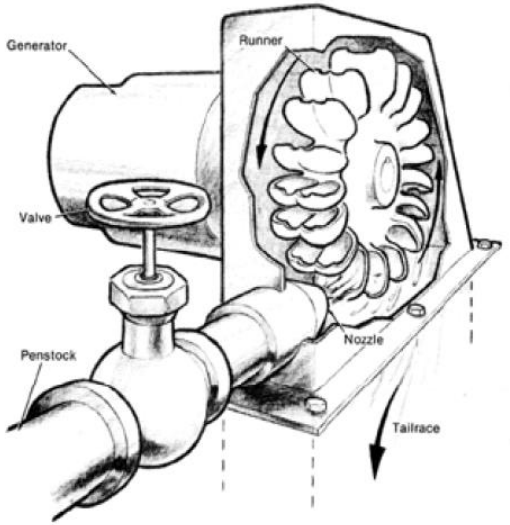


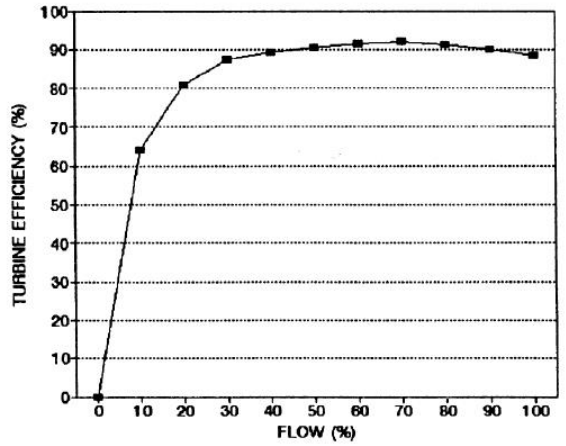
Impulse Turbines

Pelton

- Tangential flow - Horizontal shaft
- The water enters the rotor from the side from 1 to 6 nozzles
- Double-spun shaped blades
- High speed, high heads (>800m)
- Very high efficiency, up to 95%
- Very flat efficiency curve up to 20% of nominal power
- Optimal for alpine large plants

