Energia Idraulica

Impianti idroelettrici

- La potenza disponibile per un salto idraulico è:

$$P_0 = \dot{m} g h_0 = \rho Q g h_0$$

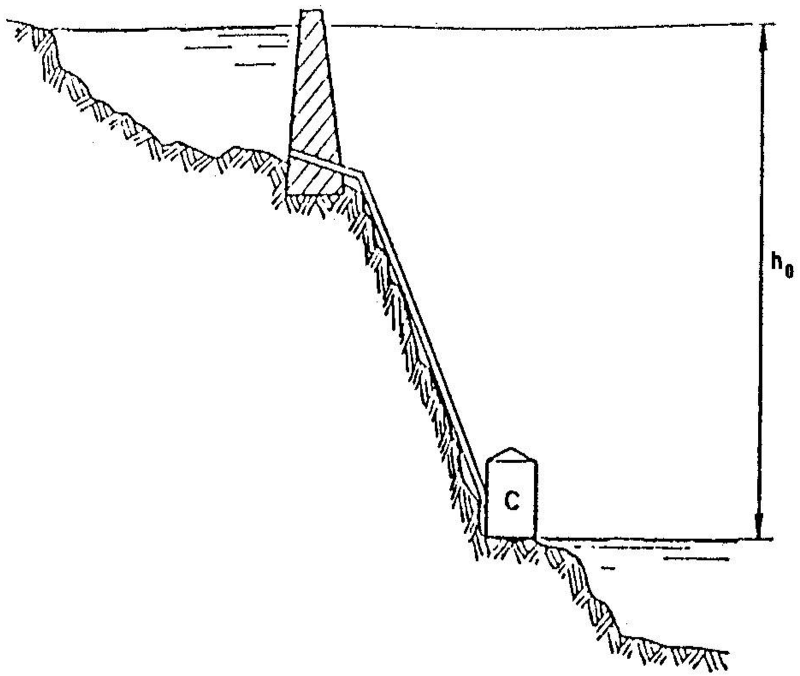
- La potenza reale è:

$$P = \dot{m} g h = \rho Q g h$$

- Il rendimento dell'impianto

è dato da:

