HYDRO AND EOLIC PLANTS

ESF II project of the University of West Bohemia in Pilsen, reg. number: CZ.02.2.69/0.0/0.0/18_056/0013239



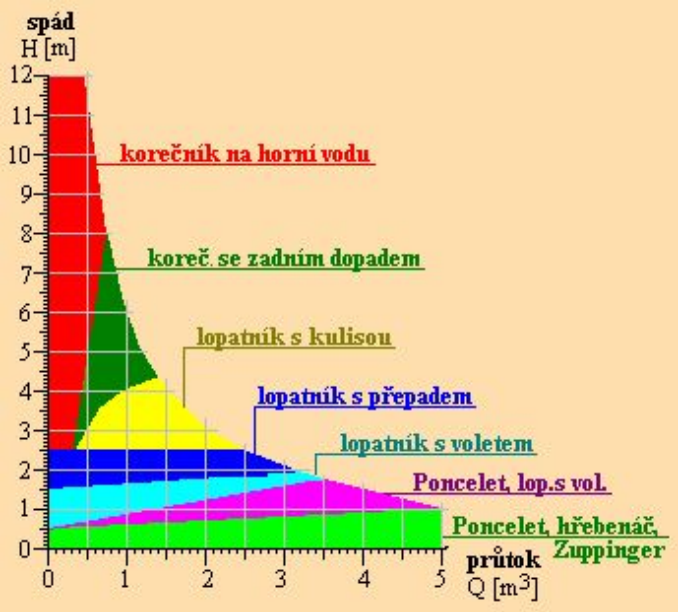
EUROPEAN UNION
European Structural and Investment Funds
Operational Programme Research,
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Hydraulic engines 2

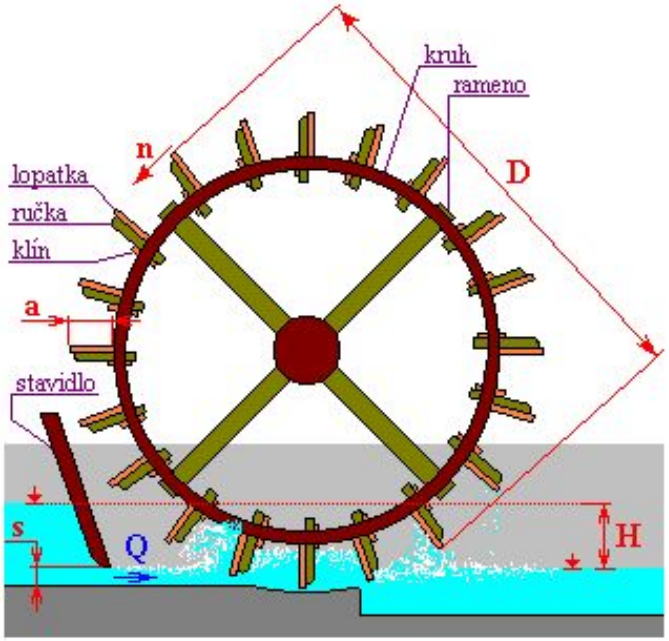
Milan Bělík

Water wheel



typ kola	účinnost [%]
korečník na horní vodu s obráceným chodem	až 85
korečník na horní vodu obyčejný	65..80
korečník se zadním dopadem	65..75
lopatník s kulisou	65..70
lopatník s přepadem	60..75
lopatník s voletem	45..55
Zuppingerovo kolo	70..78
Ponceletovo kolo	60..65%
Sagebienovo kolo	až 80%
stříkový hřebenáč	30..35%
bělík (valach)	25..30%

Low water - water wheel









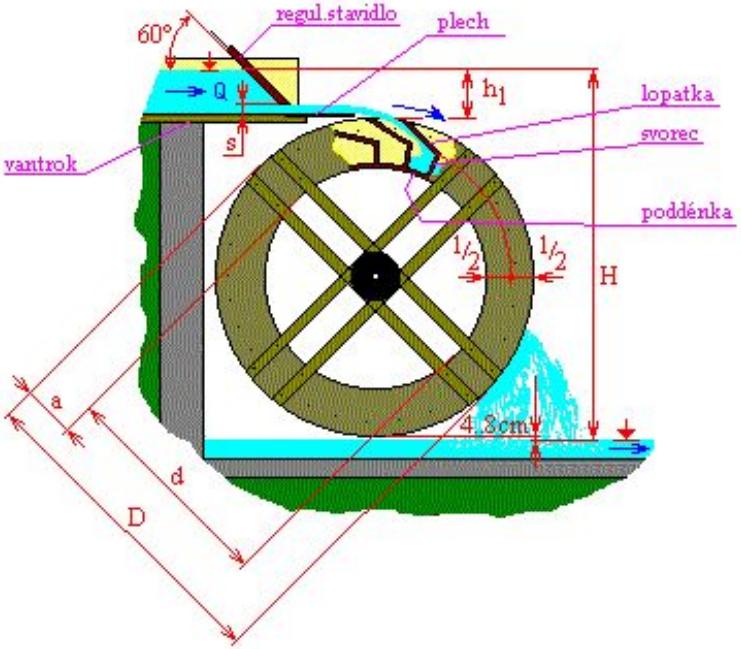


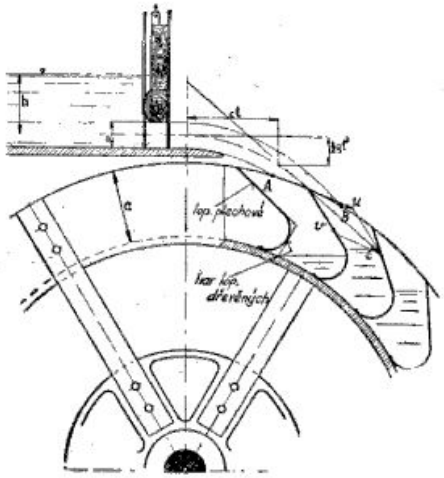
H [m]	D [m]	a [m]	s [m]	Q_1 [ltr./sec.]	P_1 [W]	n [ot./min]	lop. [ks]
0,2	4,6	0,36	0,058	113	70	3,3	40
0,25	5,0	0,38	0,061	133	110	3,4	40
0,3	5,3	0,39	0,064	153	150	3,5	44
0,35	5,6	0,41	0,067	172	200	3,6	44
0,4	6,0	0,43	0,070	191	250	3,6	44
0,45	6,3	0,44	0,072	209	310	3,6	44
0,5	6,3	0,45	0,074	228	370	3,8	44
0,55	7,0	0,47	0,076	246	440	3,6	48
0,6	7,3	0,48	0,078	264	510	3,6	48
0,65	7,6	0,49	0,080	281	590	3,6	48
0,7	8,0	0,50	0,082	299	680	3,5	48
0,75	8	0,51	0,084	0,316	0,77	3,7	48
0,8	8	0,53	0,086	0,333	0,87	3,8	48
0,85	8	0,54	0,088	0,35	0,97	3,9	48
0,9	8	0,55	0,089	0,367	1,07	4,0	48





