University of
South-Eastern Norway

FM3217 – Object-oriented Modelling of Hydro Power Systems
L2: Energy Conversion

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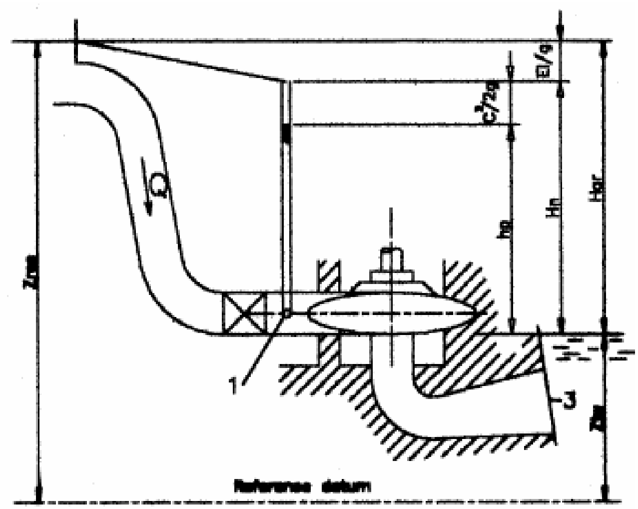
Lecture outline

- General theory
- Turbine types
- Energy equations for the different turbine types
- Operation areas

General theory

Gross quantities



Definition (Head and Energy)

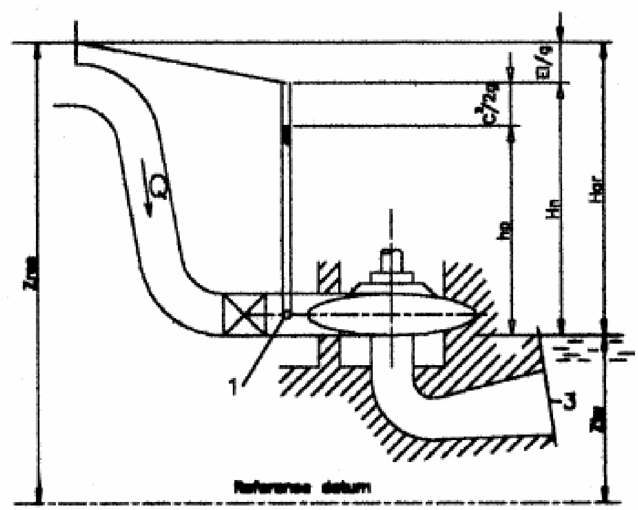
$$
\begin{aligned}
H_{gr} &= z_{res} - z_{tw} \\
E_{gr} &= gH_{gr}
\end{aligned}
$$

Definition (Power)

$$P_{gr} = \rho Q g H_{gr} \quad (1)$$

General theory

Net quantities



Definition (Head and Energy)

$$
\begin{aligned}
H_n &= H_{gr} - \frac{E_L}{g} = H_{gr} - H_L \\
&= h_p + \frac{c^2}{2g} \\
E_n &= gH_n
\end{aligned}
$$

Definition (Power)

$$P_n = \rho Q g H_n \quad (2)$$

General theory

Turbomachinery – video

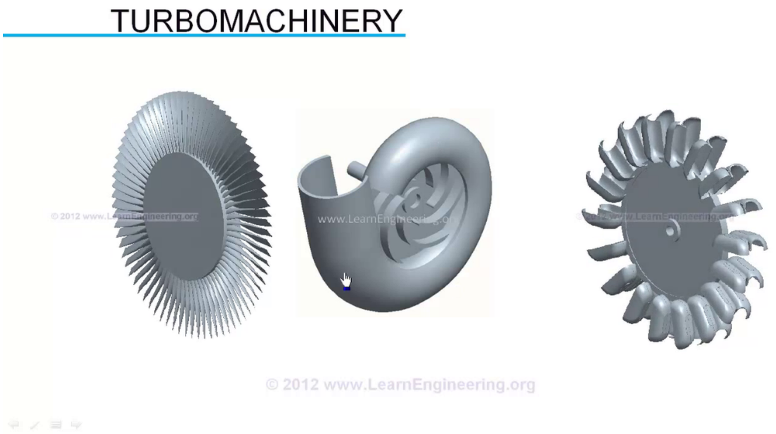


Figure: https://youtu.be/473XQrJjDZE

Turbine types

Based on the conversion principle

1. Impulse type (partial turbine):
   - Pelton turbines
   - Crossflow turbines
2. Reaction type (full turbine)
   - Francis turbines
   - Kaplan turbines
   - Bulb turbines

