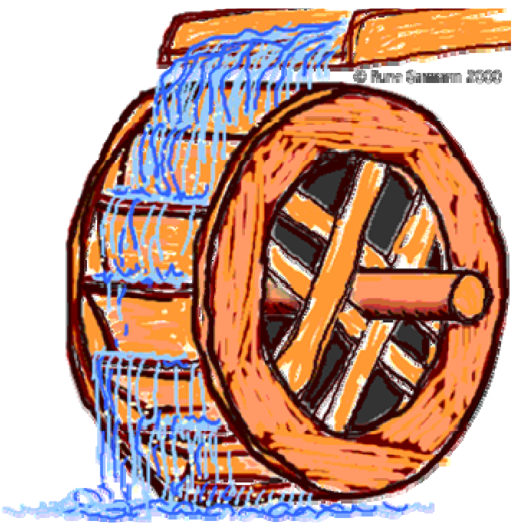
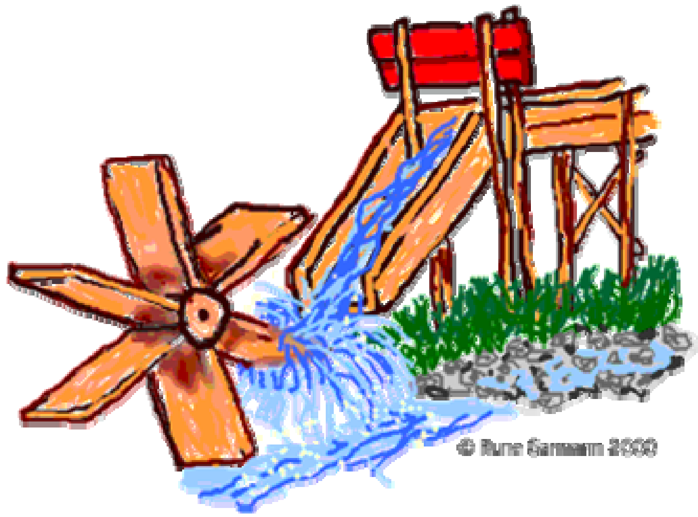
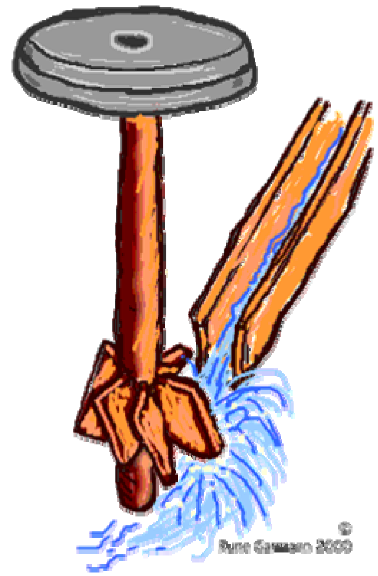
Turbines for very low head



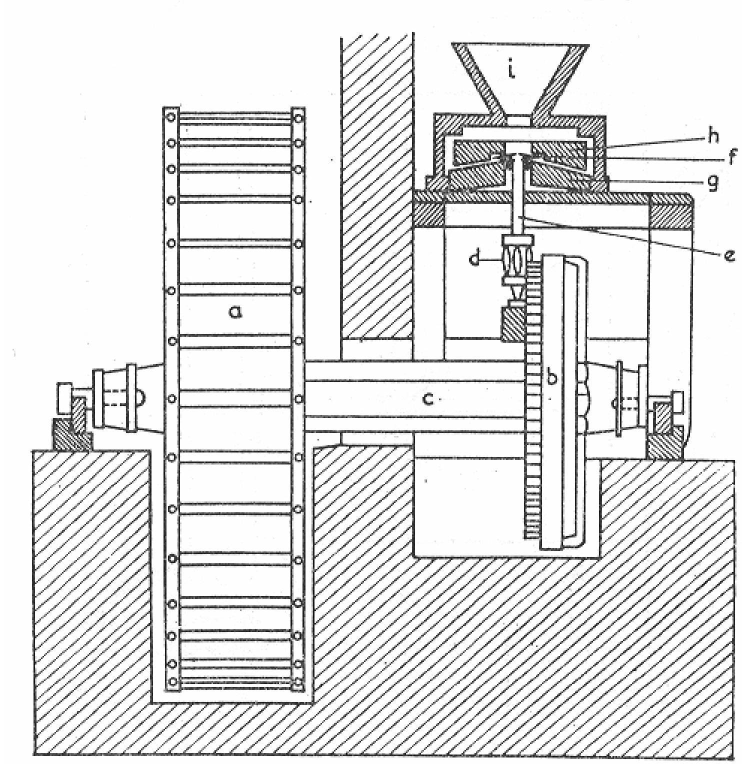




Torbjørn K. Nielsen
14.okt 2005

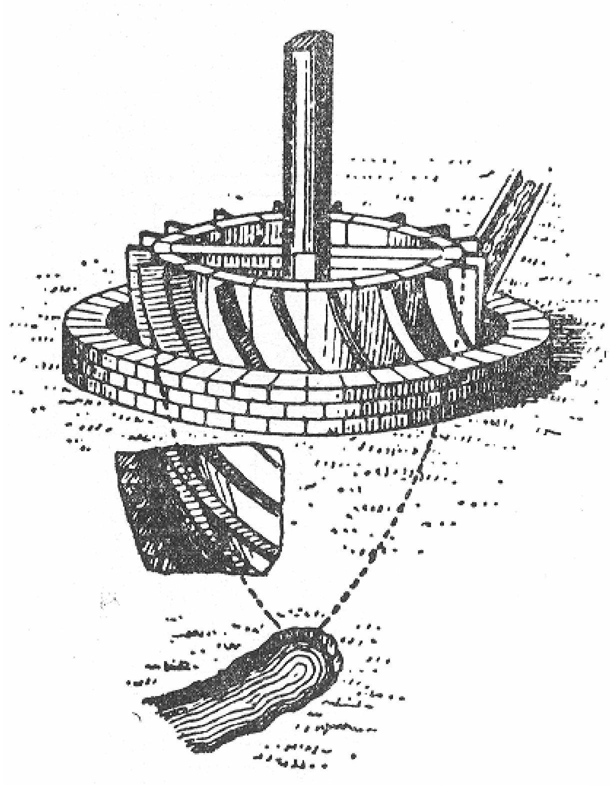
- The oldest known text that mentions a water-powered machine is over 2000 years old

- Norse mills had then already been used for a long time in the mediterranean countries