Upper water – water wheel



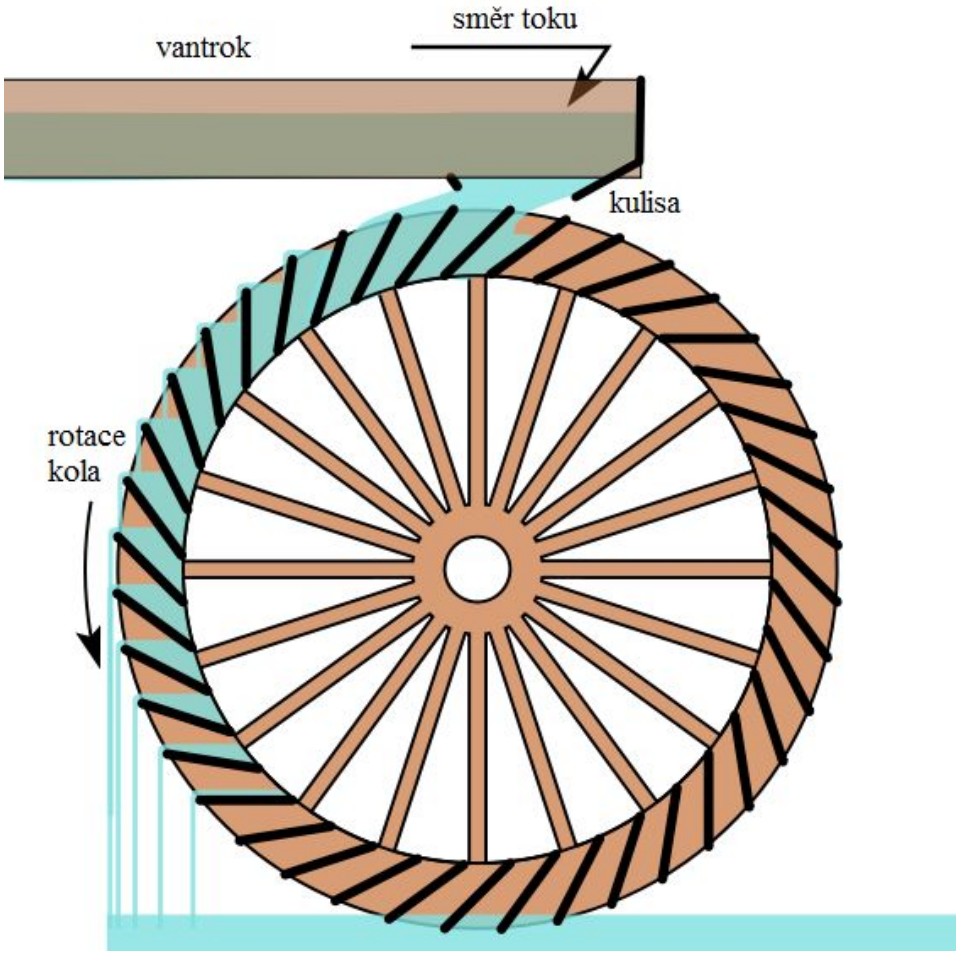




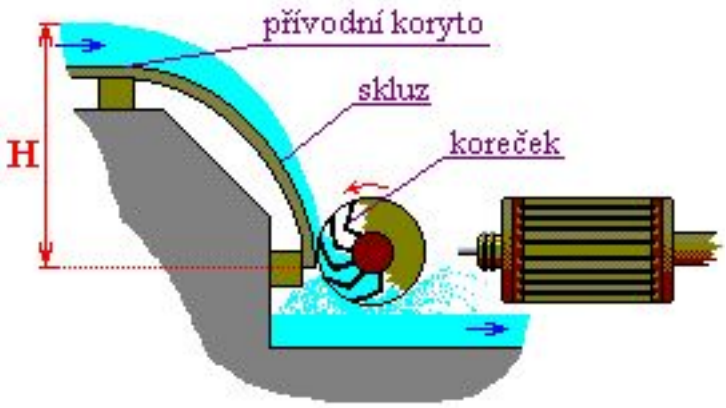


H [m]	D [m]	d [m]	h_1 [m]	s [m]	lop. [ks]	n [ot./min.]	Q_1 [ltr./sec.]	P_1 [W]
1,6	1,31	0,91	0,24	0,037	24	14,6	60	691
1,8	1,51	1,11	0,24	0,037	24	12,7	60	778
2	1,71	1,27	0,24	0,040	28	11,2	66	950
2,2	1,91	1,47	0,24	0,040	28	10	66	1 045
2,4	2,00	1,56	0,35	0,040	28	11,4	79	1 369
2,6	2,14	1,62	0,41	0,048	30	11,6	101	1 898
2,8	2,34	1,82	0,41	0,048	32	10,6	101	2 044
3	2,54	2,02	0,41	0,048	32	9,8	101	2 190
3,2	2,74	2,22	0,41	0,048	36	9,1	101	2 336
3,4	2,94	2,42	0,41	0,048	36	8,4	101	2 482
3,6	3,08	2,48	0,47	0,055	36	8,7	1,26	3 266
3,8	3,21	2,61	0,54	0,055	38	8,9	135	3 694
4	3,41	2,81	0,54	0,055	40	8,4	135	3 888
4,2	3,61	3,01	0,54	0,055	42	7,9	135	4 082
4,4	3,81	3,21	0,54	0,055	44	7,5	135	4 277
4,6	4,01	3,41	0,54	0,055	46	7,2	135	4 471
4,8	4,21	3,61	0,54	0,055	48	6,8	135	4 666
5	4,41	3,81	0,54	0,055	48	6,5	135	4 860
5,2	4,53	3,83	0,62	0,064	46	6,7	168	6 290
5,4	4,61	3,91	0,74	0,064	46	7,3	184	7 144
5,6	4,81	4,11	0,74	0,064	48	6,9	184	7 409
5,8	5,01	4,31	0,74	0,064	48	6,7	184	7 673
6	5,21	4,51	0,74	0,064	48	6,4	184	7 938
6,5	5,71	5,01	0,74	0,064	56	5,9	184	8 600
7	6,21	5,51	0,74	0,064	60	5,4	184	9 261
7,5	6,58	5,88	0,87	0,064	64	5,5	200	10 773
8	6,99	6,29	0,96	0,064	68	5,5	210	12 096
8,5	7,49	6,79	0,96	0,064	72	5,1	210	12 852
9	7,99	7,29	0,96	0,064	76	4,8	210	13 608
9,5	8,49	7,79	0,96	0,064	80	4,5	210	14 364
10	8,99	8,29	0,96	0,064	84	4,3	210	15 120