Turbine types

Comparison of Pelton, Francis and Kaplan – video

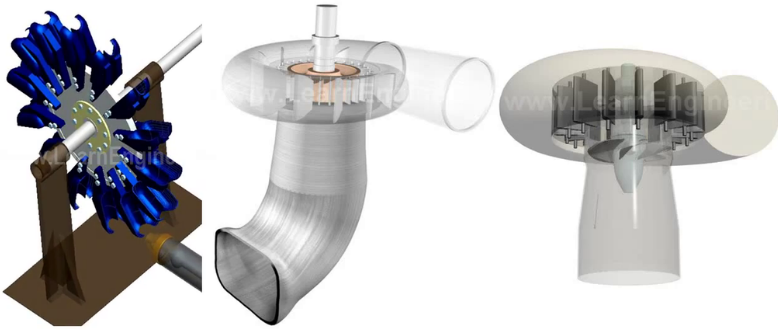
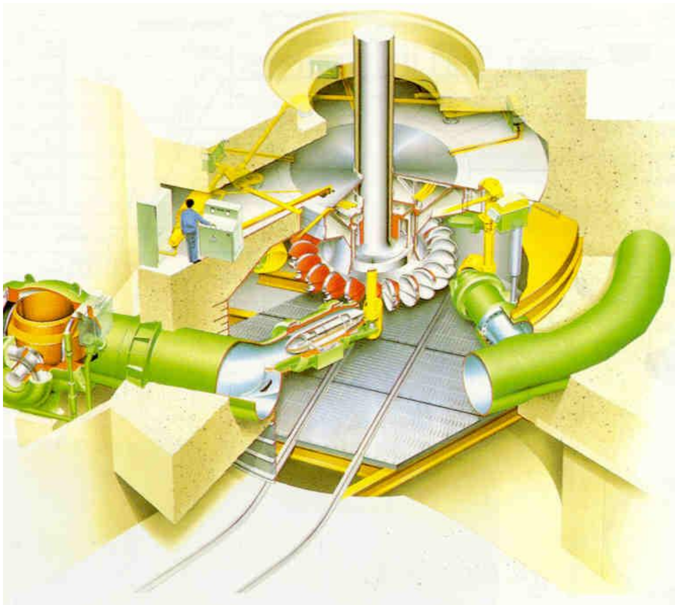


Figure: https://youtu.be/k0BLOKEZ3KU

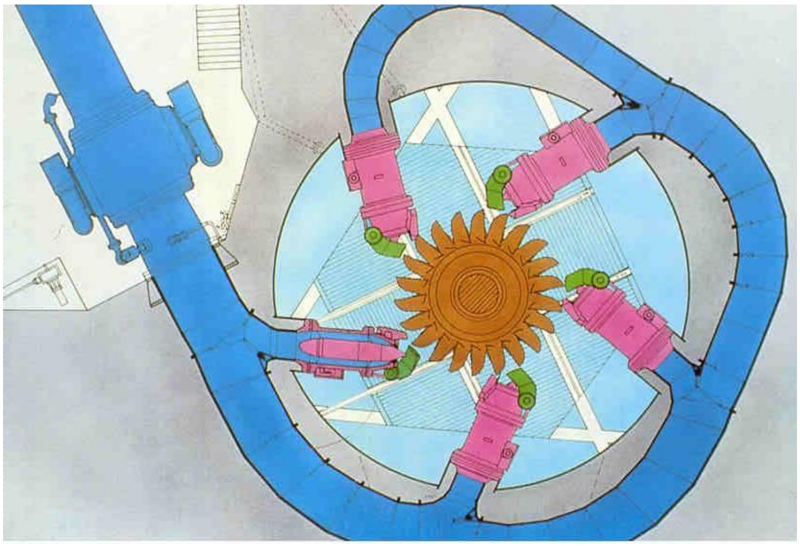
Impulse turbines

Pelton – physical installation



Impulse turbines

Pelton – physical installation (top view)



Impulse turbines

Pelton – video

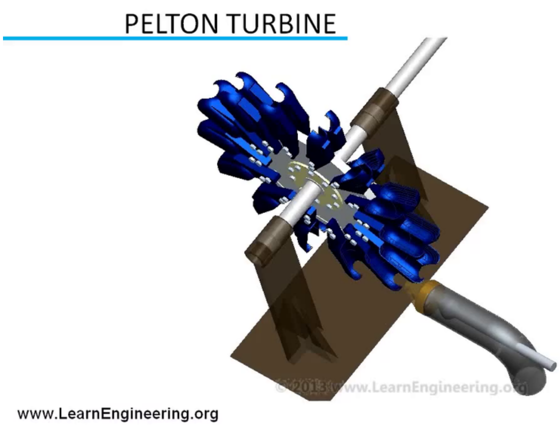
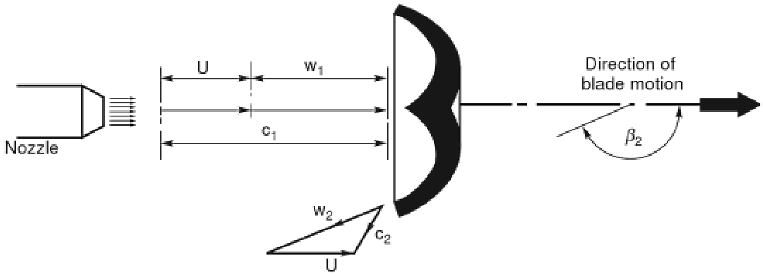