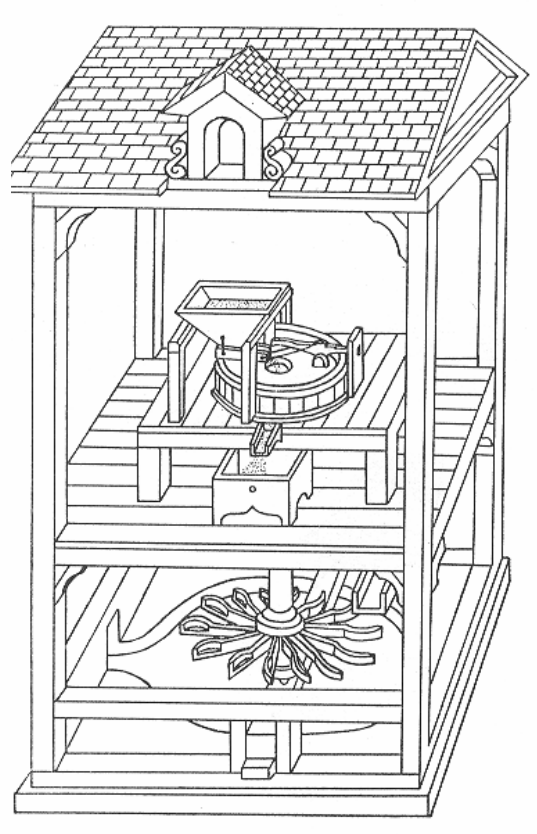


Vitruvius mill with gear

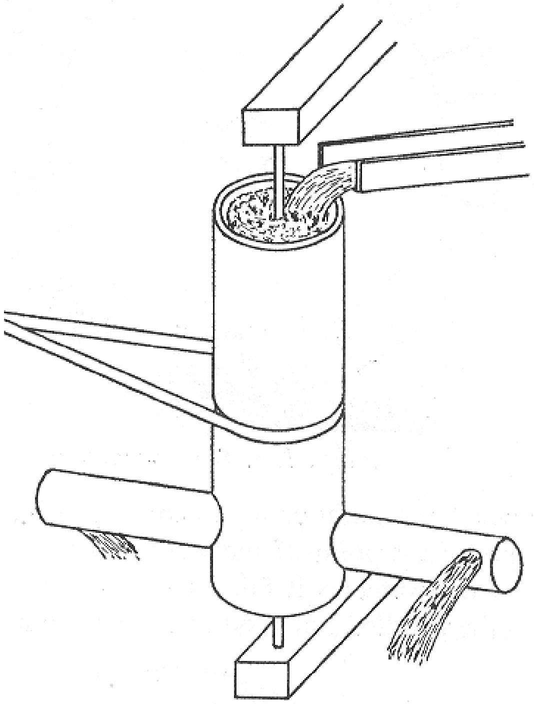
Besson 1568



Ramelli 1588



Barker 1740
Segner 1750

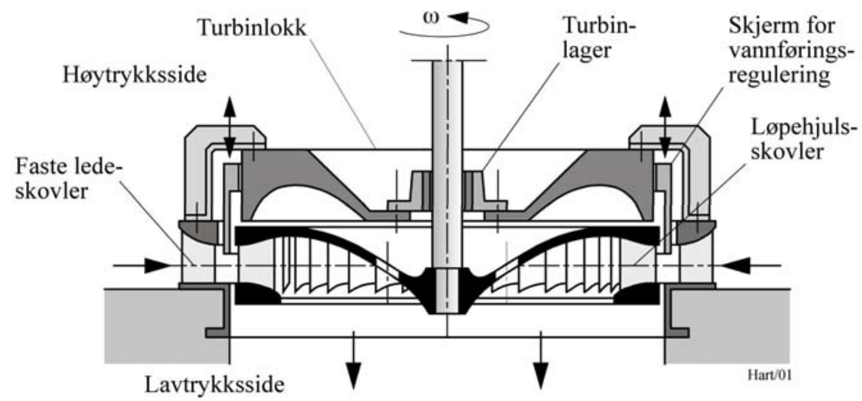


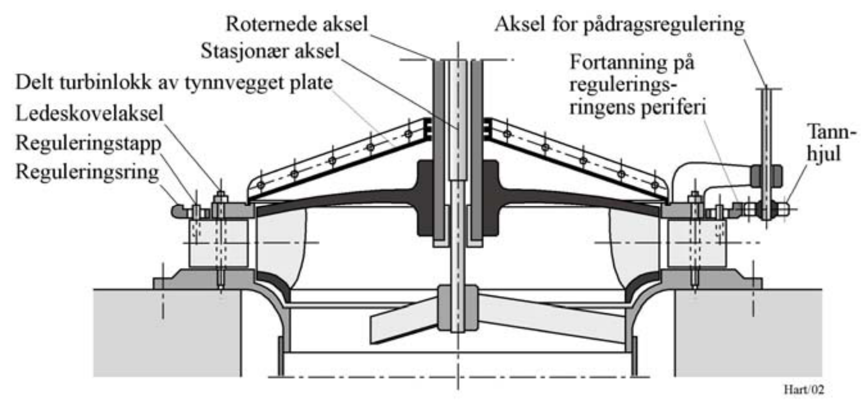
Turbine development – modern time

- 1750 J.A.Segner – reaction turbine
- 1750-54 Euler develops the turbine theory
- 1827 Forneyron - radial turbine, 30 – 40 hp, D = 0.5 m
- 1840 Henschel/Jonval – aksial turbine
  Jonval – draft tube
- 1849 Francis – Francis turbine
  Fink – Load regulation with guide vanes
- 1890 Pelton – Pelton turbine, impilse turbine
- 1913 Kaplan – Kaplan turbine, propeller

Francis turbin

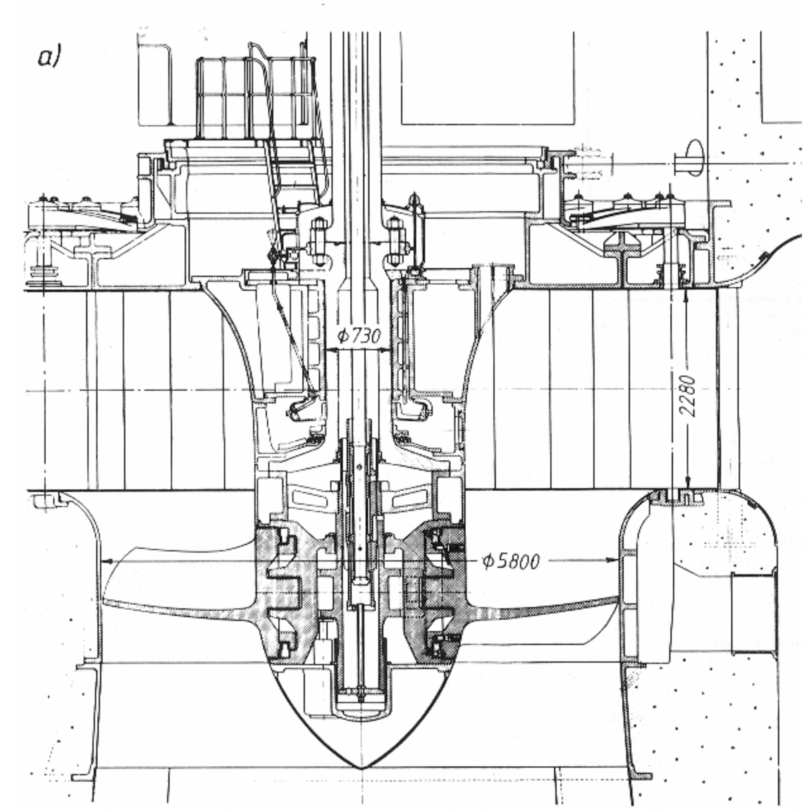
- 1855: J. B. Francis presents a inward-flow turbine
- Hydraulically well-shaped vanes and blades
- Efficiency equal to Fourneyron and Jonval turbines
- 1873: Voith and Kankelwitz add adjustable guide vanes