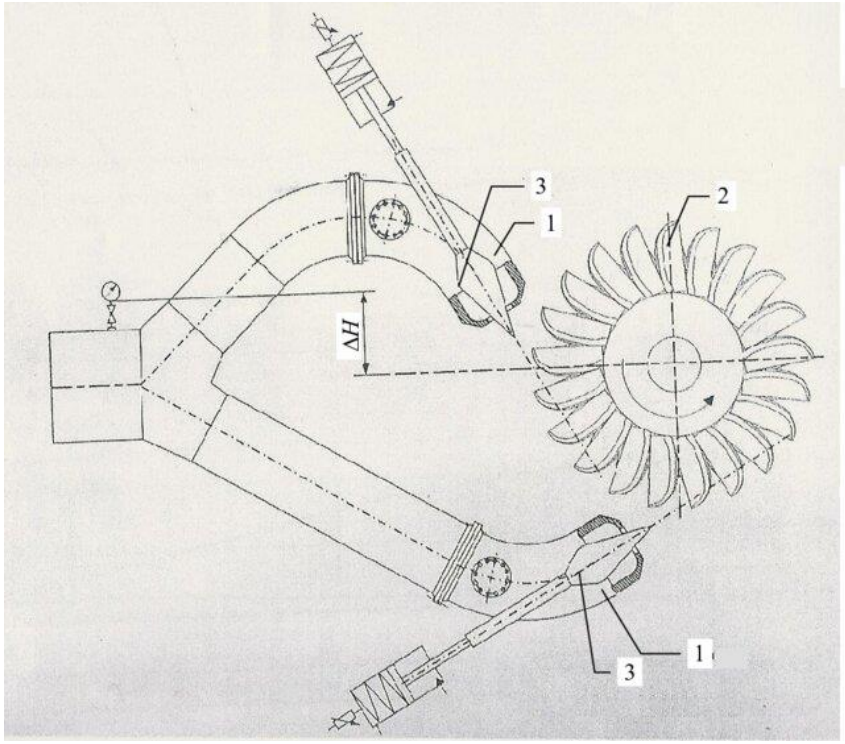


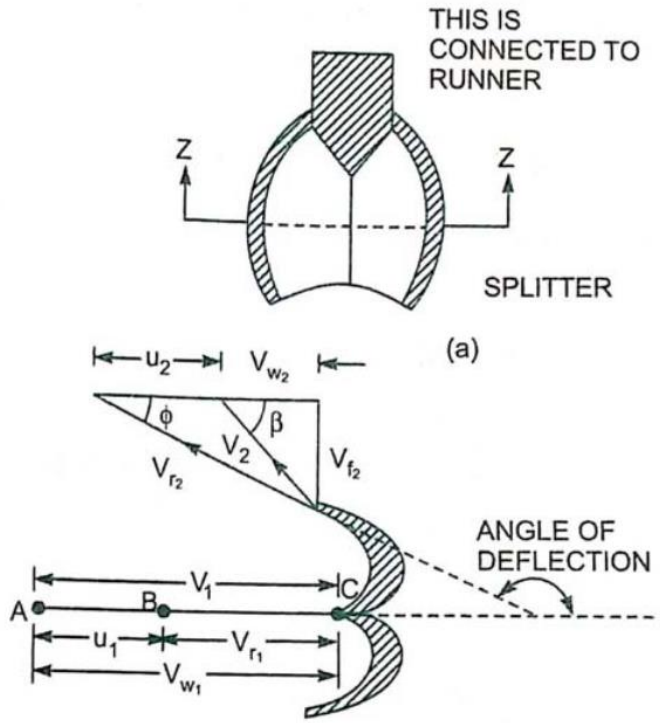




Impulse Turbines

Pelton

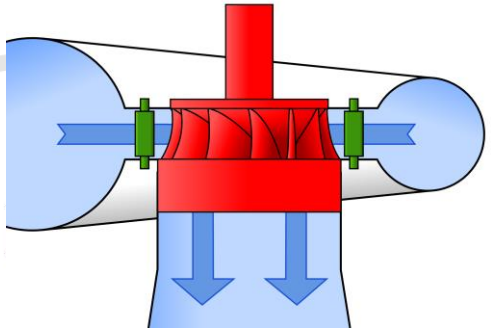


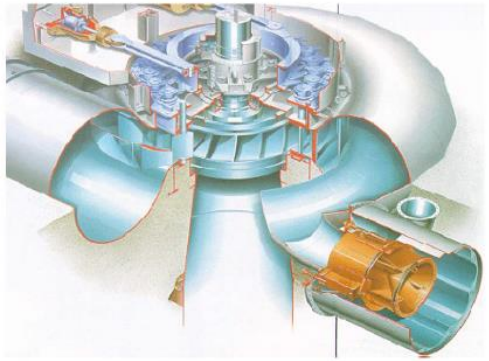


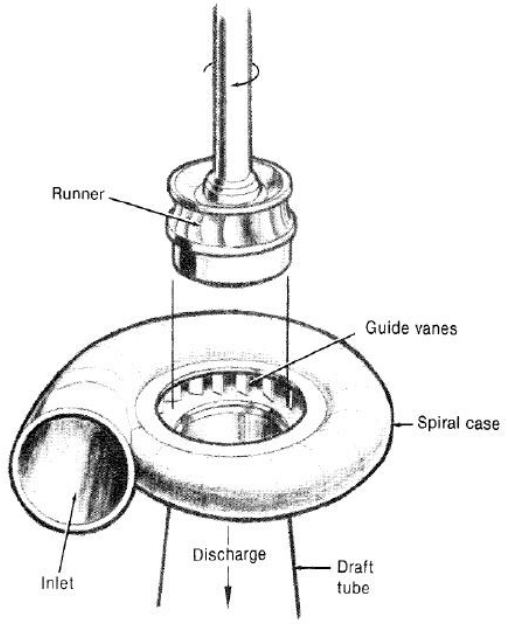
Reaction Turbines

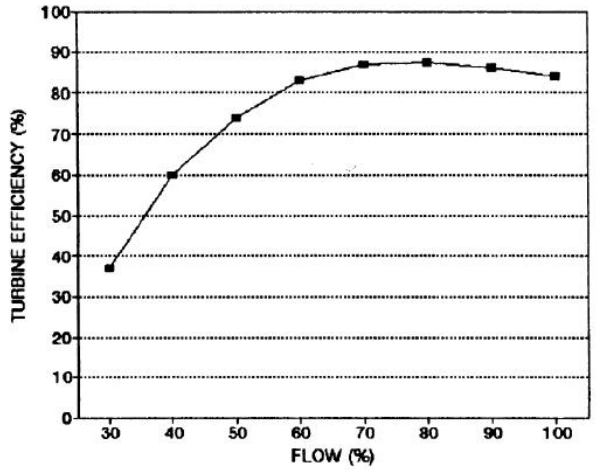
Francis

- Radial flow – Horizontal or vertical shaft
- The water enters the turbine radially and leaves it axially
- Wicket gates (distributor) adjust attack angles
- High speed, low to medium heads, from (30-800m)
- Good efficiency, up to 90%
- Looses efficiency at partial flow rates
- Optimal for large plants with stable power production