Figure: https://youtu.be/rf9meqw2SQA

Impulse turbines

Pelton – flow diagram



$$\Delta W = u w_1 (1 - k\cos\beta_2) = u(c_1 - u)(1 - k\cos\beta_2)$$

Definition (Runner Power)

$$P_R = \rho Q u (c_{u_1} - c_{u_2})$$

General:

$$P_R = \rho Q (u_1 c_{u_1} - u_2 c_{u_2})$$

for $u_2 = u_1$ we can write:

$$P_R = \rho Q u_1 (c_{u_1} - c_{u_2})$$

Reaction turbines

Francis – physical installation

Reaction turbines

Francis turbine – video

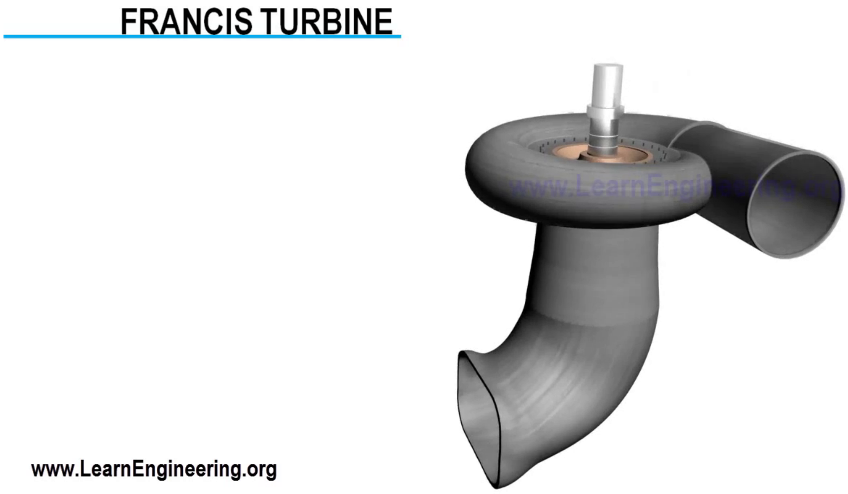
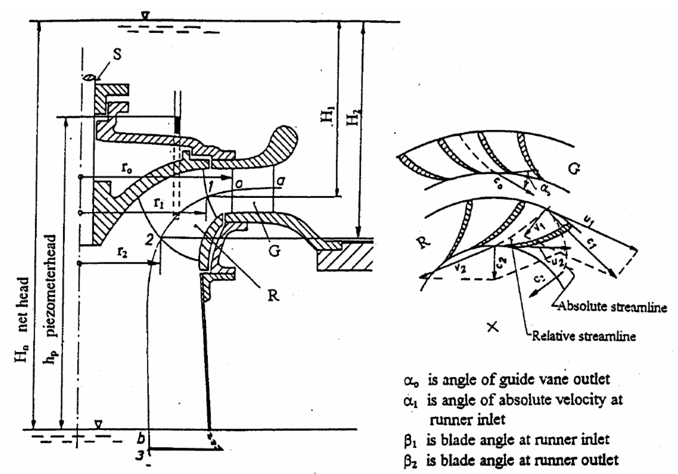