$$\eta_0 = \frac{P}{P_0} = \frac{h}{h_0}$$



Bacino superiore, condotta forzata, centrale (C), bacino inferiore

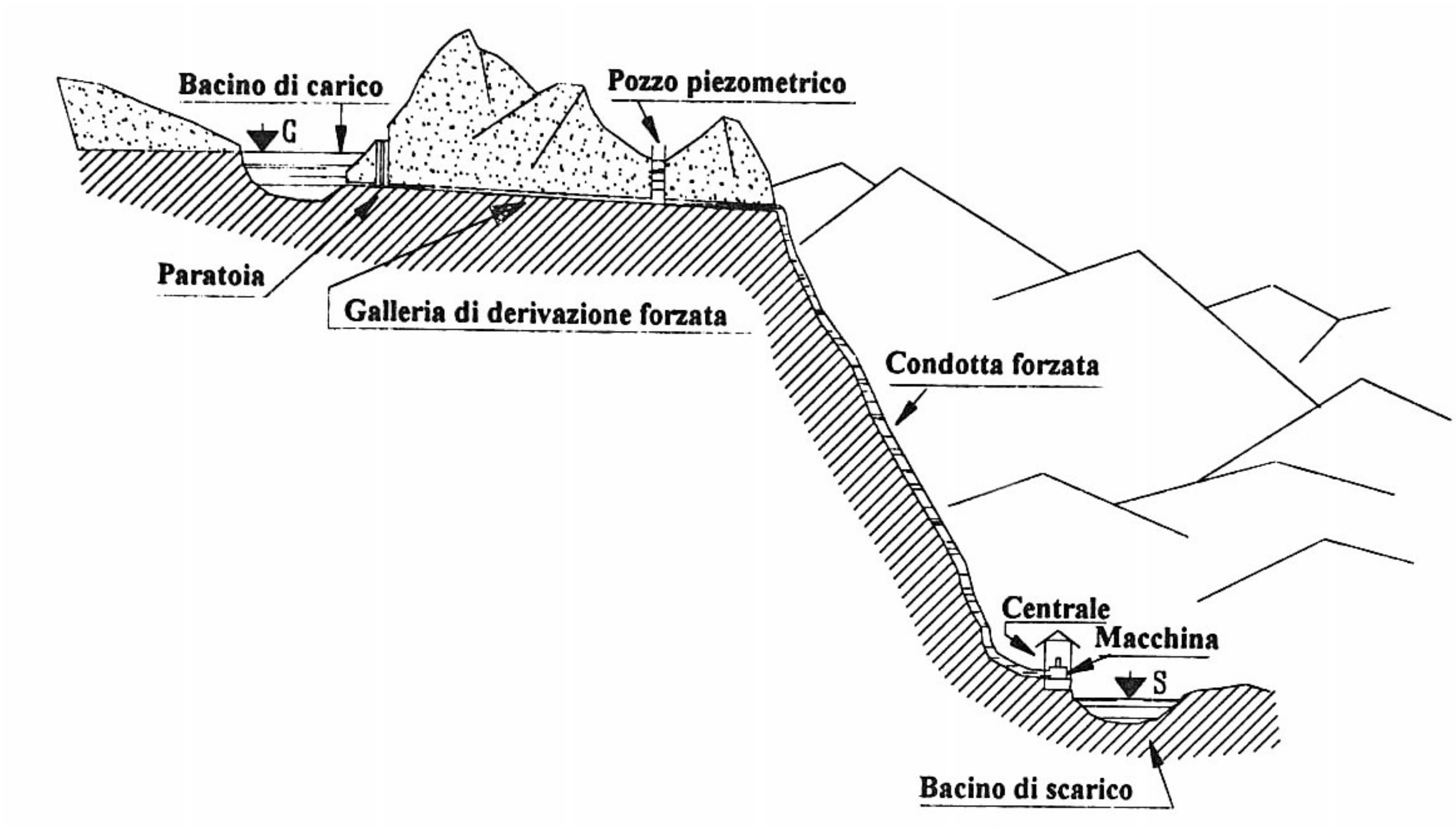
Potenza reale

- Consideriamo i seguenti rendimenti:
- Rendimento macchina idraulica: $\eta_i = \frac{P_i}{P}$
- Rendimento meccanico: $\eta_m = \frac{P_e}{P_i}$

