Fluid machinery

Fluid machine – a device exchanging energy (work) between a fluid and a mechanical system.

In particular: a turbomachine is a device using a rotating mechanical system.

The flow of energy can be in either direction:

1. Turbine → the flow does work on the mechanical system (i.e. energy is transmitted from the fluid to the mechanical system)

2. Pumps, fans, compressors, blowers → the mechanical system does work on the flow (i.e. energy is transmitted from the rotor to the fluid)

Contact between the mechanical and fluid parts is via an impeller
Types of turbine

**Impulse turbine** – e.g. Pelton wheel. Free jet of water impinges on revolving impeller (runner) and is deflected. Change of momentum of water $\equiv$ change of momentum (torque) for impeller.

Total available head converted into kinetic energy head $\rightarrow$ work done on impeller.

**Reaction turbine** – e.g. centrifugal, Kaplan turbine. Turbine completely enclosed in water, which can be pressurised. Shape of blades forces change in momentum of water – torque on blades – power. Reaction turbine uses available pressure head directly, without conversion to k.e.
Contact between the mechanical and fluid parts is via an **impeller**

1. Axial flow: fluid approaches and leaves impeller along the axis of rotation
2. Centrifugal flow: fluid approaches axially, leaves radially (in plane of impeller)
3. Mixed flow: part axial, part radial
Centrifugal pumps/turbines
Kaplan turbine (axial flow)
Define the efficiency of a turbine

\[ \eta = \frac{\text{Actual power generated by turbine}}{\text{Head available to turbine}} \]

Power generated by turbine will be reduced by a number of losses:

- Mechanical losses – bearing friction etc.
- Hydraulic losses, including:
  - Impeller power loss – inefficiencies in the impeller design
  - Leakage power loss – some flow evades the impeller
  - Casing power loss – friction with casing
For a turbine, supplied with water flow rate $Q$ at head $H$, the power generated will be

\[ P = \eta \rho g Q H \]

Reaction turbines will also operate as pumps – mechanical work used to increase energy of fluid.

For a pump, pumping flow rate $Q$ against head $H$, the power necessary will be

\[ P = \frac{\rho g Q H}{\eta} \]

Efficiencies, power, head etc. will depend on design of system and operating conditions.
For a pump, we are interested in how the developed head $H$, power $P$ and efficiency $\eta$ vary as flow rate $Q$ changes. Plot these against $Q$:
For a turbine, plot power $P$, flow rate $Q$, efficiency $\eta$ against turbine speed $N$.

Pumps, turbines designed to work at a particular point on the characteristic curve – hopefully at the most efficient point. Usually quote the performance at this design point.

What determines the conditions that the pump operates under? How do we couple the pump to the surrounding pipes?
For pipes in series, head losses sum.

Head losses have the form

\[ h_l = K \frac{Q^2}{2gA^2} \]

- i.e. quadratic curve
Pump/pipe systems

1. For pipes in series, head losses sum
2. Head losses have the form
   \[ h_l = K \frac{Q^2}{2gA^2} \]  
   – i.e. quadratic curve
3. Pump characteristic inverted
1. For pipes in series, head losses sum

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3. Pump characteristic inverted

4. System will function where head and flow both match