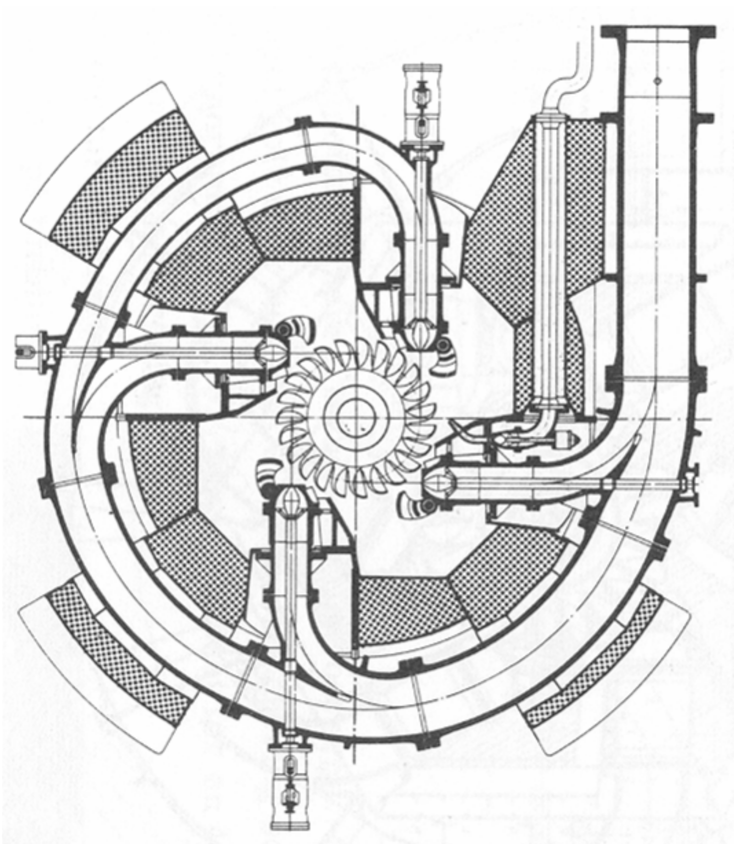


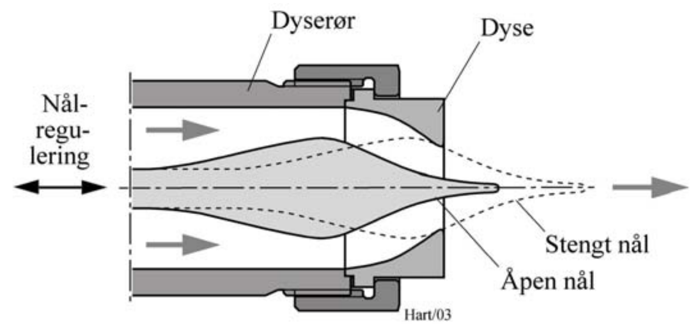
Kaplan

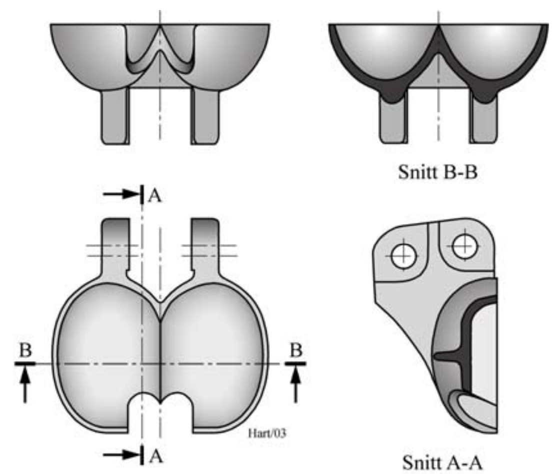
- 1926: First large Kaplan turbine installed at Lilla Edet
- Efficiency up to 92,5%
- Part load efficiency above 83%
- Final break-trough for Kaplan turbines



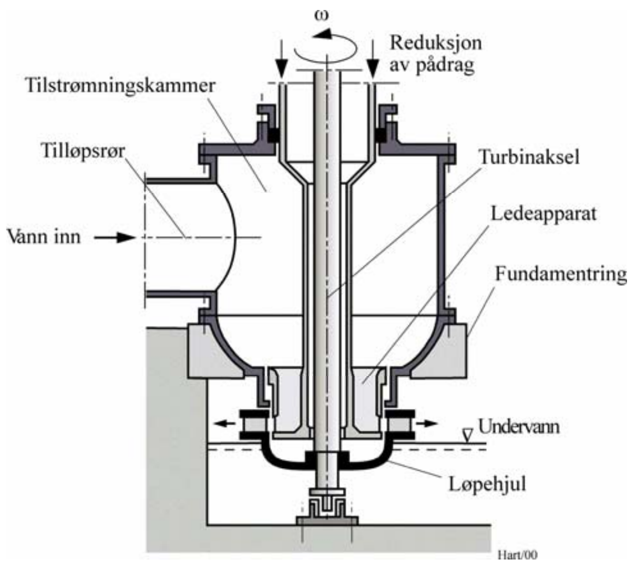
Pelton turbine – impulse turbine



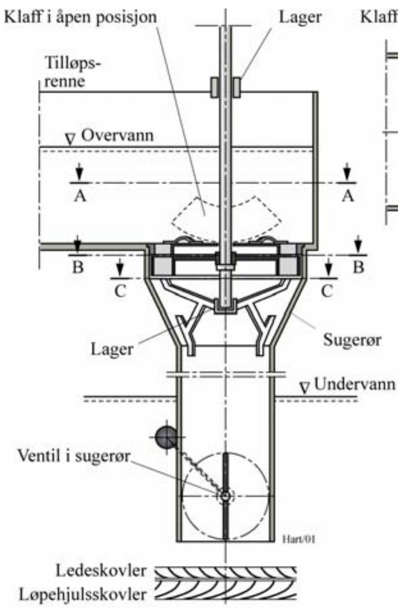




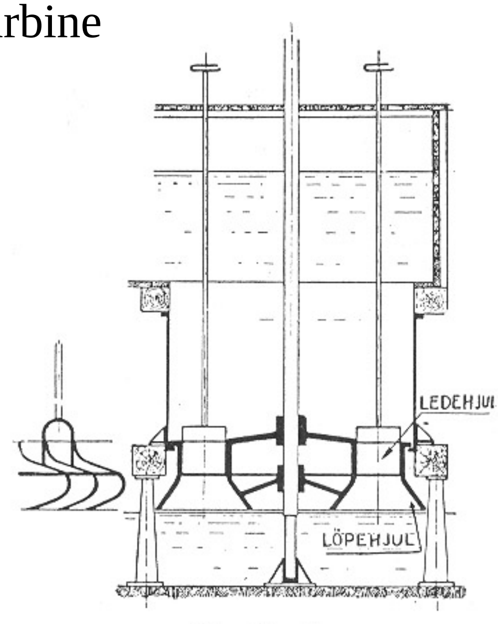
Fourneyron turbine



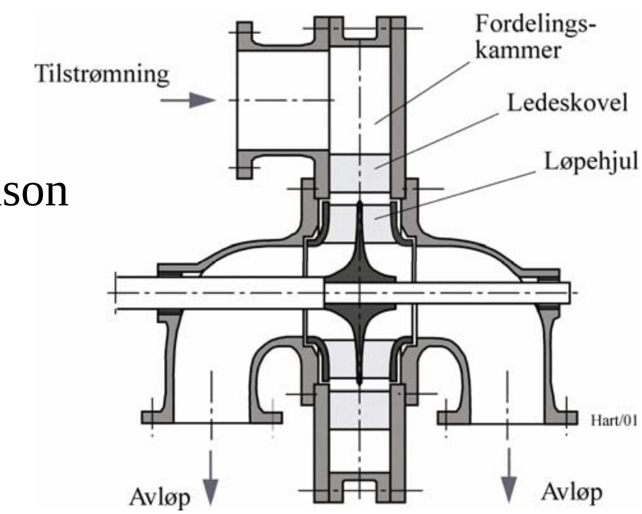
Jonval-Henschel turbine



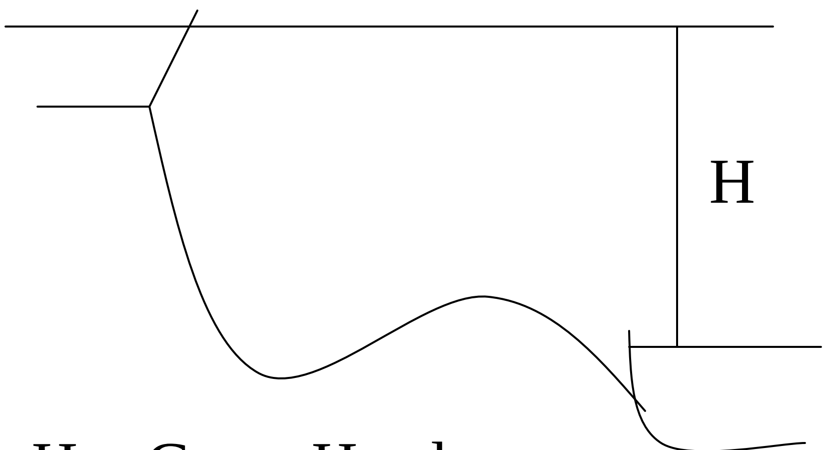
The Girard turbine



Thomson



Hydraulic energi



H = Gross Head

Q – Flow

ρ – density

g – gravitation

Available from nature

$$P = \rho g Q H$$

$$\left[\frac{kg\ m\ m^3}{m^3\ s^2\ s}\ m \right]$$

$$= \left[\frac{Nm}{s} \right] = [W]$$

Power transformation

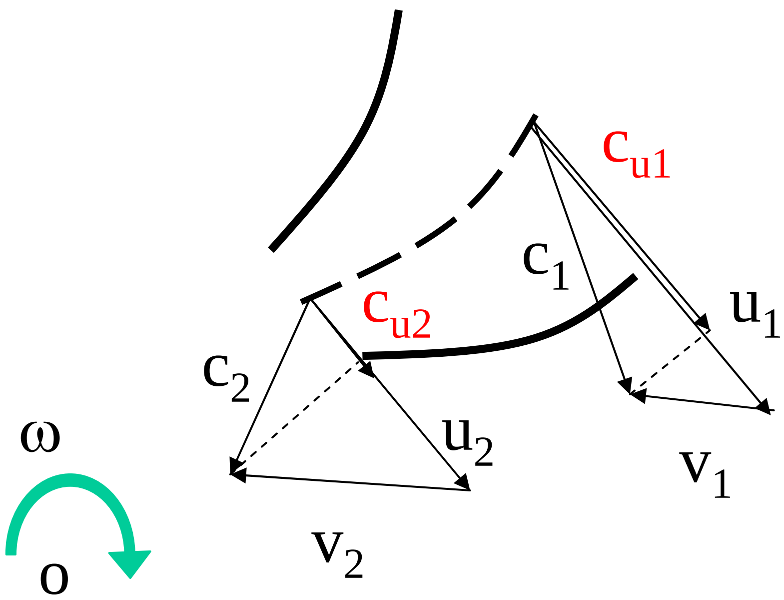
Hydraulic power

$\Rightarrow$ Mechanical rotating power

$\Rightarrow$ Electric energy

$$\rho g Q H \overset{\text{Turbine}}{\Rightarrow} M\omega \overset{\text{Generator}}{\Rightarrow} UI$$