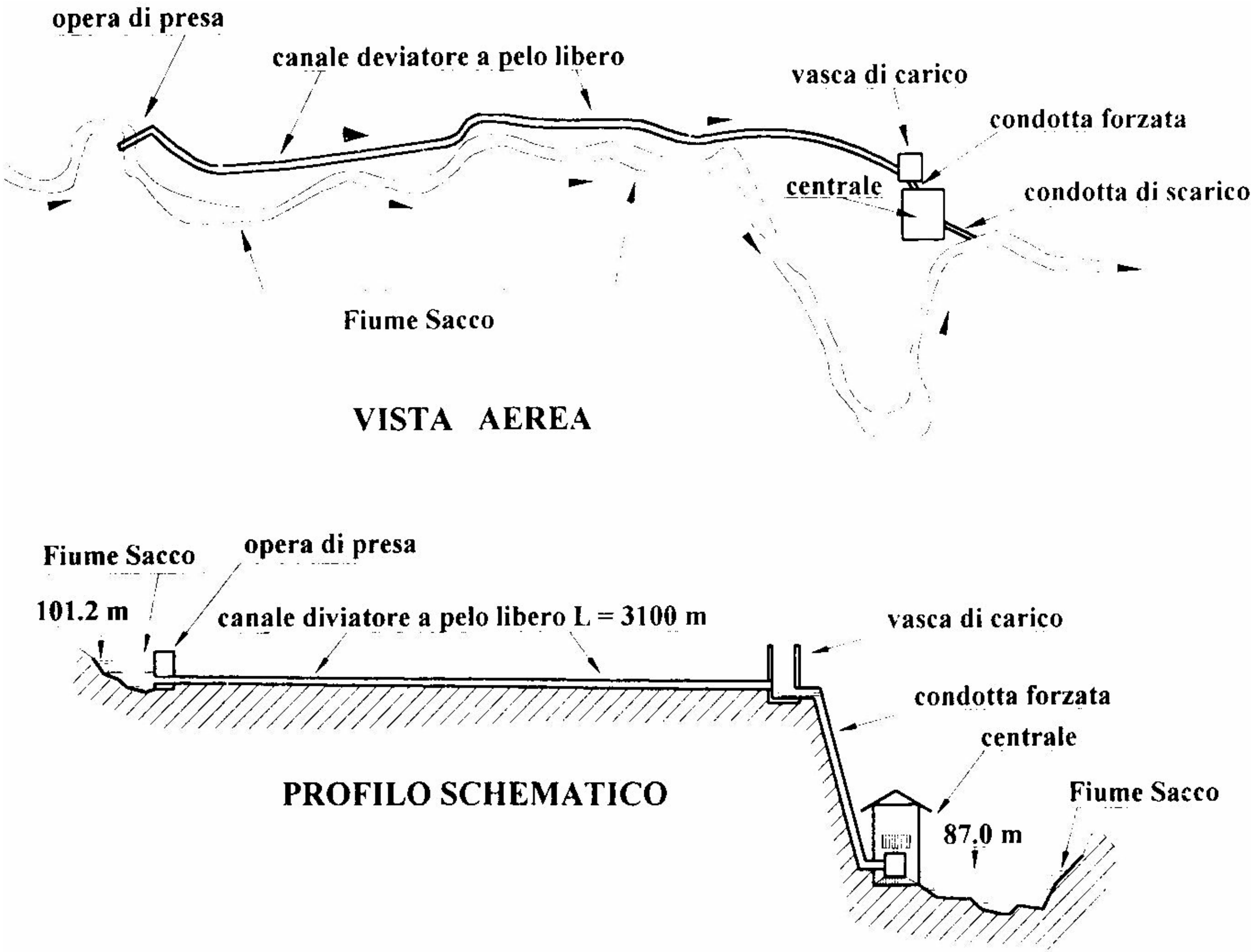
- Rendimento complessivo: $\eta = \frac{P_e}{P_0} = \eta_0 \eta_i \eta_m$
- Da cui:

$$P = \eta \rho Q g h_0$$

Impianti idroelettrici



Impianti ad acqua fluente



Turbine idrauliche

- Si può definire come nelle turbine a vapore e a gas un grado di reazione:

$$R = \frac{gH_r}{gH} = \frac{gH - \frac{c_1^2}{2\varphi^2}}{gH}$$

Parametri specifici

- Data una turbina A che elabora una portata Q_A e un salto idraulico H_A con un rendimento η_A si può progettare una turbina B sulla base della seguente teoria della similitudine:

$$Q_A = 2\pi \mathrm{r}_A b_A c_A sen\alpha_A$$

$$Q_B = 2\pi \mathrm{r}_B b_B c_B sen\alpha_B$$

- Avremo che gli angoli di ingresso sono uguali e per la similitudine geometrica anche i rapporti r/b sono uguali

Parametri specifici

- Quindi facendo il rapporto tra le portate:

$$\frac{Q_A}{Q_B}=\frac{2\pi r_A b_A c_A sen\alpha_A}{2\pi r_B b_B c_B sen\alpha_B}=\frac{r_A b_A c_A}{r_B b_B c_B}=\frac{r_A^2 c_A}{r_B^2 c_B}$$

- La velocità in ingresso dipende dal salto e dal grado di reazione:

$$c \propto \sqrt{gH\left(1-R\right)} \Rightarrow$$

$$\frac{Q_A}{Q_B}=\frac{r_A^2\sqrt{gH_A\left(1-R_A\right)}}{r_B^2\sqrt{gH_B\left(1-R_B\right)}}=\frac{r_A\sqrt{gH_A}}{r_B\sqrt{gH_B}}\Rightarrow\frac{r_A}{r_B}=\frac{\sqrt{Q_A}\sqrt[4]{gH_B}}{\sqrt{Q_B}\sqrt[4]{gH_A}}$$