Reverse motion water wheel



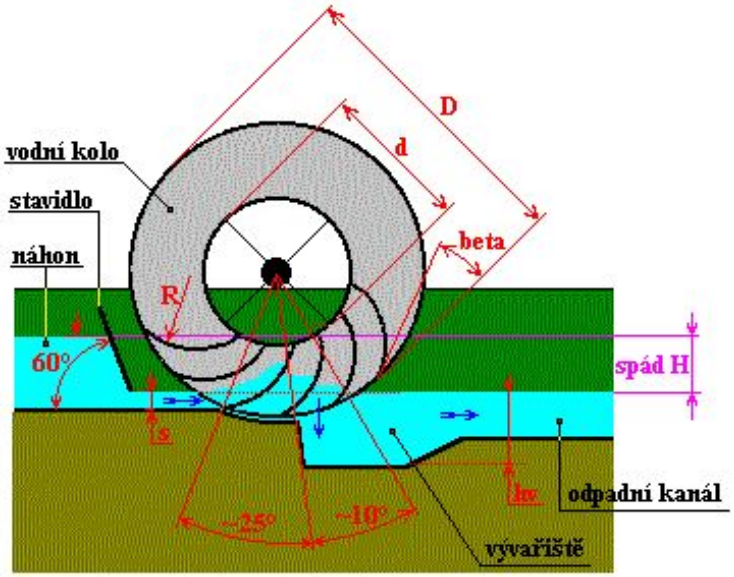
Belik (valach)



Poncelet wheel

- **1826 – Jean Poncelet**

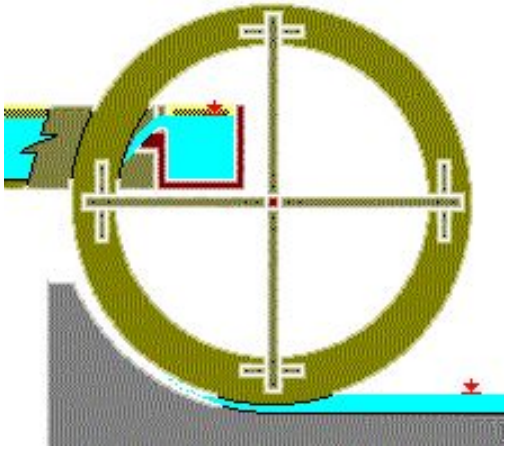


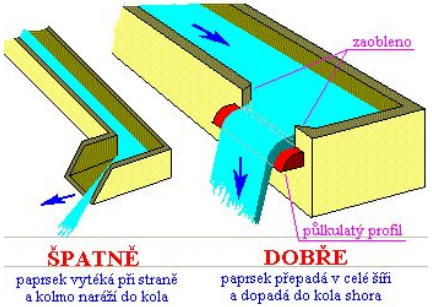




Bozek wheel

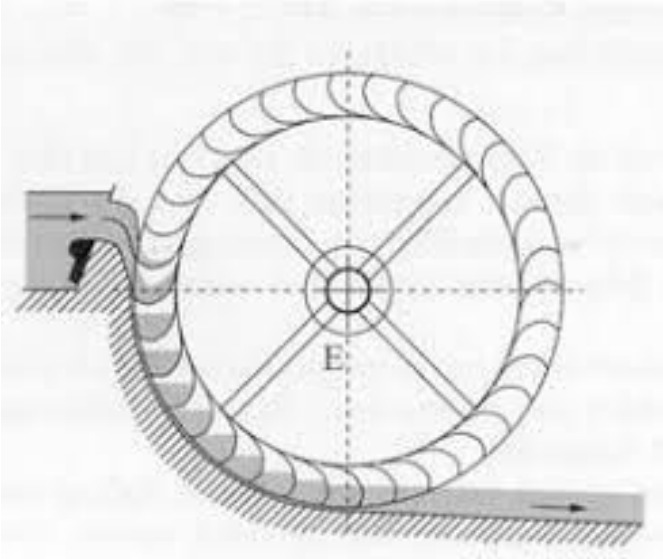
- **1865 – Romuald Božek (syn Josefa Božka)**