Velocity components



u – peripheral velocity

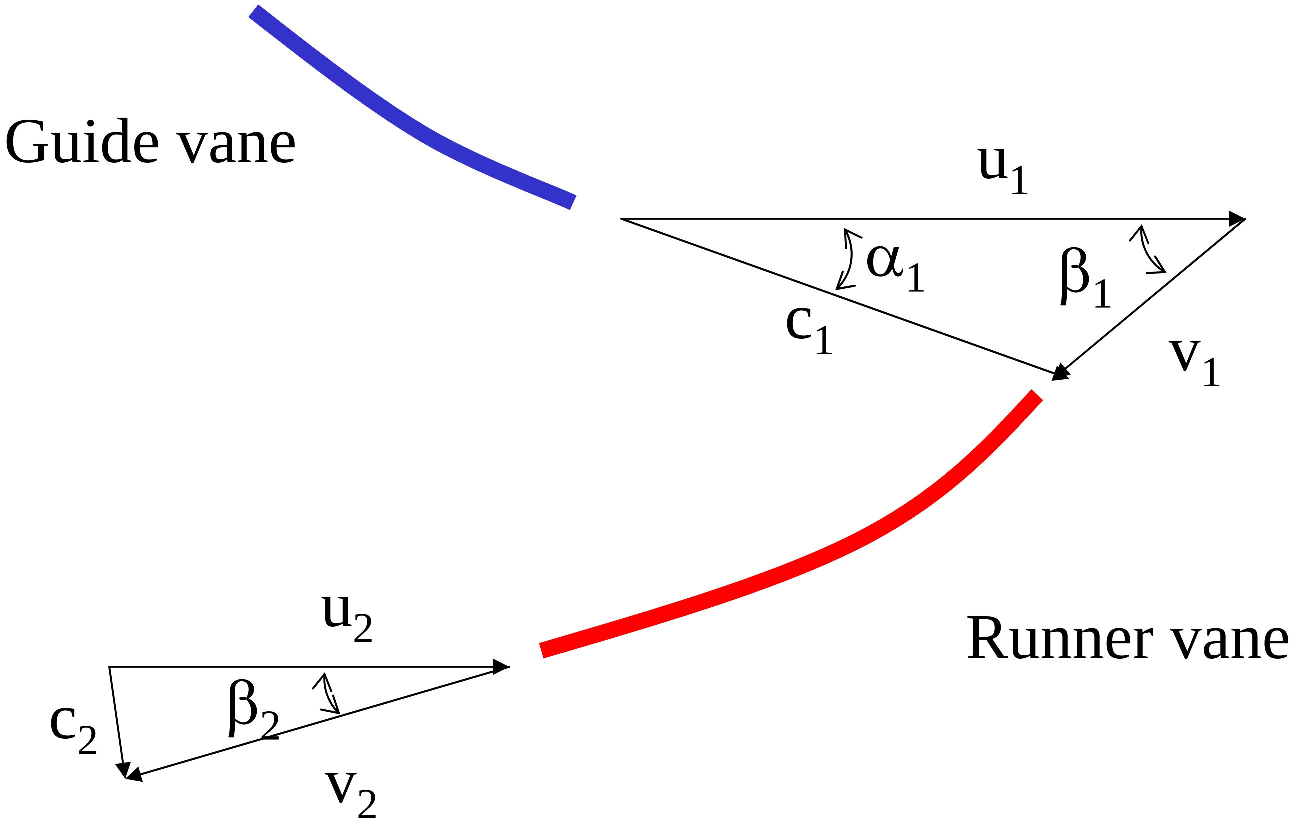
v – relative velocity

c – absolute velocity

$$P = \rho Q(u_1 c_{u1} - u_2 c_{u2})$$

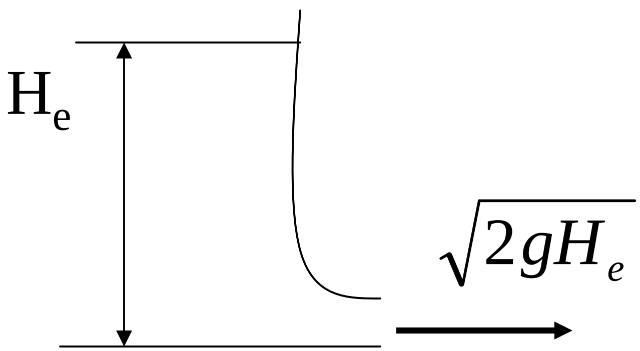
$$\overline{c} = \overline{u} + \overline{v}$$

Inlet – and outlet velocity triangle



Dimensionless velocities

All velocities are scaled related to the velocity of ”Toricellis theorem” - Reduced velocities:



$$\underline{c} = \frac{c}{\sqrt{2gH_e}}$$

$$\underline{u} = \frac{c}{\sqrt{2gH_e}}$$

$$\underline{v} = \frac{c}{\sqrt{2gH_e}}$$

Hydraulic efficiency: $$\eta_h = \frac{P}{P_{natur}}$$

$$P = T\omega = \rho Q(u_1 c_{u1} - u_2 c_{u2})$$

$$P_{natur} = \rho g Q H_e$$

$$\eta_h = \frac{\rho Q(u_1 c_{u1} - u_2 c_{u2})}{\rho g Q H_e} = \frac{(u_1 c_{u1} - u_2 c_{u2})}{g H_e}$$

Or:

$$g H_e = \eta_h (u_1 c_{u1} - u_2 c_{u2})$$

Introducing reduced velocities:

$$\eta_h H_e = \frac{1}{g}(u_1 c_{u1} - u_2 c_{u2}) \quad \Bigg| \quad \frac{1}{\sqrt{2gH_e}}\frac{1}{\sqrt{2gH_e}}$$

$$\frac{\eta_h H_e}{2gH_e} = \frac{1}{g}\left(\frac{u_1 c_{u1}}{\sqrt{2gH_e}} - \frac{u_2 c_{u2}}{\sqrt{2gH_e}}\right)$$

$$\boxed{\eta_h = 2\left(\underline{u}_1 \underline{c}_{u1} - \underline{u}_2 \underline{c}_{u2}\right)}$$

Redused flow: $$\underline{Q} = \frac{Q}{\sqrt{2gH_e}} \quad \left[m^2\right]$$

Redused angular speed: $$\underline{\omega} = \frac{\omega}{\sqrt{2gH_e}} \quad \left[\frac{1}{m}\right]$$

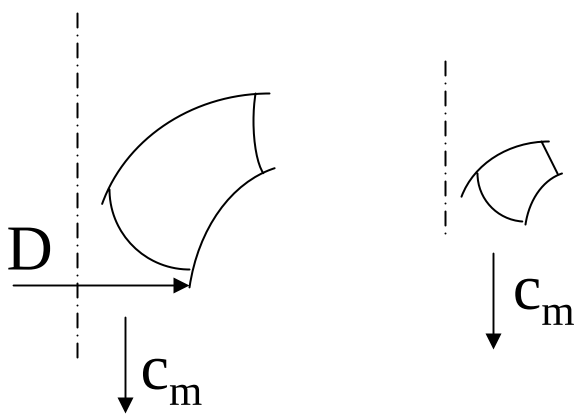
Then the following equations still applies:

$$\underline{Q} = A\underline{c}$$

$$\underline{u} = \underline{\omega}$$

Speed number – classification of turbines

Geometric similar turbines but different in size,
Shall have the same specification – a speed number



Two geometric similar turbines has the same redused velocity triangles:

1) $$\underline{c}_m = \frac{\underline{Q}}{\frac{\pi}{4} D^2} \Rightarrow \frac{\underline{Q}}{D^2} = konst_1$$

2) $$\underline{u} = \underline{\omega} D \Rightarrow \underline{\omega} D = konst_2$$

$$From \quad eq.2: \quad \frac{1}{D} = \frac{\underline{\omega}}{konst_2}$$

$$Put \quad in\, eq.1: \quad \frac{\underline{Q}\underline{\omega}^2}{konst_2} = konst_1$$

$$\underline{\omega}\sqrt{\underline{Q}} = konst$$

$$\underline{\Omega} = \underline{\omega}\sqrt{\underline{Q}} \quad \text{Speed number}$$

The turbine must be designet optimal for a given operational point defined by:
Q, H og w (or RPM) *- denotes BEP :

$$\underline{{}^{*}\Omega} = \underline{{}^{*}\omega}\sqrt{\underline{{}^{*}Q}}$$

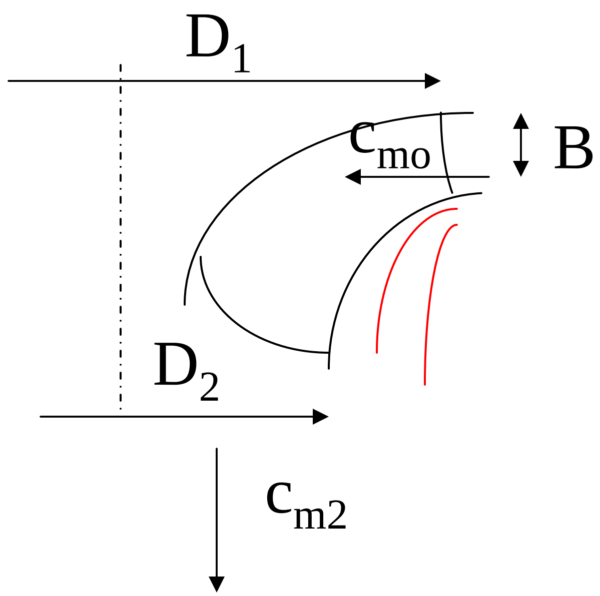
Another classification number is ”spesific speed ”:

$$n_q = \frac{n\sqrt{Q}}{H^{3/4}}$$

$$n_q = 89\,\underline{{}^{*}\Omega}$$

How the form of a turbine changes with the speed number:

Speed number: $\underline{\Omega} = \underline{\omega}\sqrt{\underline{Q}}$ eller: $\underline{\Omega} = \dfrac{\omega}{\sqrt{2gH_e}}\sqrt{\dfrac{Q}{\sqrt{2gH_e}}}$



$$\underline{c}_{m2} = \frac{\underline{Q}}{\frac{\pi}{4}D_2^{\ 2}} \quad \Rightarrow \quad D_2^{\ 2} = \frac{\underline{Q}}{\frac{\pi}{4}\underline{c}_{m2}}$$

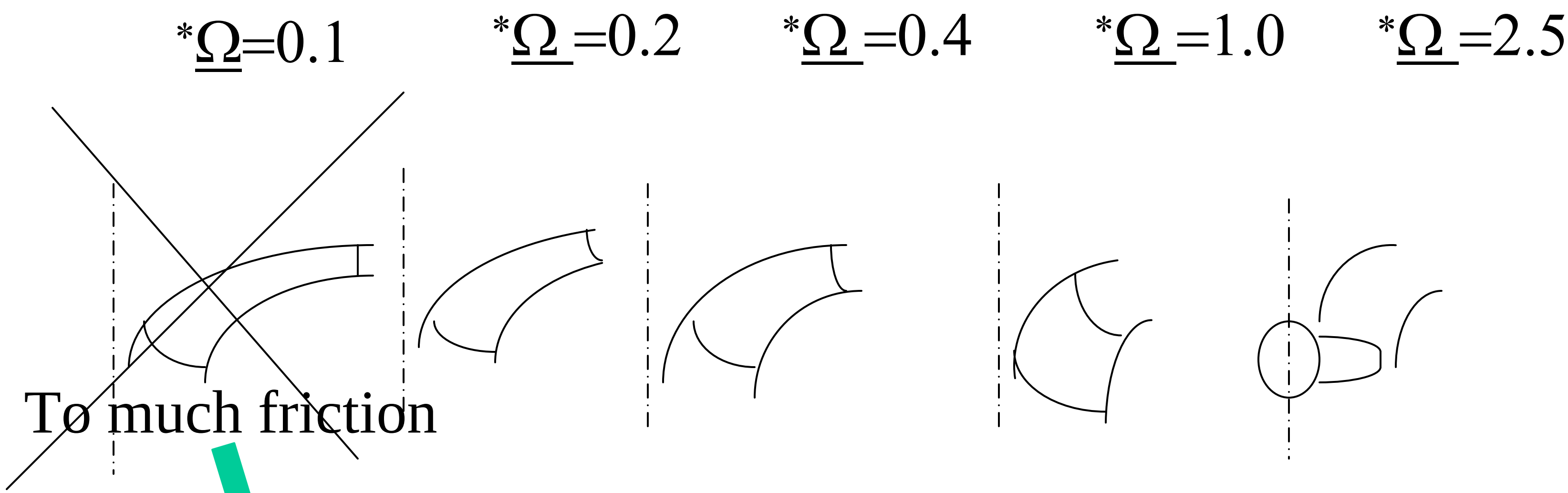
$$\underline{u}_1 = \underline{\omega}\frac{D_1}{2} \quad \Rightarrow \quad D_1 = \underline{u}_1 \frac{2\sqrt{2gH_e}}{\underline{\omega}}$$

$$\underline{Q} = \pi D_1 B \underline{c}_{mo} \quad \Rightarrow \quad B = \frac{\underline{Q}}{\pi D_1 \underline{c}_{mo}}$$

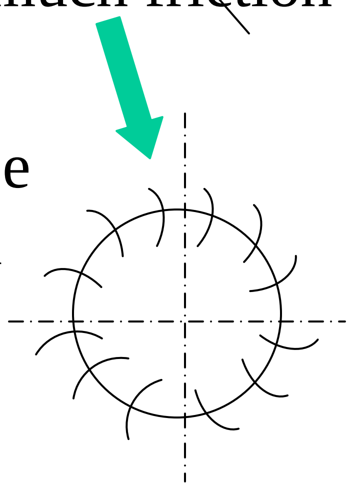
The redused velocities are approximate constant