Parametri specifici

- Dato che le velocità periferiche sono:

$$u \propto c \propto \sqrt{gH}$$

$$u_A = r_A \omega_A \qquad u_B = r_B \omega_B$$

$$\frac{u_A}{u_B} = \frac{\sqrt{gH_A}}{\sqrt{gH_B}} = \frac{\omega_A r_A}{\omega_B r_B} = \frac{\omega_A \dfrac{\sqrt{Q_A}}{\sqrt[4]{gH_A}}}{\omega_B \dfrac{\sqrt{Q_B}}{\sqrt[4]{gH_B}}} \Rightarrow$$

$$\frac{\sqrt{gH_A}}{\sqrt{gH_B}} = \omega_A \frac{\sqrt{Q_A}}{\sqrt[4]{gH_A}} \frac{1}{\omega_B} \frac{\sqrt[4]{gH_B}}{\sqrt{Q_B}} \Rightarrow$$

$$\frac{\left(gH_A\right)^{3/4}}{\left(gH_B\right)^{3/4}} = \frac{\omega_A}{\omega_B} \frac{\sqrt{Q_A}}{\sqrt{Q_B}}$$

Parametri specifici

- Quindi definiamo velocità specifica il parametro che deriva dalla seguente uguaglianza:

$$\frac{\omega_B\sqrt{Q_B}}{\left(gH_B\right)^{3/4}}=\frac{\omega_A\sqrt{Q_A}}{\left(gH_A\right)^{3/4}}$$

$$\omega_s=\frac{\omega\sqrt{Q}}{\left(gH\right)^{3/4}}=\frac{2\pi n\sqrt{Q}}{\left(gH\right)^{3/4}}$$

$$\frac{2u_B\sqrt{Q_B}}{D_B\left(gH_B\right)^{3/4}}=\frac{2u_A\sqrt{Q_A}}{D_A\left(gH_A\right)^{3/4}}\Rightarrow\frac{D_B\left(gH_B\right)^{1/4}}{\sqrt{Q_B}}=\frac{D_A\left(gH_A\right)^{1/4}}{\sqrt{Q_A}}\Rightarrow D_s=\frac{D\left(gH\right)^{1/4}}{\sqrt{Q}}$$