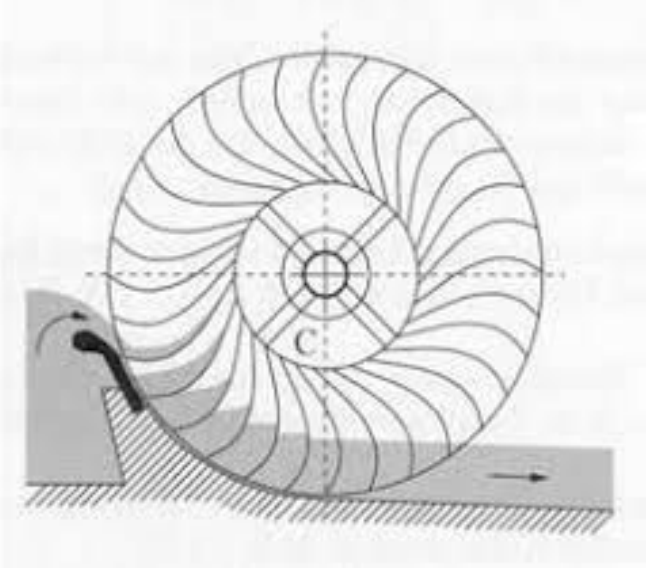






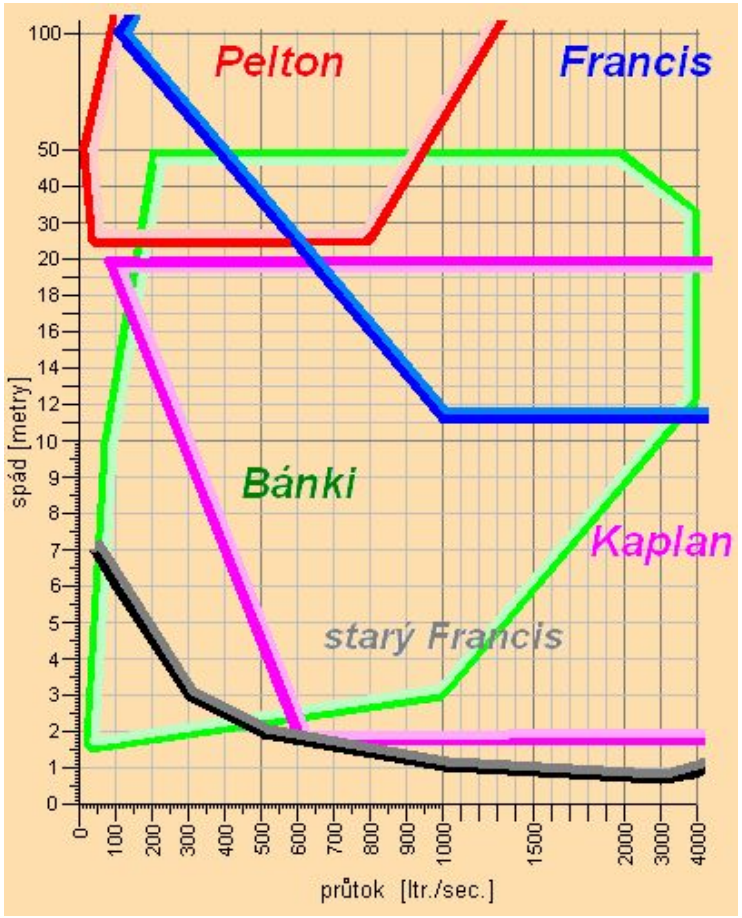
Middle water – water wheel





Hydraulic turbines

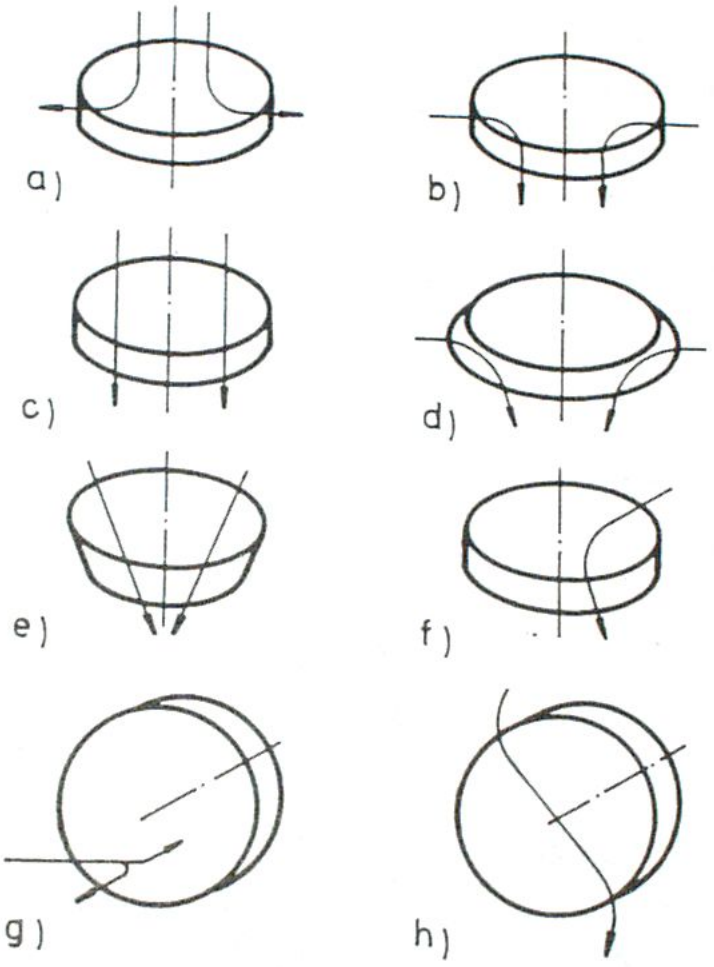
- **Action turbines**
  - Pelton turbin
  - Reiffenstein turbine
  - Sfindex turbine
  - Swift turbine
  - Segner turbine
  - Zuppinger turbine
  - Turgo turbine
  - Girard turbine
  - Hänel turbine
  - Schwamkrug turbine
  - Bánki turbine
- **Reaction turbines**
  - Kaplan
  - Thoman
  - propeler
  - Francis
  - Fourneyron
  - Jonval
  - Henschel-Jonval
  - Francis-Reiffenstein
  - Dériaz