Incresed speed number: D_2 and B increases

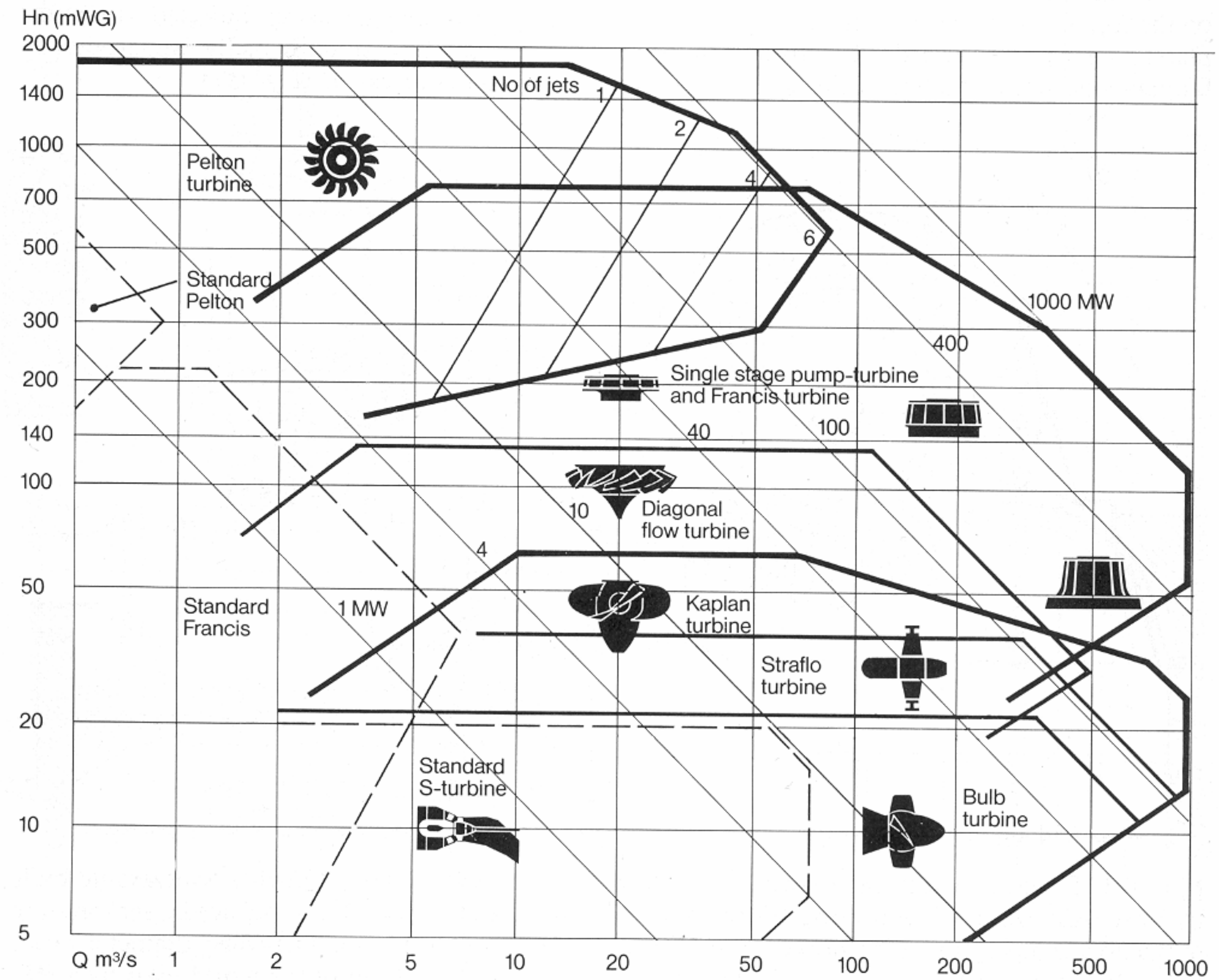
Turbine types



Choose
Pelton



KAPLAN:	$^*\underline{\Omega} = 1.5 – 2.5$
FRANCIS:	$^*\underline{\Omega} = 0.2 – 1.2$
PELTON:	$^*\underline{\Omega} = 0.08$□– 0.15



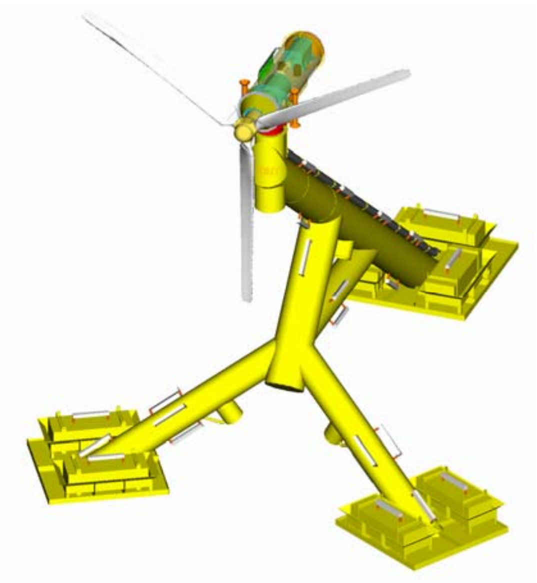
Hn (mWG)
2000
1400
1000
700
500
300
200
140
100
50
20
10
5
Q m³/s
1
2
5
10
20
50
100
200
500
1000
No of jets
1
2
4
6
Pelton turbine
Standard Pelton
1000 MW
400
Single stage pump-turbine and Francis turbine
40
100
10
Diagonal flow turbine
4
Standard Francis
1 MW
Kaplan turbine
Straflo turbine
Standard S-turbine
Bulb turbine

Turbindimensjoner

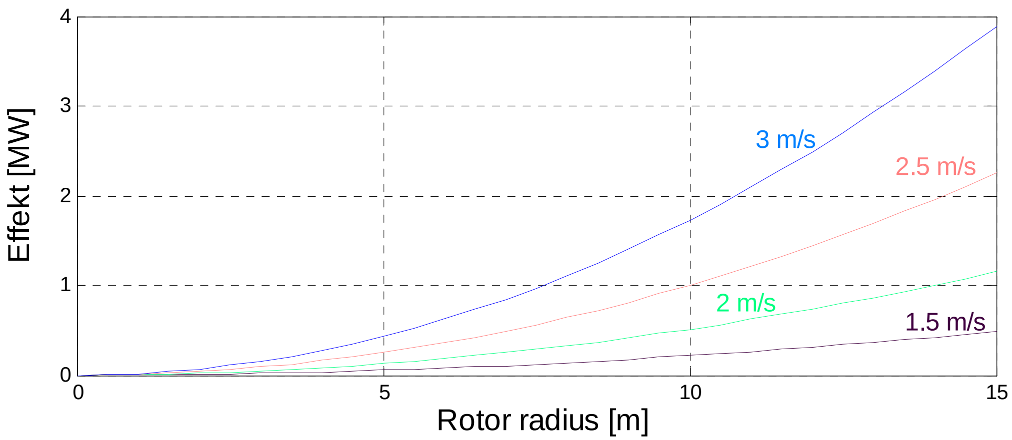
						Lavtrykks vannkraft:	
H	3	3	5	5	m	35	m
Q	5	10	10	100	m3/s	80	m3/s
Polpar	15	20	14	40		10	
n	200	150	214,2857	75	RPM	300	RPM
eta	0,8	0,8	0,8	0,8		0,8	
Effekt	117,84	235,68	392,8	3928	kW	21996,8	kW
w	20,94	15,71	22,44	7,85	rad/s	31,42	rad/s
sqrt(2gH)	7,67	7,67	9,90	9,90	m/s	26,20	m/s
Qred	0,65	1,30	1,01	10,10		3,05	
wred	2,73	2,05	2,27	0,79		1,20	
Fartstall	2,20	2,34	2,28	2,52		2,09	
u2	40,00	40,00	40,00	40,00	m/s	40,00	m/s
D2	3,82	5,09	3,57	10,19	m	2,55	m