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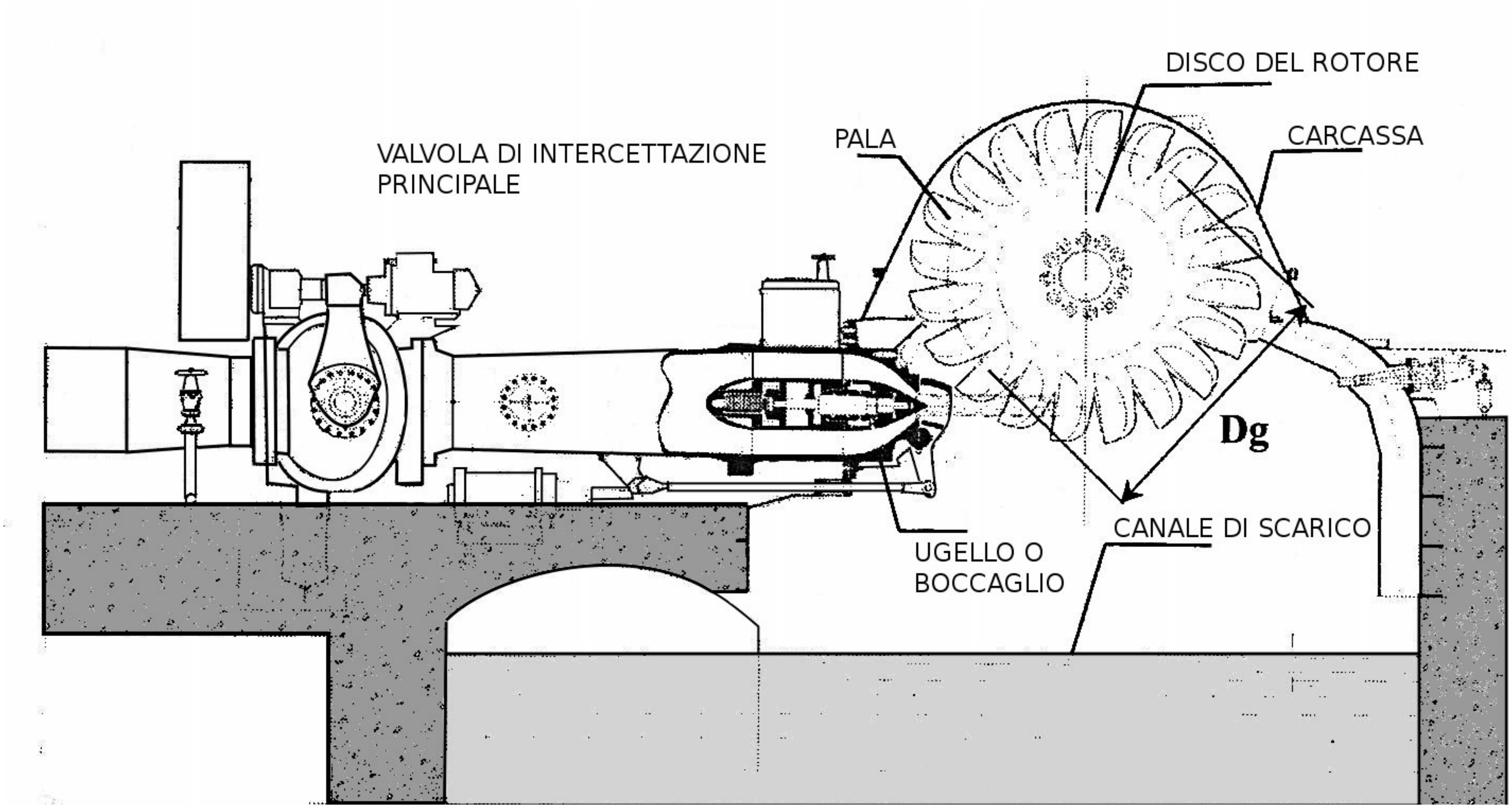