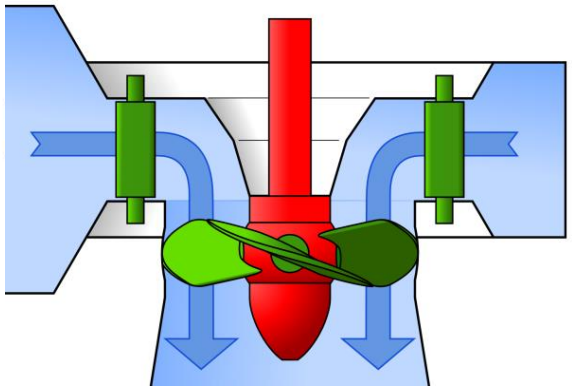


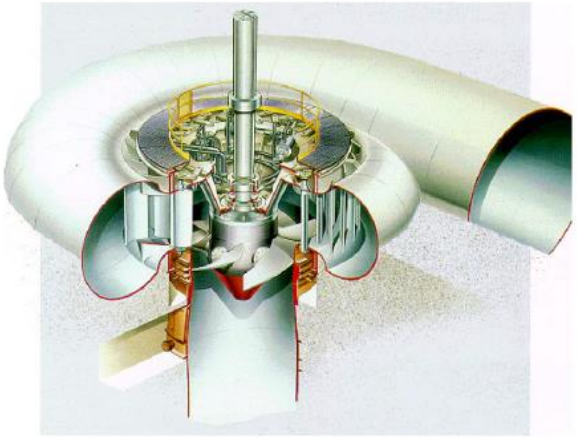


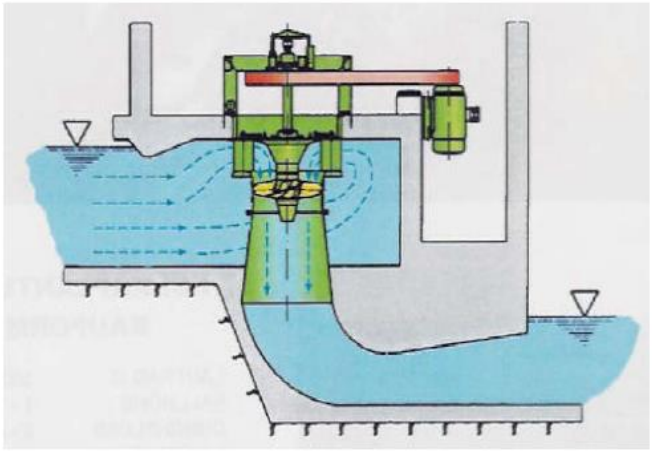
Reaction Turbines

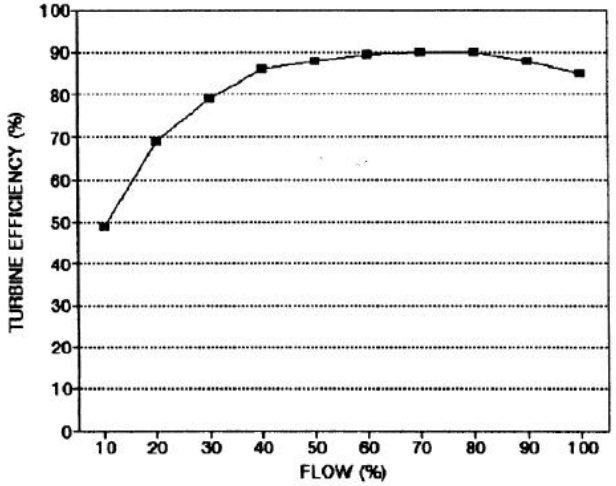
Kaplan

- Axial flow – Vertical shaft
- The water enters the turbine radially, but enters the rotor axially
- Wicket gates (distributor) and propeller blades (rotor) adjust attack angles
- High speed, low heads, (10-70m)
- Good efficiency, over 90%
- Very good efficiency down to 40% of the nominal power
- Optimal for very large plants with variable power production