Turbin i fri strøm

$$P = C_P \frac{\rho_V}{2} A_R \cdot V^3$$



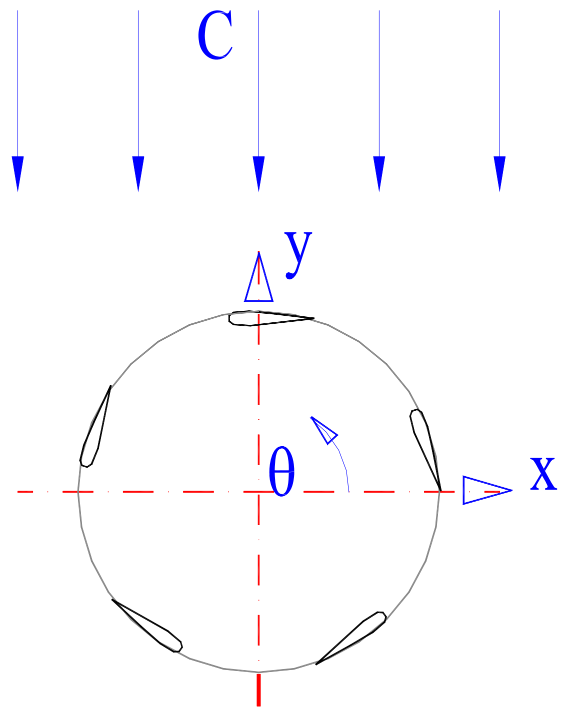
$$C_p \approx 0.4$$

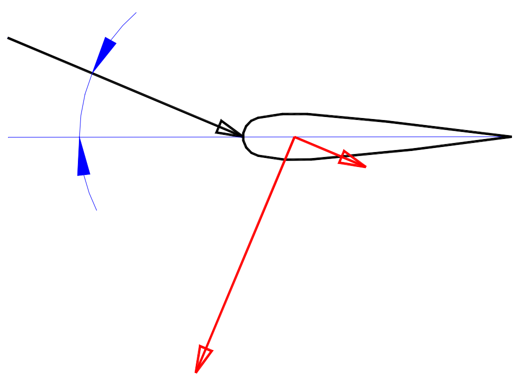


Wells turbinen

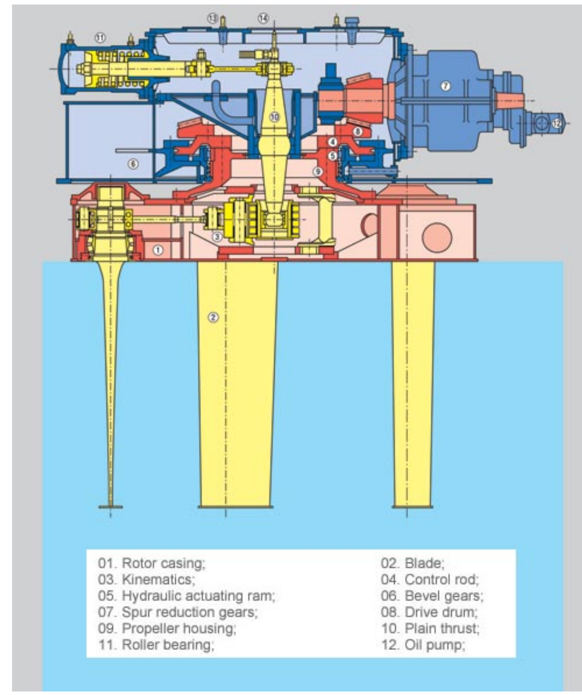
- Luftturbin
- Roterer samme vei uansett retning på strømningen
- Negativt startmoment