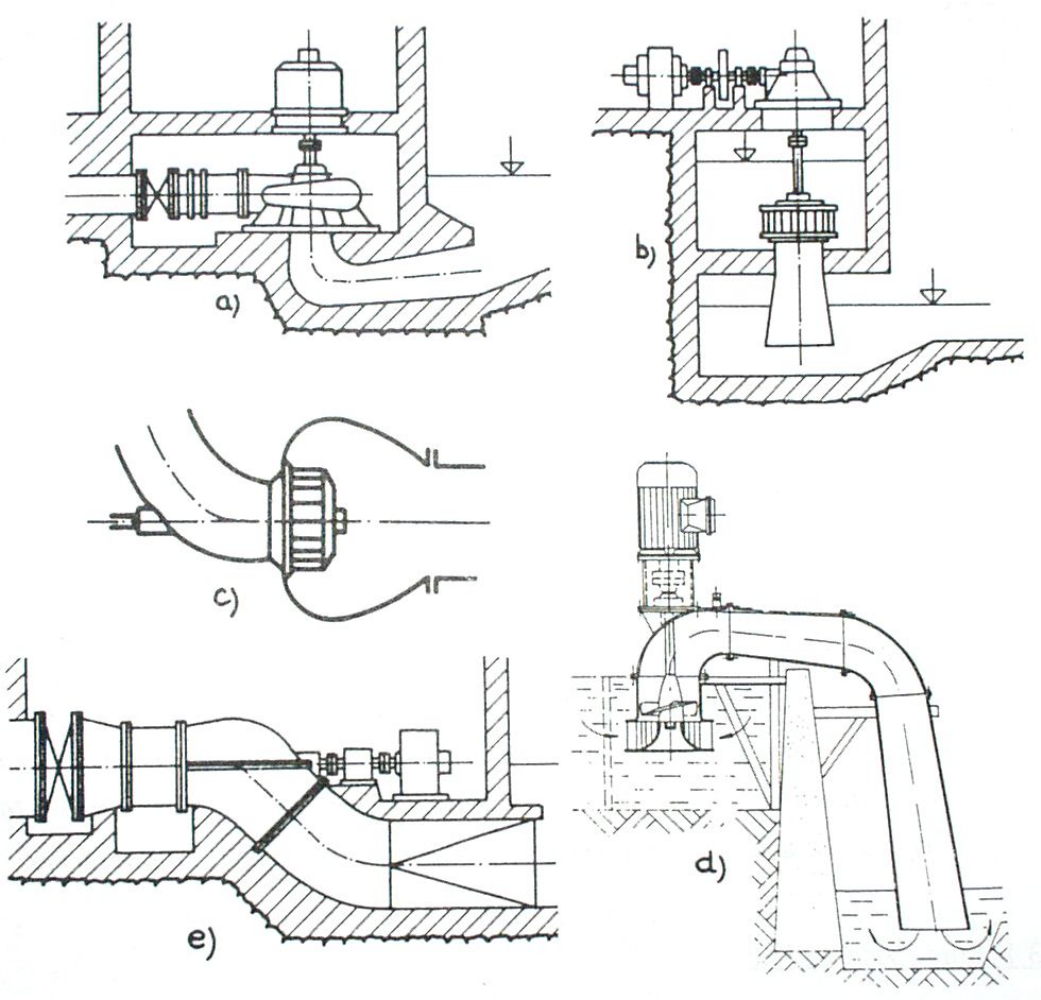


Characteristics of turbines

- centrifugal
- centripetal
- axial
- radial axial
- diagonal

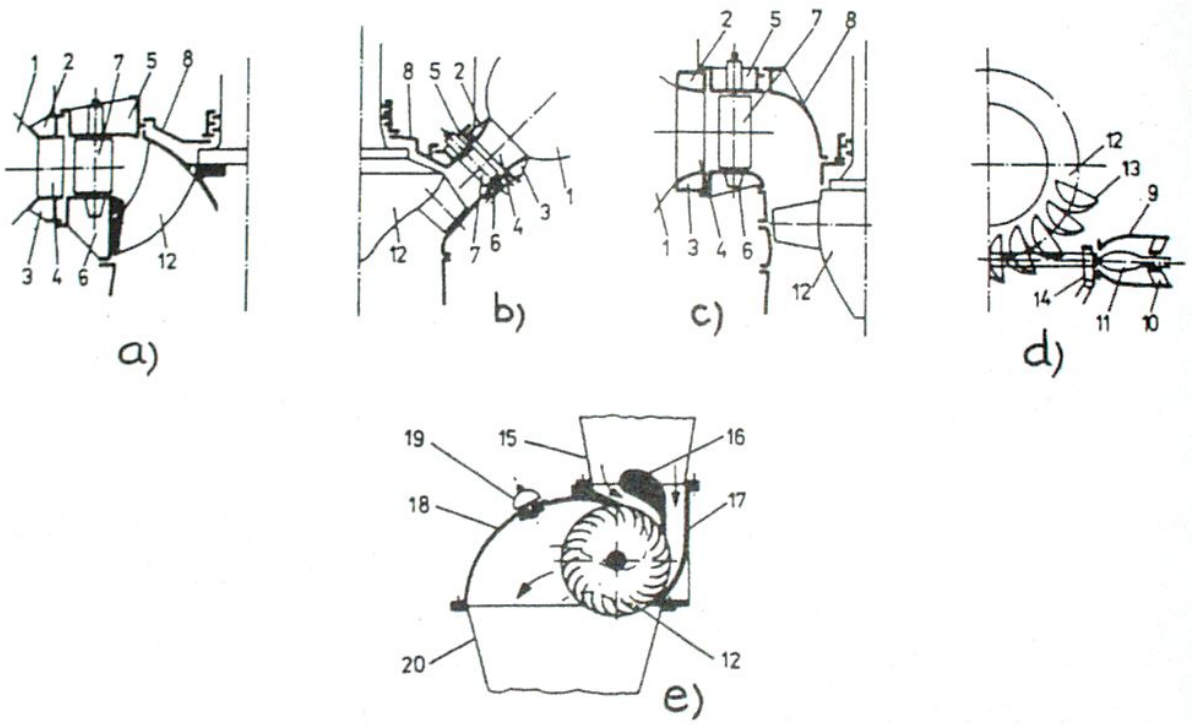


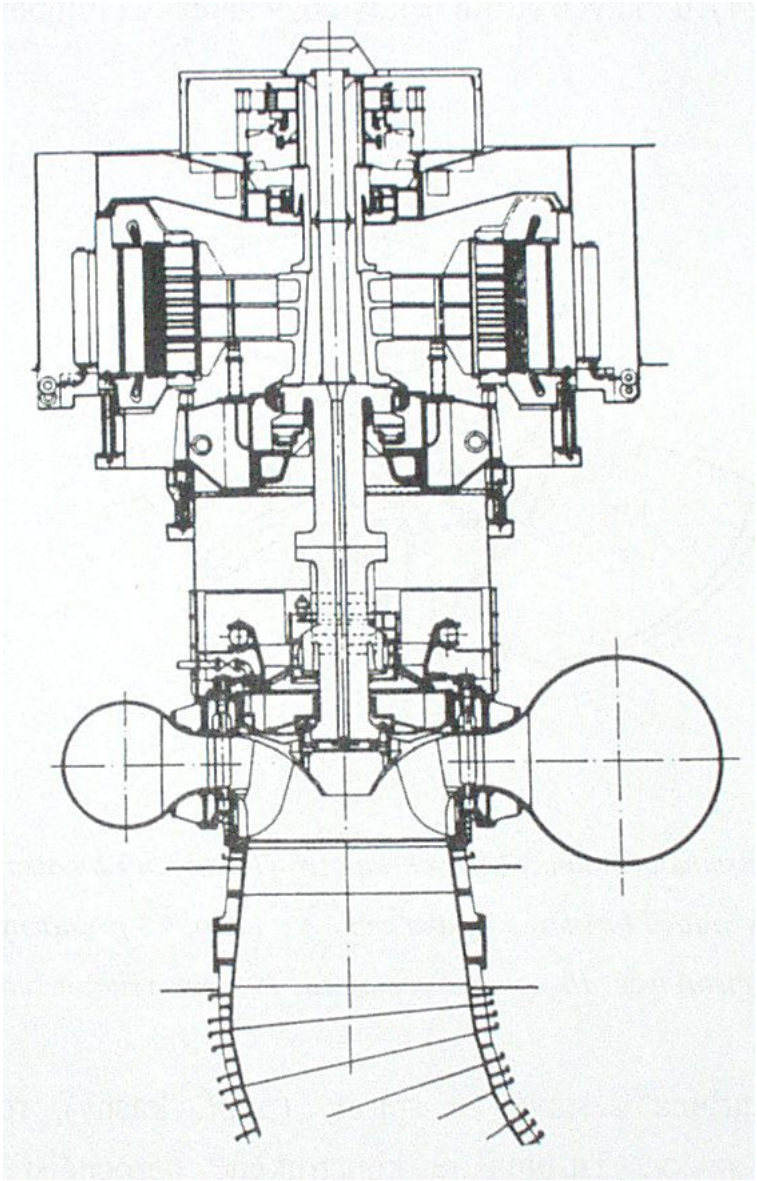