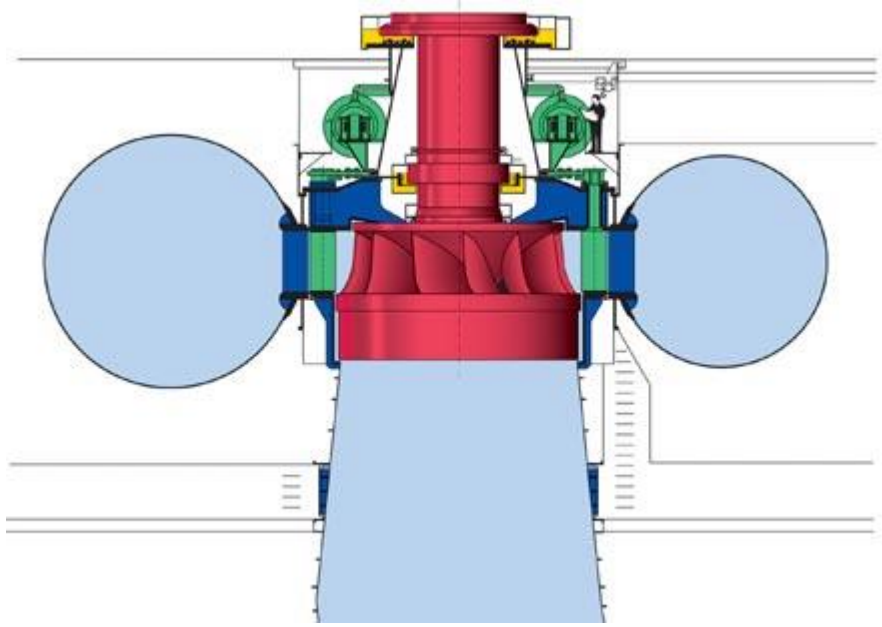




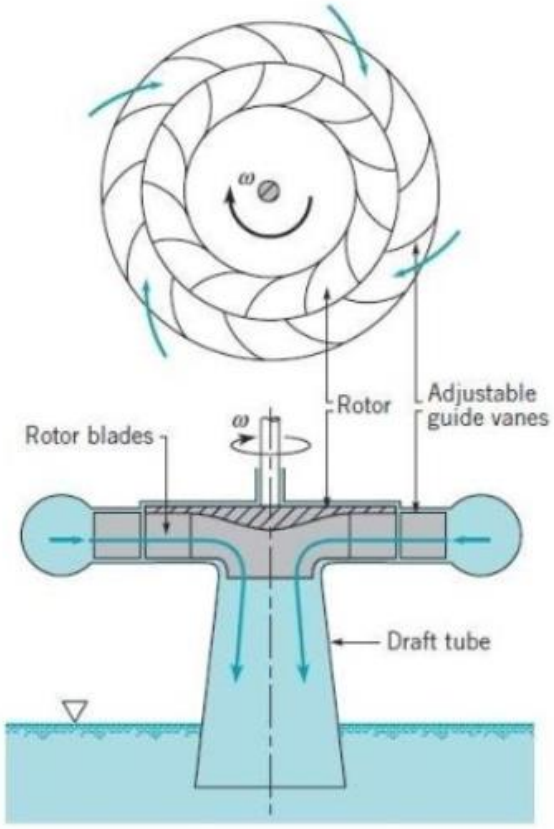




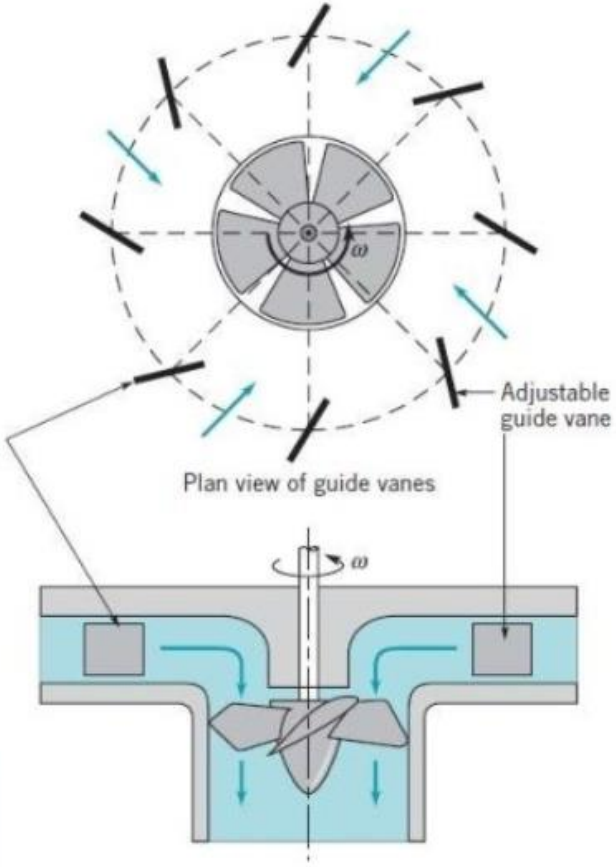
Reaction Turbines