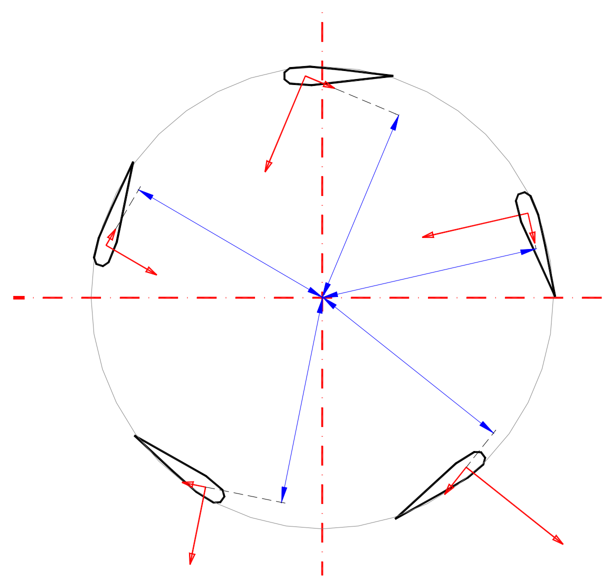
Darrius turbin



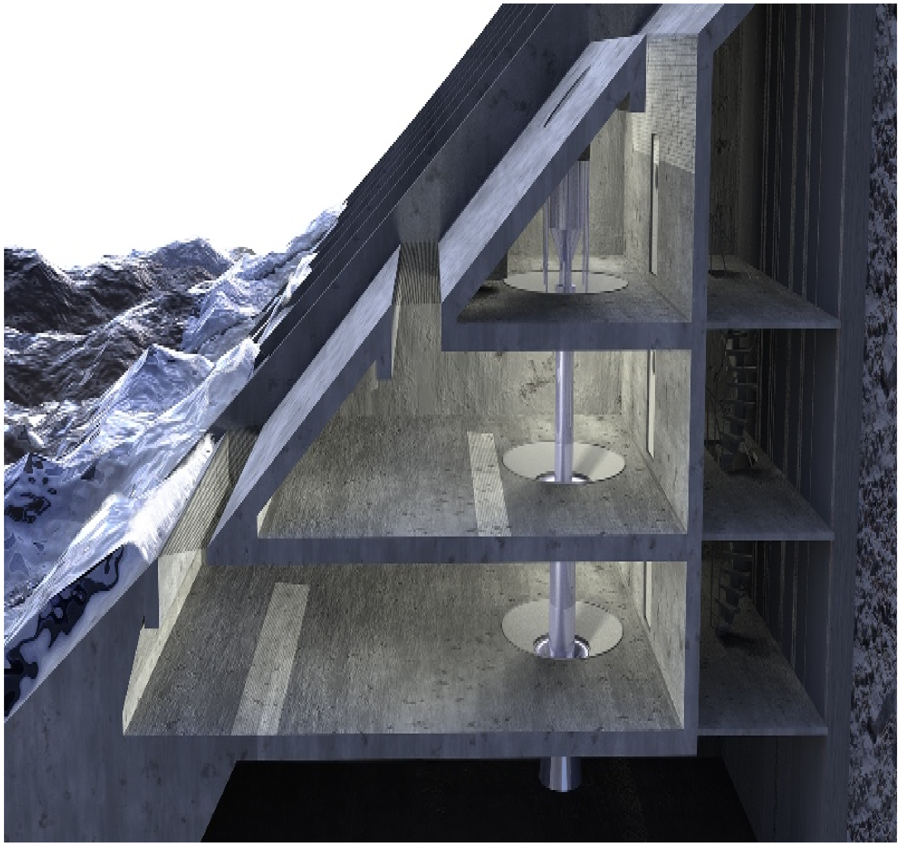


Voith-Schneider propell





Seawave Slot-Cone

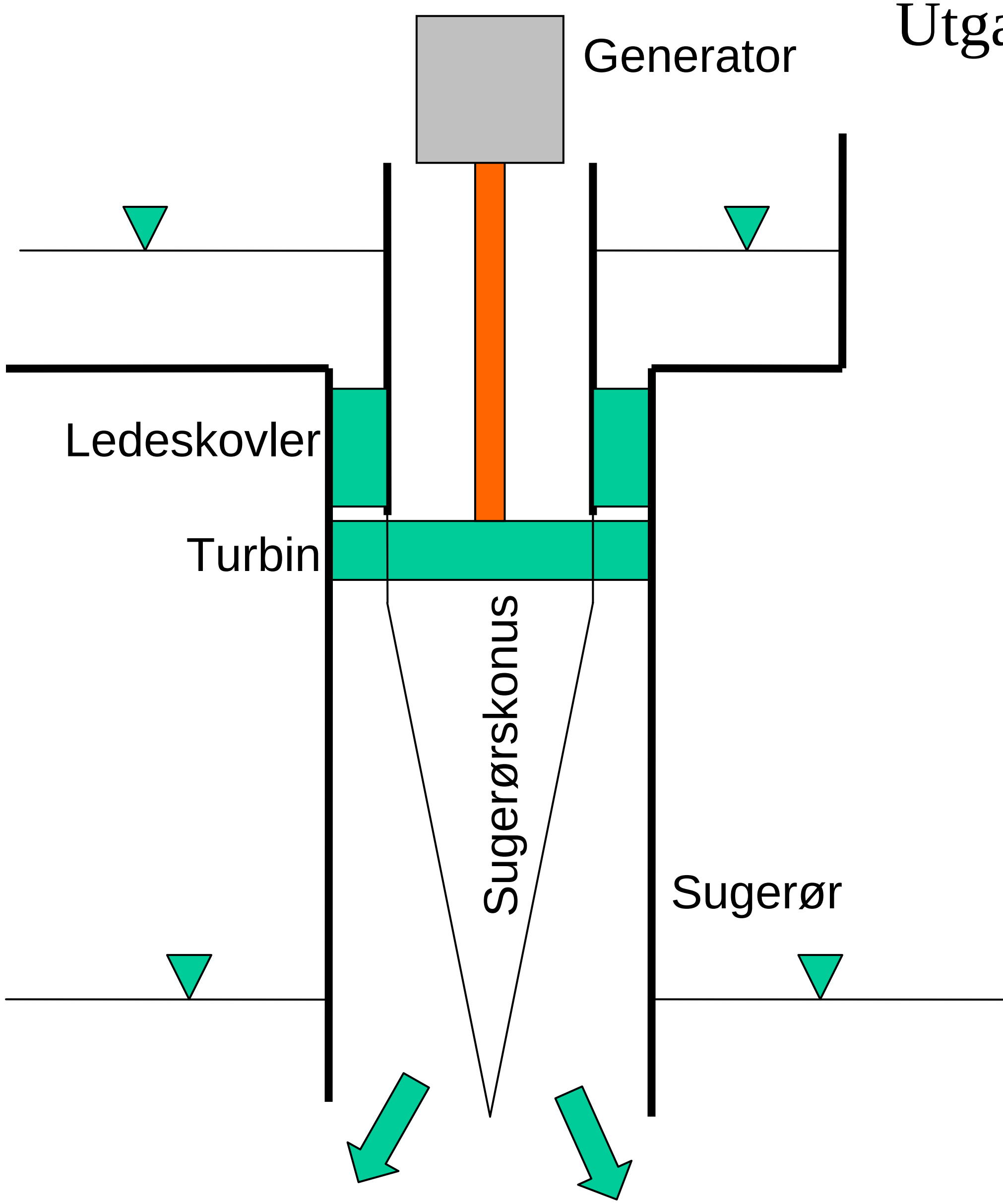


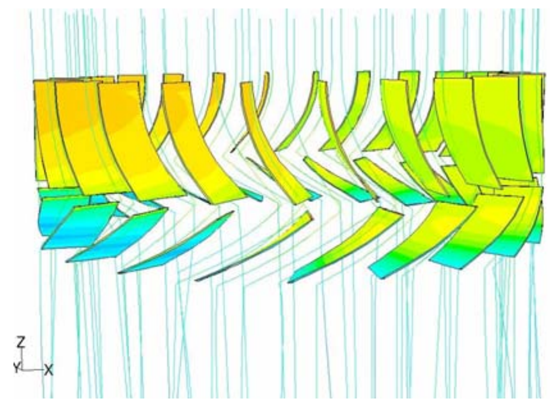
- Turbin:

1-3 m fallhøyde

- Flertrinns

Utgangspunkt: Jonval turbin





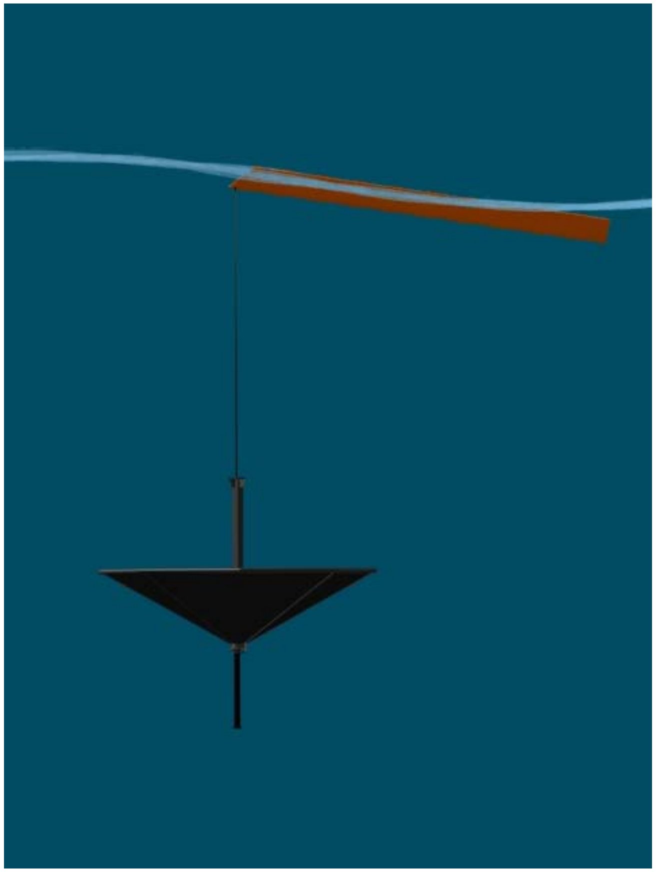
- Uten sugerøret avløpstap:

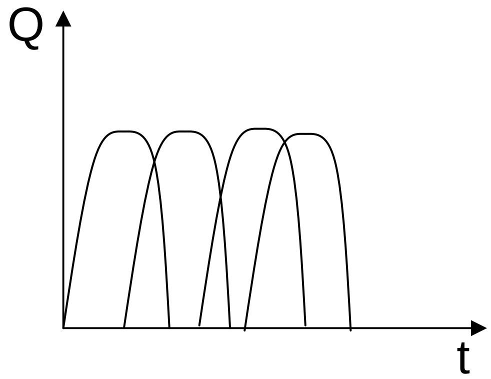
$$\Delta h = \frac{c^2}{2g} = \frac{3{,}5^2}{19{,}62} = 0{,}62m$$

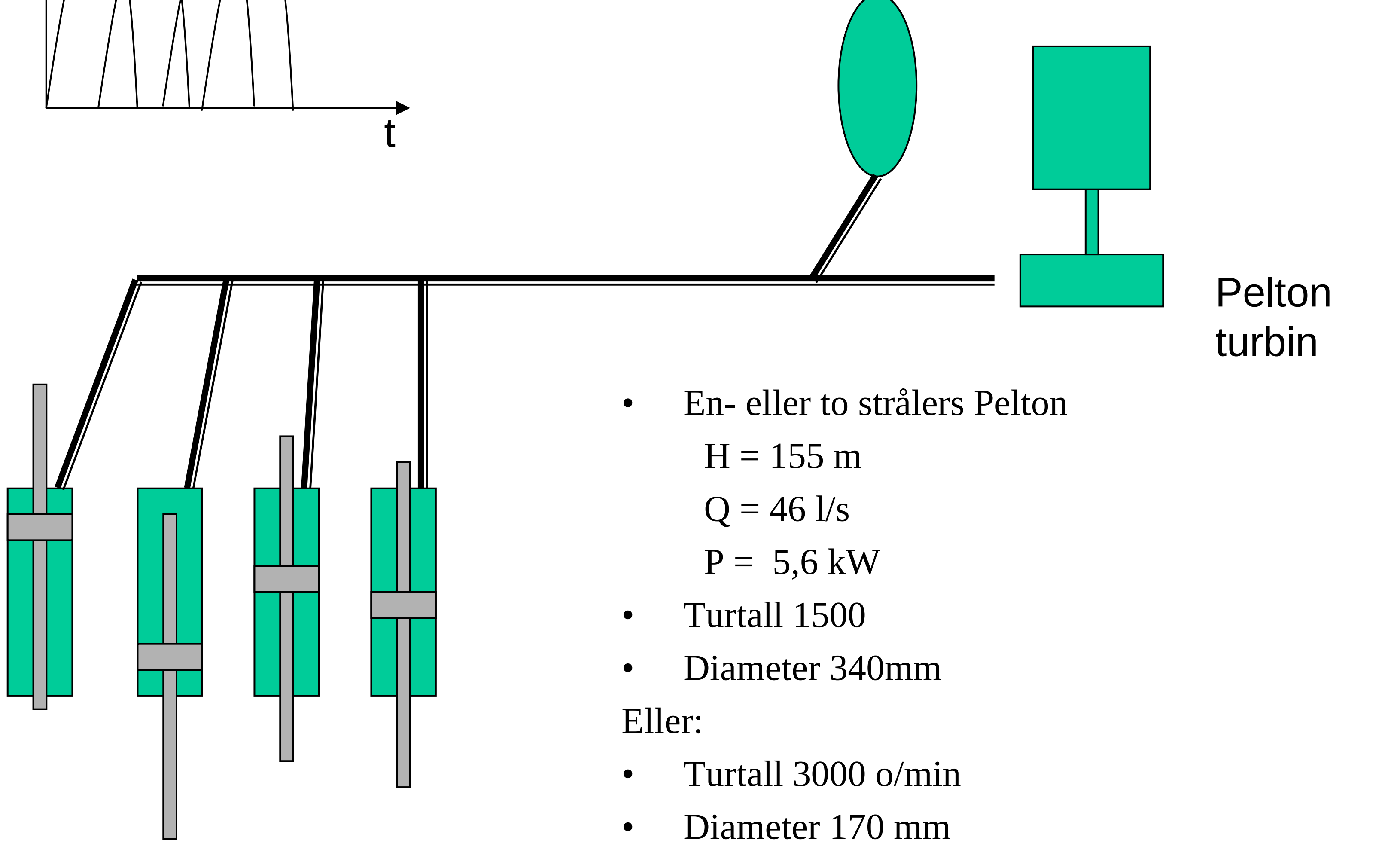
- Gjenvinnes i sugerøret

- Low head gives
  - low speed of rotation
  - huge dimensions on turbine and generator
  - High torque

- How to increase head?
  - Amplification
  - Displacement pump







- En- eller to strålers Pelton
  H = 155 m
  Q = 46 l/s
  P = 5,6 kW
- Turtall 1500
- Diameter 340mm

Eller:

- Turtall 3000 o/min
- Diameter 170 mm