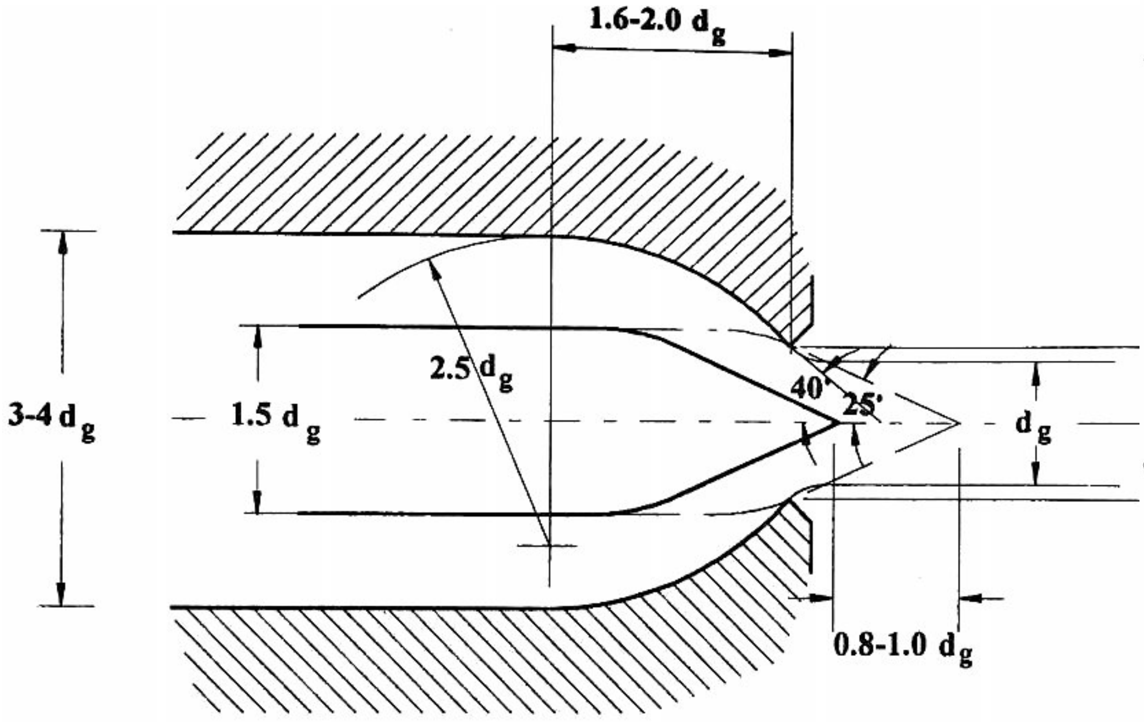
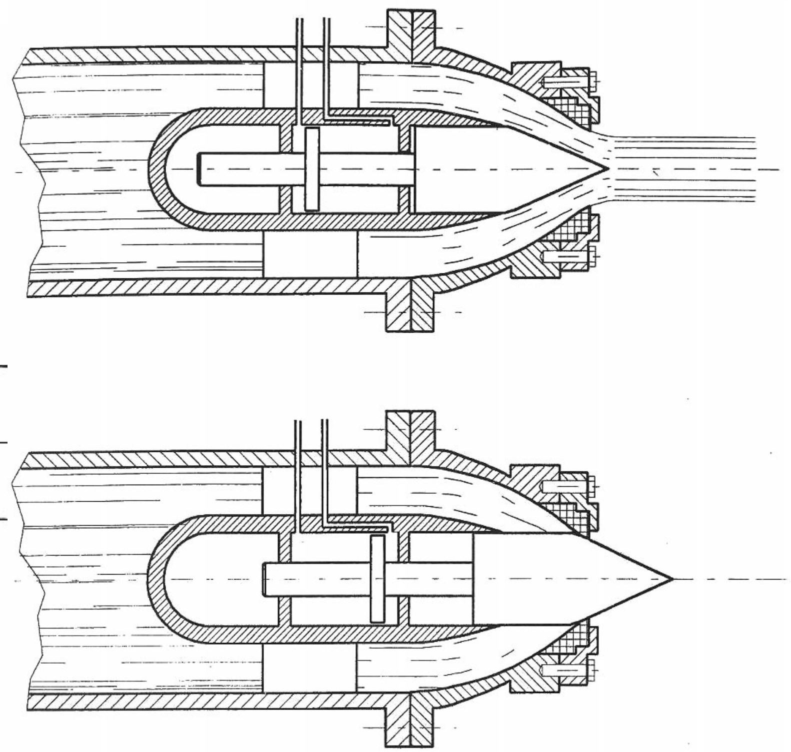
$$\omega_s = 0.03 - 0.05 \qquad D_s = 5 - 30$$