Francis Turbine – Radial section

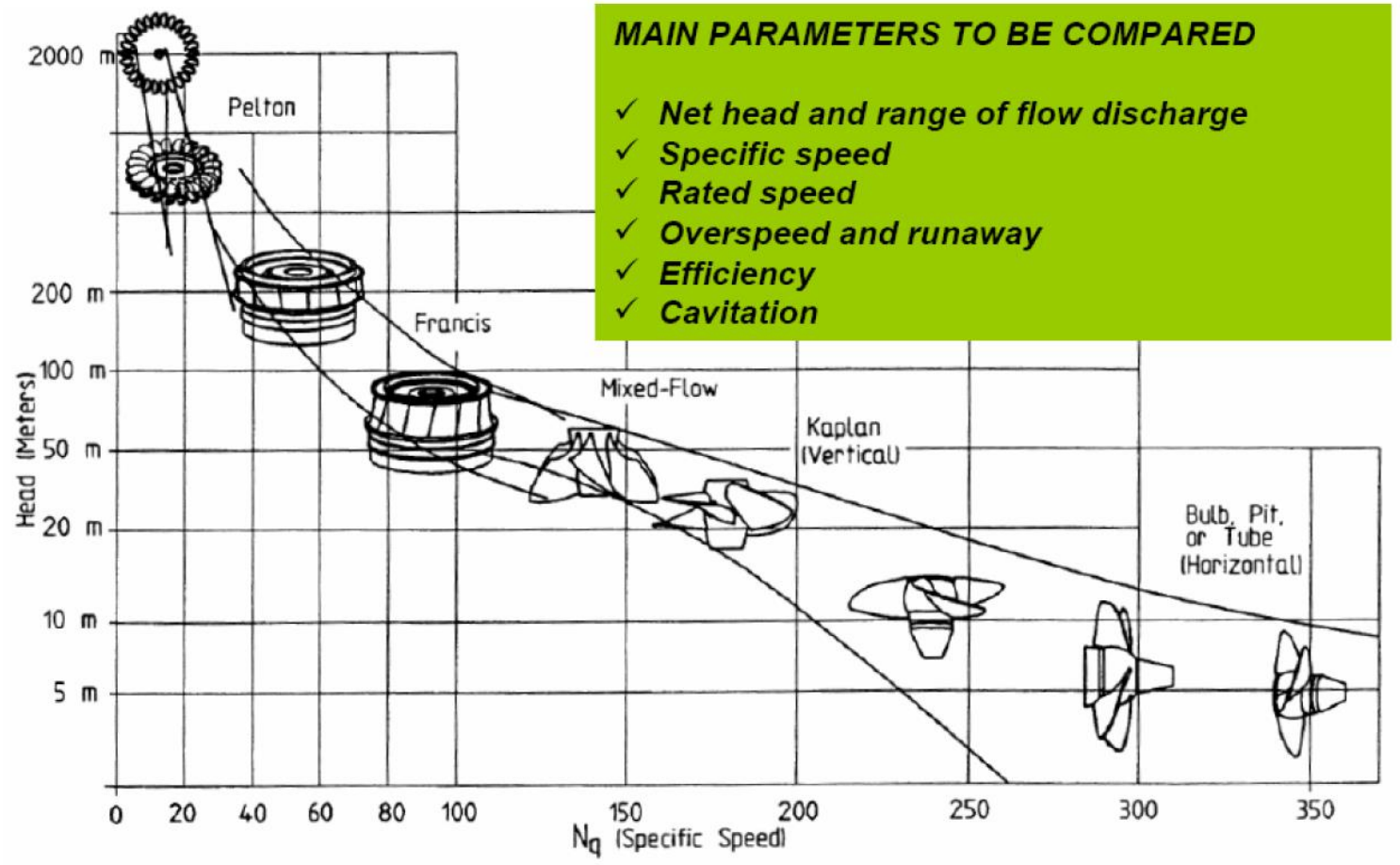


Typical radial-flow Francis turbine



Typical axial-flow Kaplan turbine