Classification of turbines

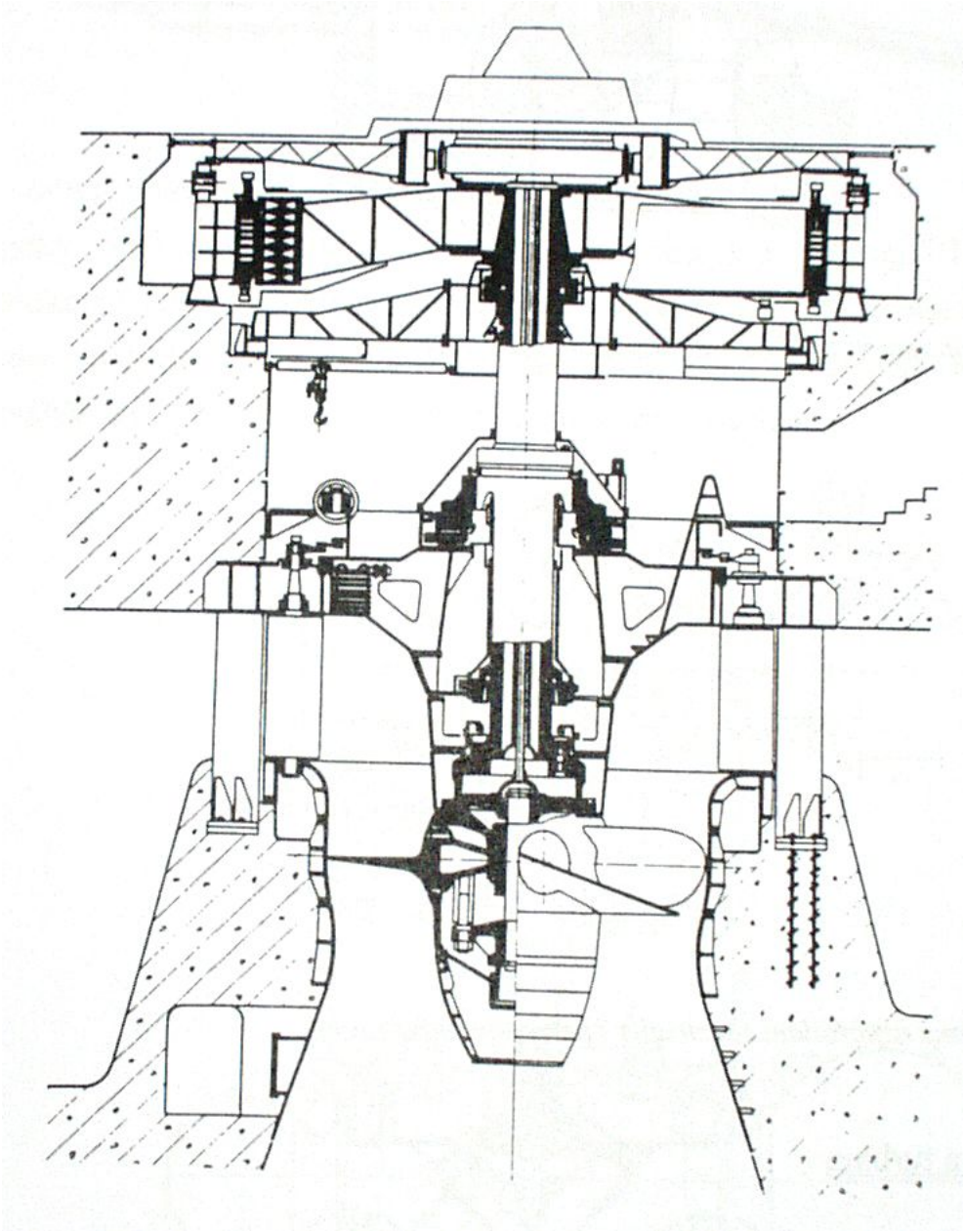


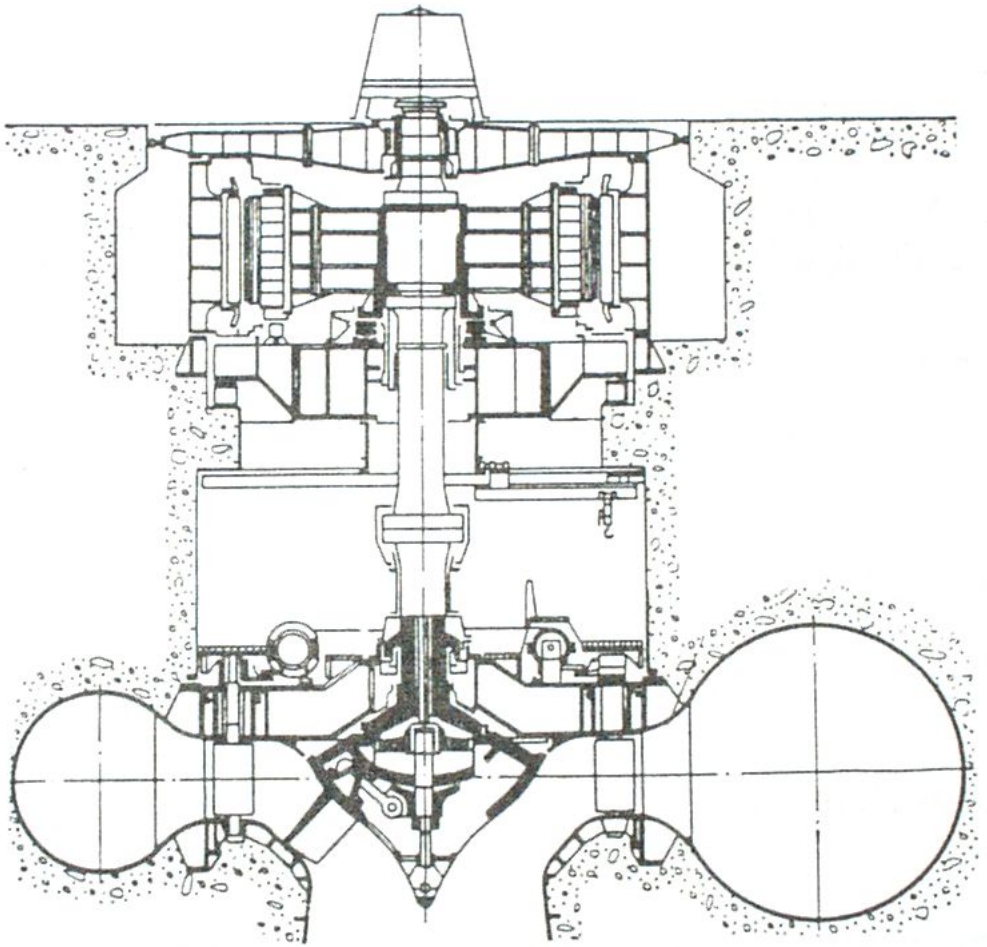
Most common turbines

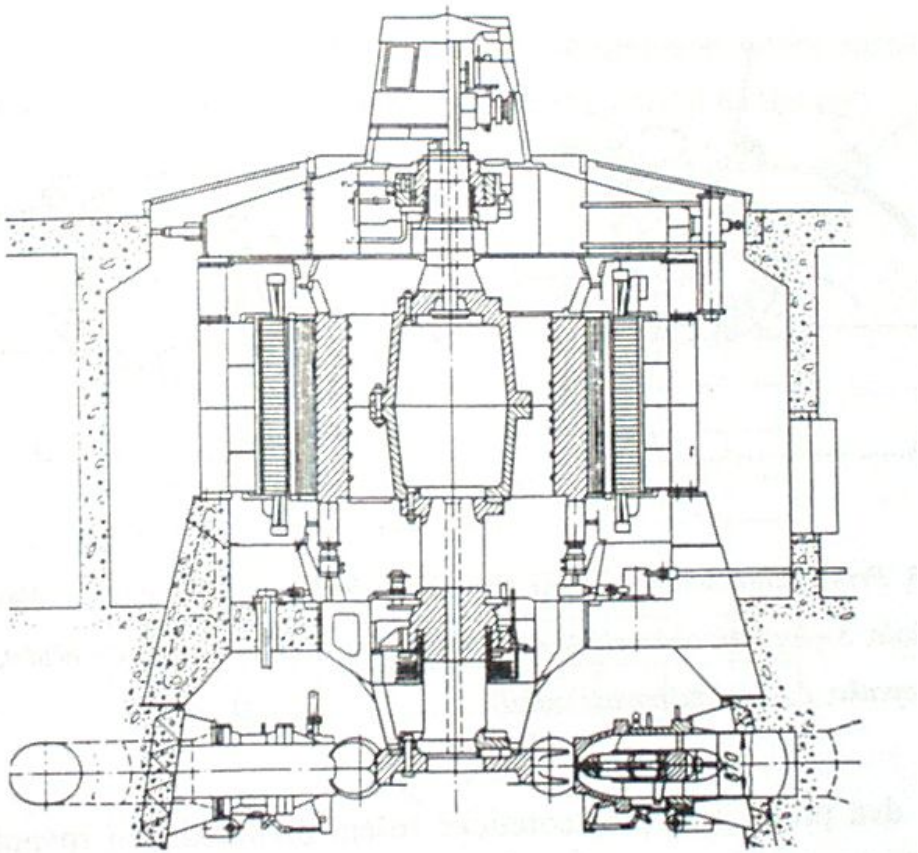
- **Francis**
- **Dériaz**
- **Kaplan**
- **Pelton**
- **Bánki**