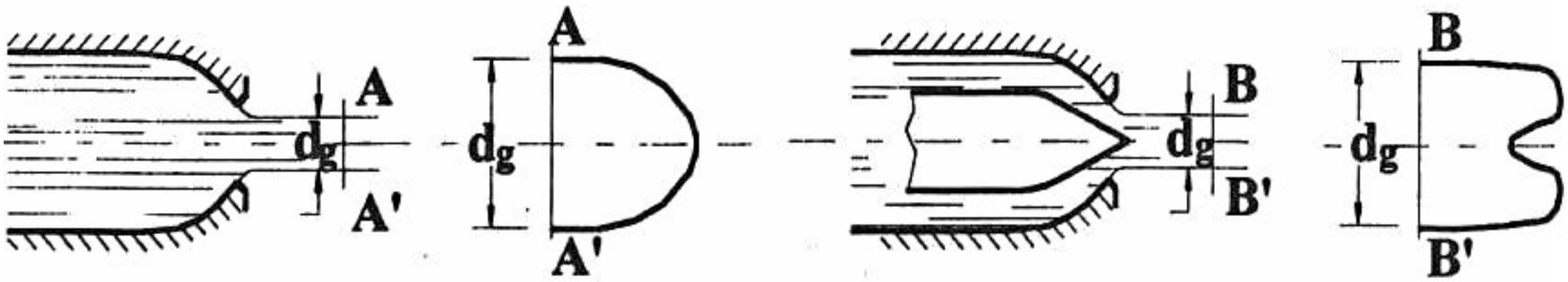


Ugello Doble

$$\Delta P = 2L\frac{c}{t}\rho \cdot 10^{-5}$$

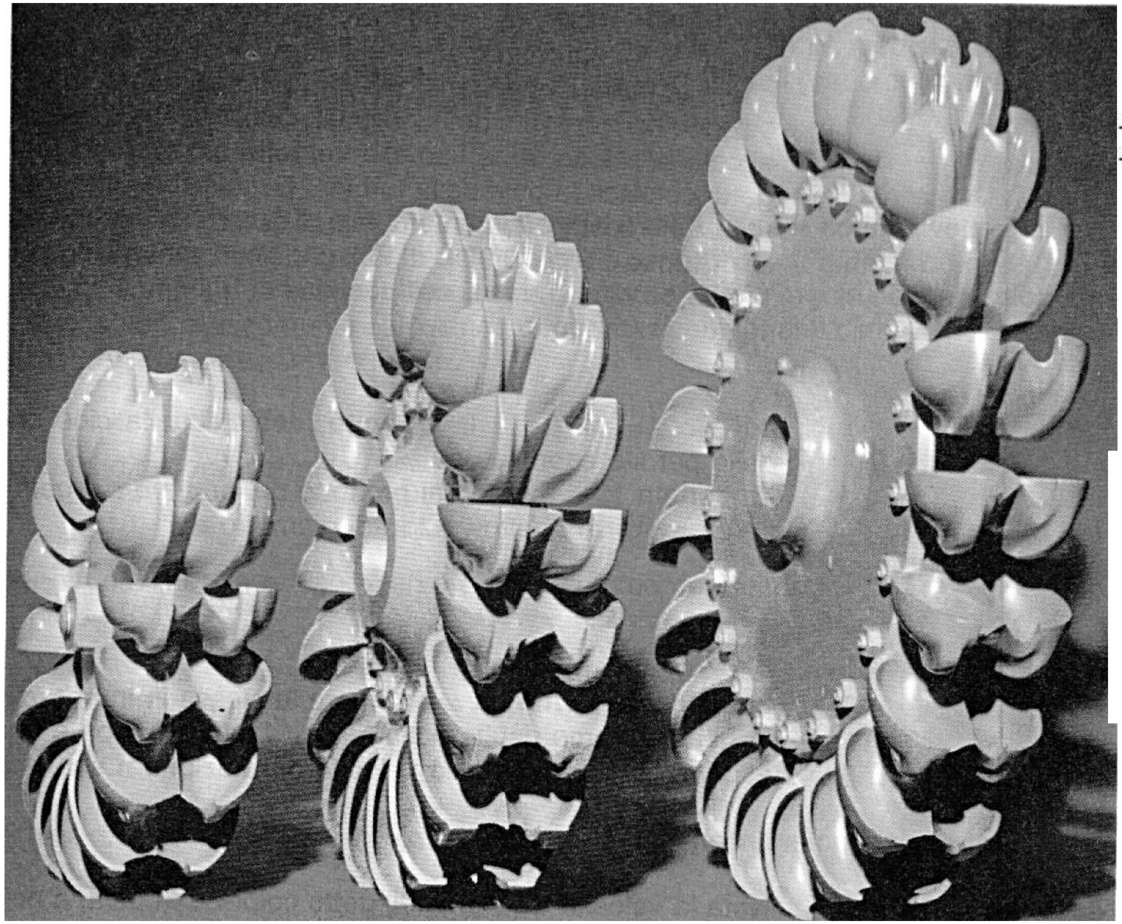


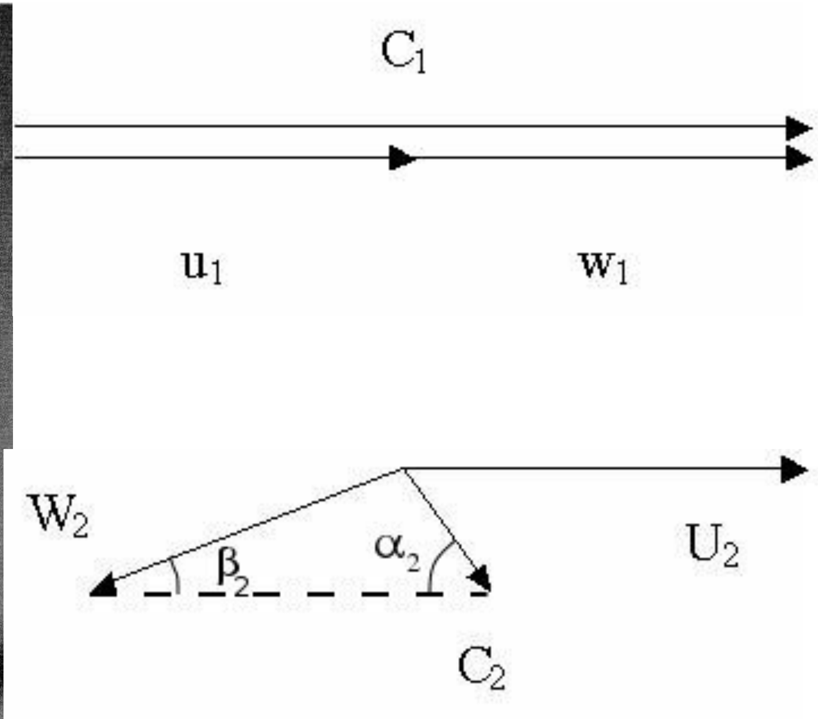




a) b)

La ruota





$$c_2 = \sqrt{w_2^2 + u_2^2 - 2u_2 w_2 \cos\beta_2}$$

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- L'energia utile che investe la ruota è:
  $$\frac{c_1^2}{2}\cdot\eta_v = \varphi^2 g H_u \eta_v$$
- La perdita per variazione di velocità relativa è data da:
  $$\frac{w_1^2 - w_2^2}{2}\cdot\eta_v = w_1^2\,\frac{1-\psi^2}{2}\eta_v$$
- E il fluido lascia la ruota a velocità:
  $$\frac{c_2^2}{2}\cdot\eta_v$$

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- Il rendimento della ruota è quindi:

$$\eta_r = \frac{\left(\frac{c_1^2}{2} - \frac{c_2^2}{2}\right)\eta_v - w_1^2 \frac{1-\psi^2}{2}\eta_v}{\frac{c_1^2}{2}\eta_v}$$

- Potendo scrivere c_2 come per il caso in cui non abbiamo perdite nel distributore e nella ruota per cui $w_1=w_2$:

$$c_2^2 = w_2^2 + u_2^2 - 2u_2 w_2 \cos\beta_2 = w_1^2 + u_1^2 - 2u_1 w_1 \cos\beta_2$$