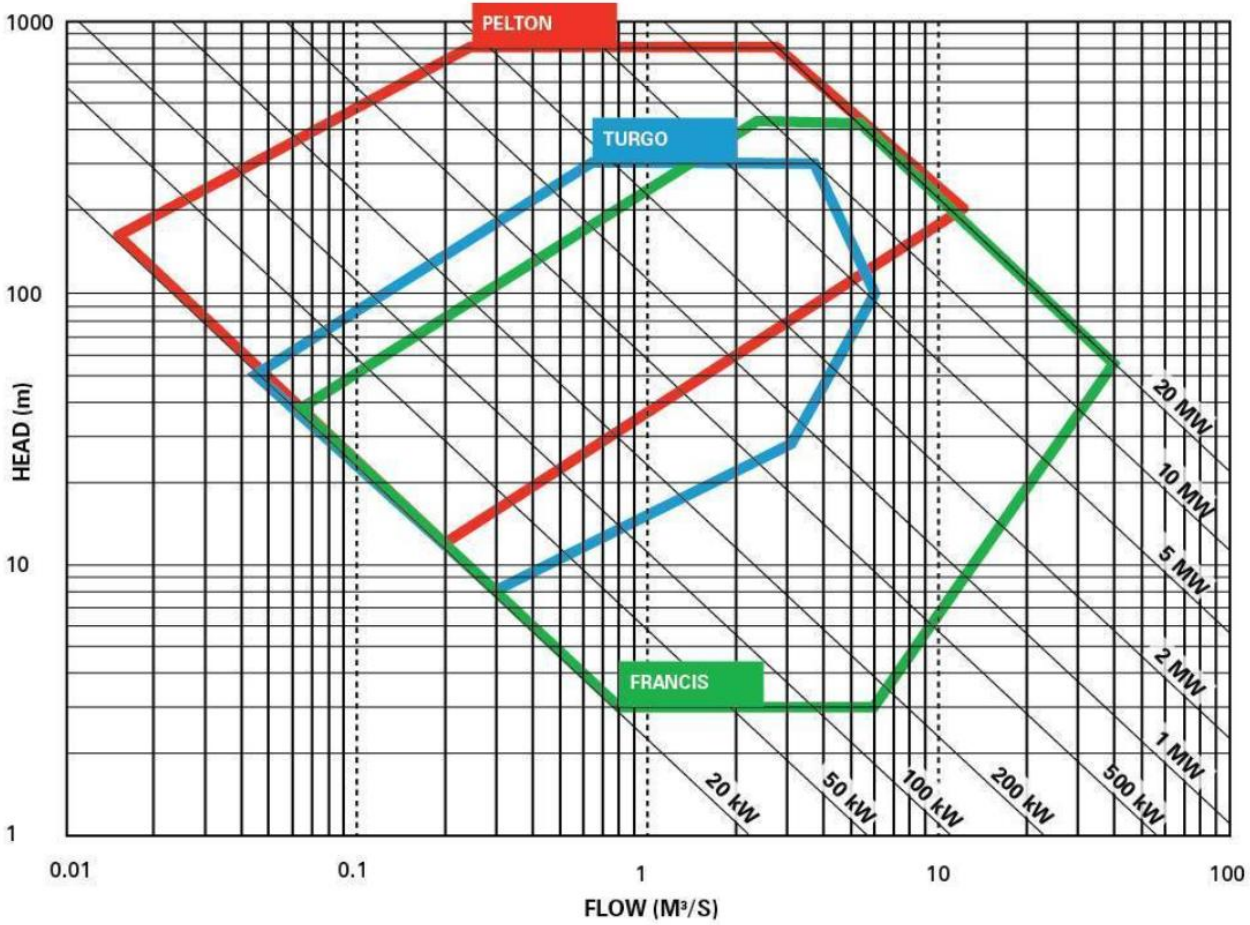
Choice of a Hydraulic Turbine

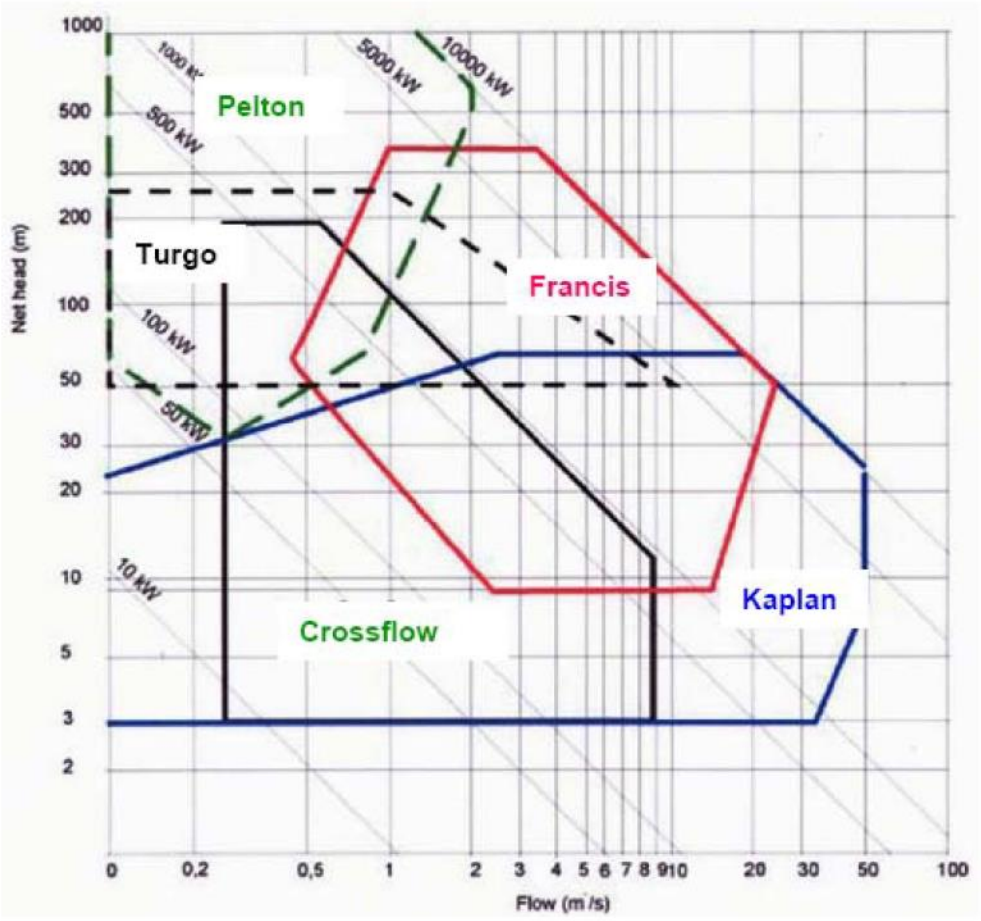


MAIN PARAMETERS TO BE COMPARED

- ✓ ***Net head and range of flow discharge***
- ✓ ***Specific speed***
- ✓ ***Rated speed***
- ✓ ***Overspeed and runaway***
- ✓ ***Efficiency***
- ✓ ***Cavitation***