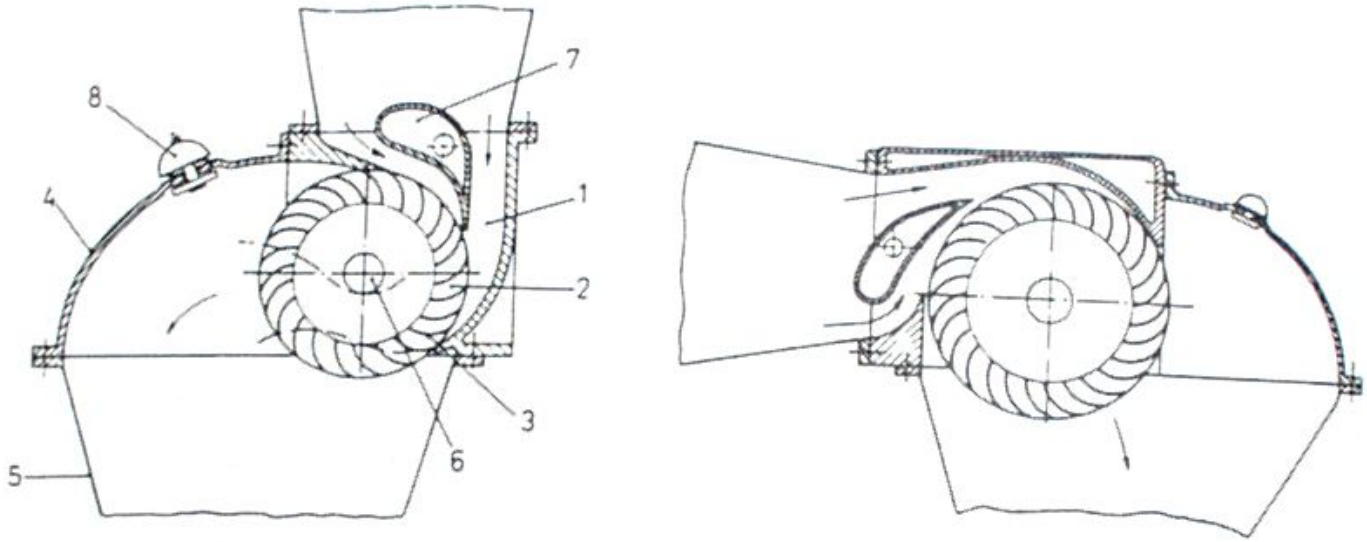











8
7
4
1
2
3
6
5

Theory of water turbines

- **energy**
  - **potential Ez**
  - **pressure Ep**
  - **kinetic Ev**

$$E = E_z + E_p + E_v$$

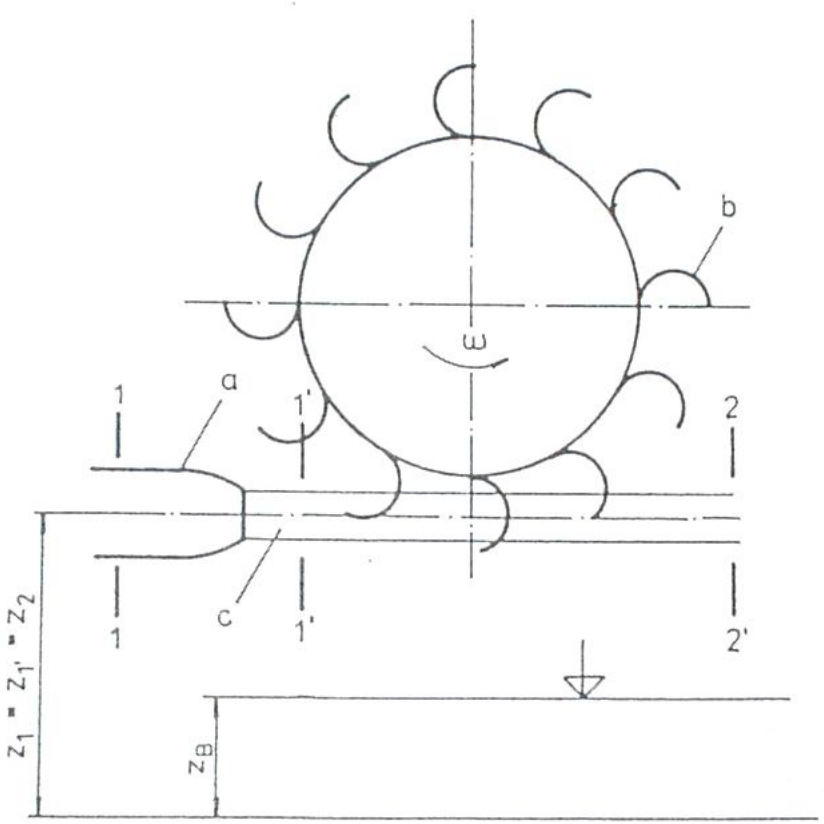
$$E = g \cdot z + \frac{p}{\rho} + \frac{v^2}{2}$$