Figure: https://youtu.be/3BCiFeykRzo

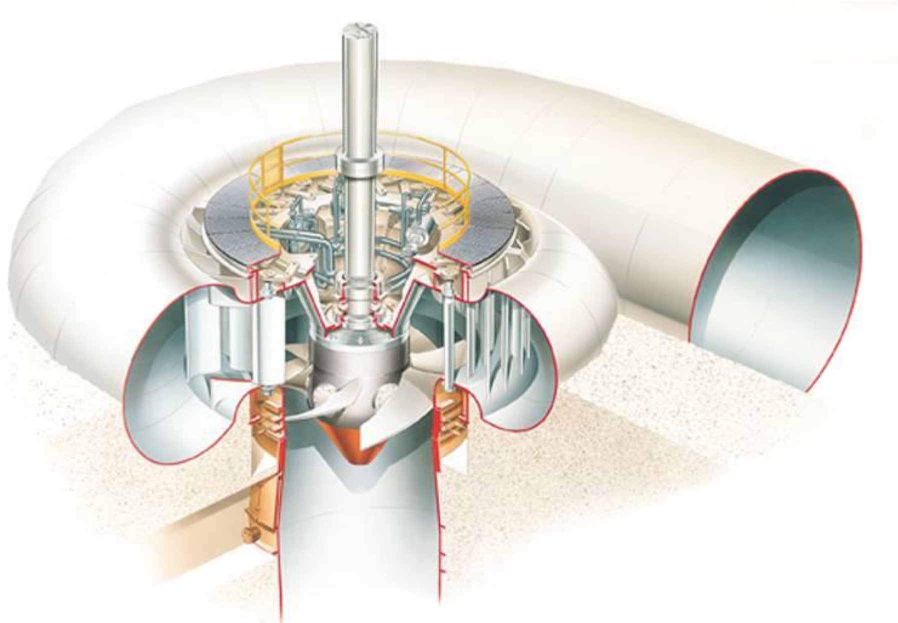
Reaction turbines

Francis – flow diagram



Reaction turbines

Kaplan – physical installation

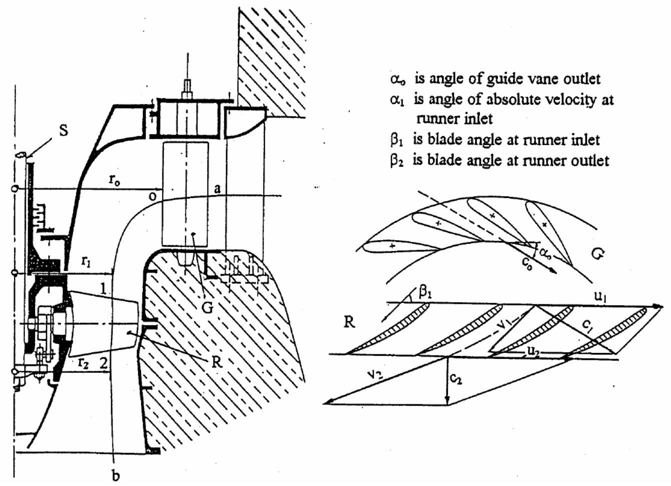


Reaction turbines

Kaplan – video

Figure: https://youtu.be/0p03UTgpnDU

Reaction turbines
Kaplan – flow diagram



Reaction turbines
Kaplan – power calculation

Definition (Rotor Power)

$$P_R = \rho Q(u_1 c_{u_1} - u_2 c_{u_2})$$

for $u_2 = u_1$ we can write:

$$P_R = \rho Q u_1 (c_{u_1} - c_{u_2})$$

Hydraulic efficiency

Part 1

Definition (Total available power)

$$P_n = \rho Q g H_n \tag{3}$$

Definition (Power of the runner)

$$P_R = \rho Q(u_1 c_{u_1} - u_2 c_{u_2}) \tag{4}$$

Definition (Hydraulic efficiency)

$$\eta_h = \frac{P_R}{P_n} = \frac{1}{g H_n}(u_1 c_{u_1} - u_2 c_{u_2}) \tag{5}$$

Hydraulic efficiency

Part 2

Definition (Total sum of losses)

$$h_L = \frac{1}{2}\left(\zeta_1 c_1^2 + \zeta_2 v_2^2 + (1+\zeta_3)c_3^2 + E_I^2\right) \tag{6}$$

Rearranging (5) gives the

Definition (Main turbine equation)

$$\eta_h H_n = \frac{1}{g}(u_1 c_{u_1} - u_2 c_{u_2}) \tag{7}$$

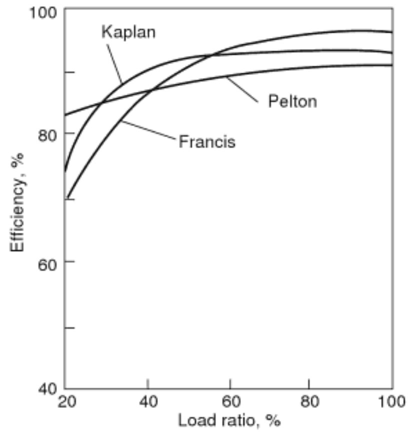
Substituting (6) into (7) then gives:

Definition (Total sum of energy transfer)

$$H_n = (1+\zeta_1)\frac{c_1^2}{2g} - \frac{c_2^2}{2g} + (1+\zeta_2)\frac{v_2^2}{2g} - \frac{v_1^2}{2g} + \frac{u_1^2}{2g} - \frac{u_2^2}{2g} + (1+\zeta_3)\frac{c_3^2}{2g} + \frac{E_I^2}{2g} \tag{8}$$

Turbine efficiencies

Francis, Kaplan, Pelton



Variation of hydraulic efficiency for various types of turbine over a range of loading, at constant speed and constant head.