Choice of a Hydraulic Turbine

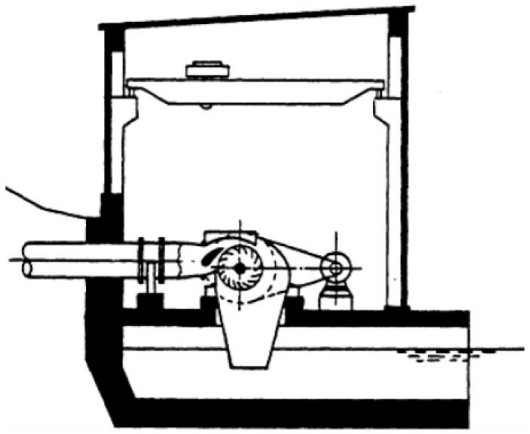




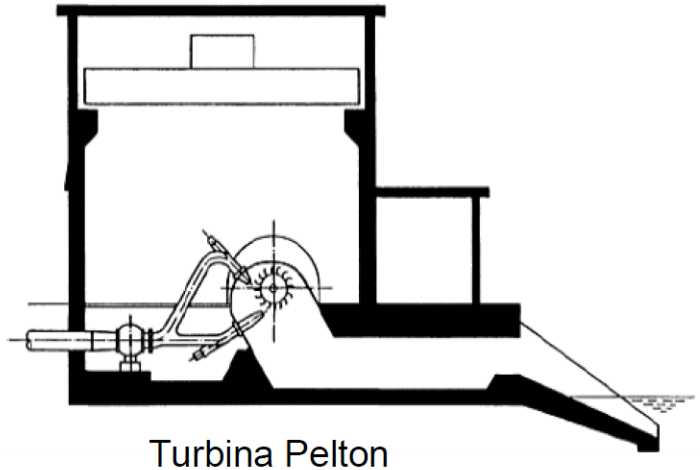
Hydraulic Turbines

Outflow

- Impulse turbines (Pelton, Turgo, Crossflow)
  - Turbine installed above the tailrace
  - A certain distance is required between the turbine axis and the free water surface (gravity outflow)



Cross Flow Turbine

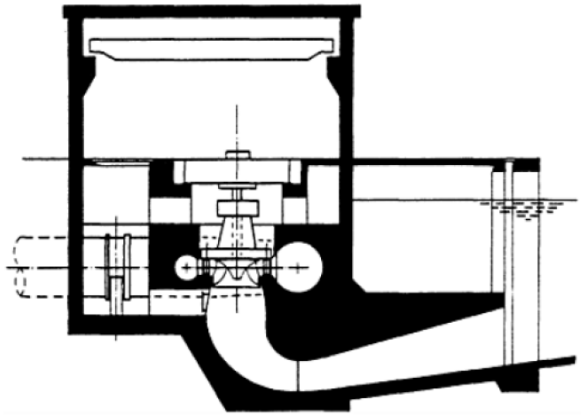


Turbina Pelton

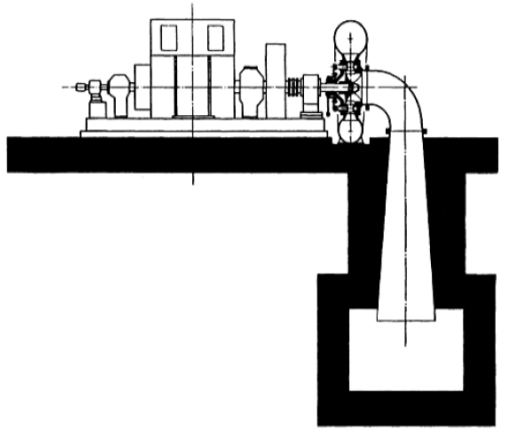
Hydraulic Turbines

Outflow

- Reaction turbines (Francis, Kaplan)
  - Connected through a draft tube with expanding section to the tailrace (avoid cavitation)
  - Water needs a not-null velocity to flow out (inertial outflow)



Turbina Francis ad asse verticale



Turbina Francis ad asse orizzontale

End of the Lesson