- **ideal flow**
  - **Bernouli equation**

$$E_1 = E_2 = konst.$$

$$E_2 < E_1$$

Action turbines



$$E_1 = \frac{p_1}{\rho} + \frac{v_1^2}{2}$$

$$E_{1'} = \frac{p_{1'}}{\rho} + \frac{v_{1'}^2}{2}$$

$$E_2 = \frac{p_2}{\rho} + \frac{v_2^2}{2}$$

$$E_1 = E_{1'} + E_{d(1-1')} = E_2 + E_{d(1-2)}$$

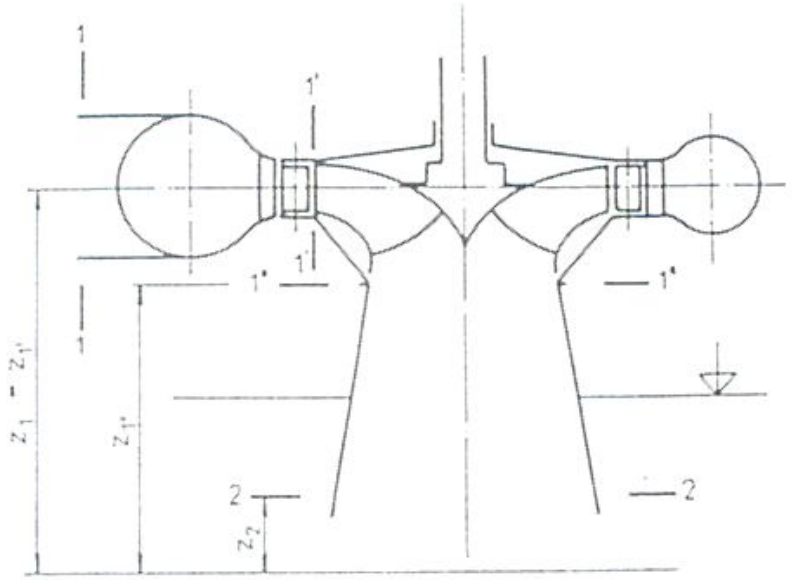
$$p_1 = p_{1''} + p_b$$

$$p_{1'} = p_2 = p_b$$

$$\frac{p_{1''}}{\rho} + \frac{v_1^2}{2} = \frac{v_{1'}^2}{2} + E_{d(1-1')} = \frac{v_2^2}{2} + E_{d(1-2)}$$

$$E = \frac{p_{1''}}{\rho} + \frac{v_1^2 - v_2^2}{2}$$

Reaction turbines



$$E_1 = z_1 \cdot g + \frac{p_1}{\rho} + \frac{v_1^2}{2}$$

$$E_{1'} = z_{1'} \cdot g + \frac{p_{1'}}{\rho} + \frac{v_{1'}^2}{2}$$

$$E_{1''} = z_{1''} \cdot g + \frac{p_{1''}}{\rho} + \frac{v_{1''}^2}{2}$$

$$E_2 = z_2 \cdot g + \frac{p_2}{\rho} + \frac{v_2^2}{2}$$

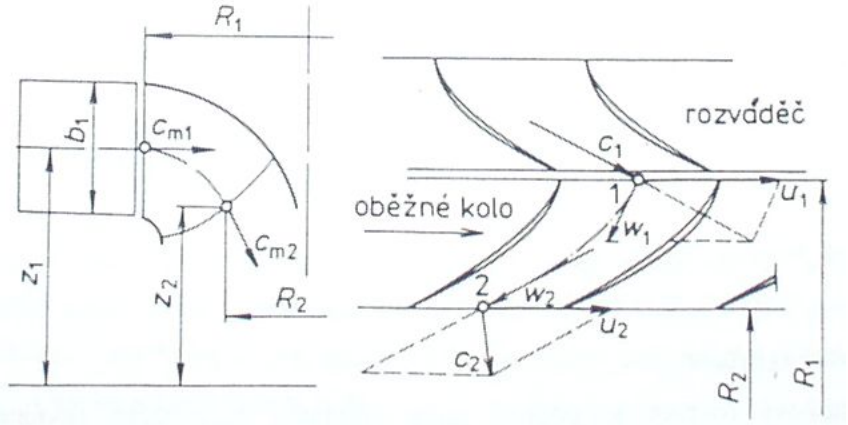
$$E_1 = E_{1'} + E_{d(1-1')}$$

$$\frac{p_1}{\rho} + \frac{v_1^2}{2} = \frac{p_{1'}}{\rho} + \frac{v_{1'}^2}{2} + E_{d(1-1')}$$

$$p_1 > p_{1'} > p_2$$

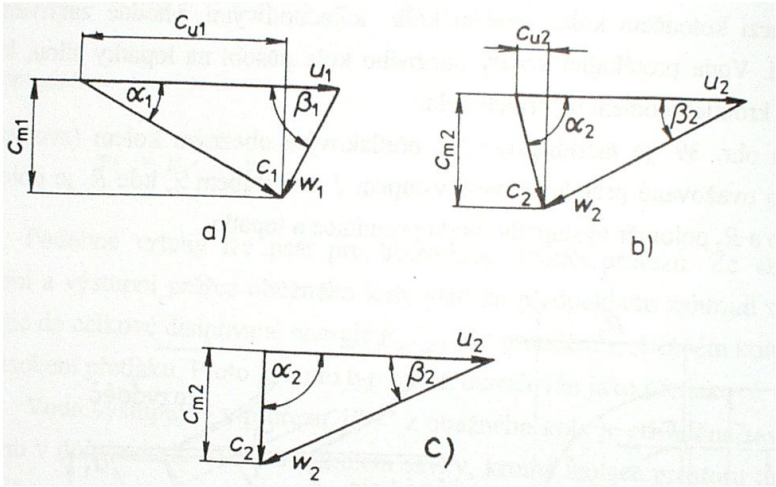
$$E = g \cdot (z_1 - z_2) + \frac{p_1 - p_2}{\rho} + \frac{v_1^2 - v_2^2}{2}$$

Euler equation



$$E \cdot \eta_h = u_1 \, c_{u1} - u_2 \, c_{u2}$$

$$Q_k = 2\pi R_1 \, b_1 \, c_{m1}$$



$$w_1^2 = c_1^2 + u_1^2 - 2\,u_1\,c_1\cos\alpha_1 \qquad c_1\cos\alpha_1 = c_{u1}$$

$$w_2^2 = c_2^2 + u_2^2 - 2\,u_2\,c_2\cos\alpha_2 \qquad c_2\cos\alpha_2 = c_{u2}$$

$$u_1\,c_{u1} - u_2\,c_{u2} = \frac{1}{2}\left(w_2^2 - c_2^2 - u_2^2 - w_1^2 + c_1^2 + u_1^2\right)$$

$$E \cdot \eta_h = \frac{c_1^2 - c_2^2}{2} + \frac{w_2^2 - w_1^2}{2} + \frac{u_1^2 - u_2^2}{2}$$

Energy balance

$$\eta = \eta_Q \cdot \eta_h \cdot \eta_m$$

$$\eta_Q = \frac{Q - Q_z}{Q} = 1 - \frac{Q_z}{Q}$$

$$\eta_h = \frac{P_h}{P_t} = \frac{E - E_z}{E}$$

$$\eta = \frac{P}{P_h} = \frac{P_h - P_z}{P_h} = 1 - \frac{P_z}{P_h}$$

Similarity of turbines

$$E\,\eta_h = u_1\,c_{u1}, \qquad E'\,\eta_h' = u_1'\,c_{u1}'$$

$$E\,\eta_h = k\,u_1^2, \qquad E'\,\eta_h' = k\,u_1'^2$$

$$\frac{u_1}{u_1'} = \frac{n}{n'} = \left(\frac{E}{E'}\right)^{1/2}$$

$$\frac{Q}{Q'} = \frac{c_{m1}}{c_{m1}'} = \frac{u_1}{u_1'} = \left(\frac{E}{E'}\right)^{1/2}$$

$$\frac{P}{P'} = \frac{Q\,E}{Q'\,E'} = \left(\frac{E}{E'}\right)^{3/2}$$

$$\frac{M}{M'} = \frac{P}{P'}\,\frac{n'}{n} = \frac{E}{E'}$$