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- Il rendimento di ruota diventa:

$$\eta_r = \frac{\left(\frac{c_1^2}{2} - \frac{c_2^2}{2}\right)}{\frac{c_1^2}{2}} = \frac{c_1^2 - c_2^2}{c_1^2} = \frac{c_1^2 - \left(w_1^2 + u_1^2 - 2u_1 w_1 \cos\beta_2\right)}{c_1^2} =$$

$$\frac{c_1^2 - u_1^2 + 2u_1\left(c_1 - u_1\right)\cos\beta_2 - \left(c_1 - u_1\right)^2}{c_1^2} =$$

$$\frac{c_1^2 - u_1^2 + 2u_1\left(c_1 - u_1\right)\cos\beta_2 - \left(c_1^2 + u_1^2 - 2u_1 c_1\right)}{c_1^2} =$$

$$\frac{-2u_1^2 + 2u_1 c_1 \cos\beta_2 - 2u_1^2 \cos\beta_2 + 2u_1 c_1}{c_1^2} = 2\frac{u_1}{c_1}\left(1 - \frac{u_1}{c_1}\right)\left(\cos\beta_2 + 1\right)$$

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- Derivando rispetto al rapporto cinetico fondamentale

$$\frac{d\eta_r}{d\left(\frac{u_1}{c_1}\right)} = 0 \Rightarrow \left(\frac{u_1}{c_1}\right)_{opt} = \frac{1}{2}$$

$$\eta_{r,\max} = \left(\frac{\cos\beta_2 - 1}{2}\right)$$

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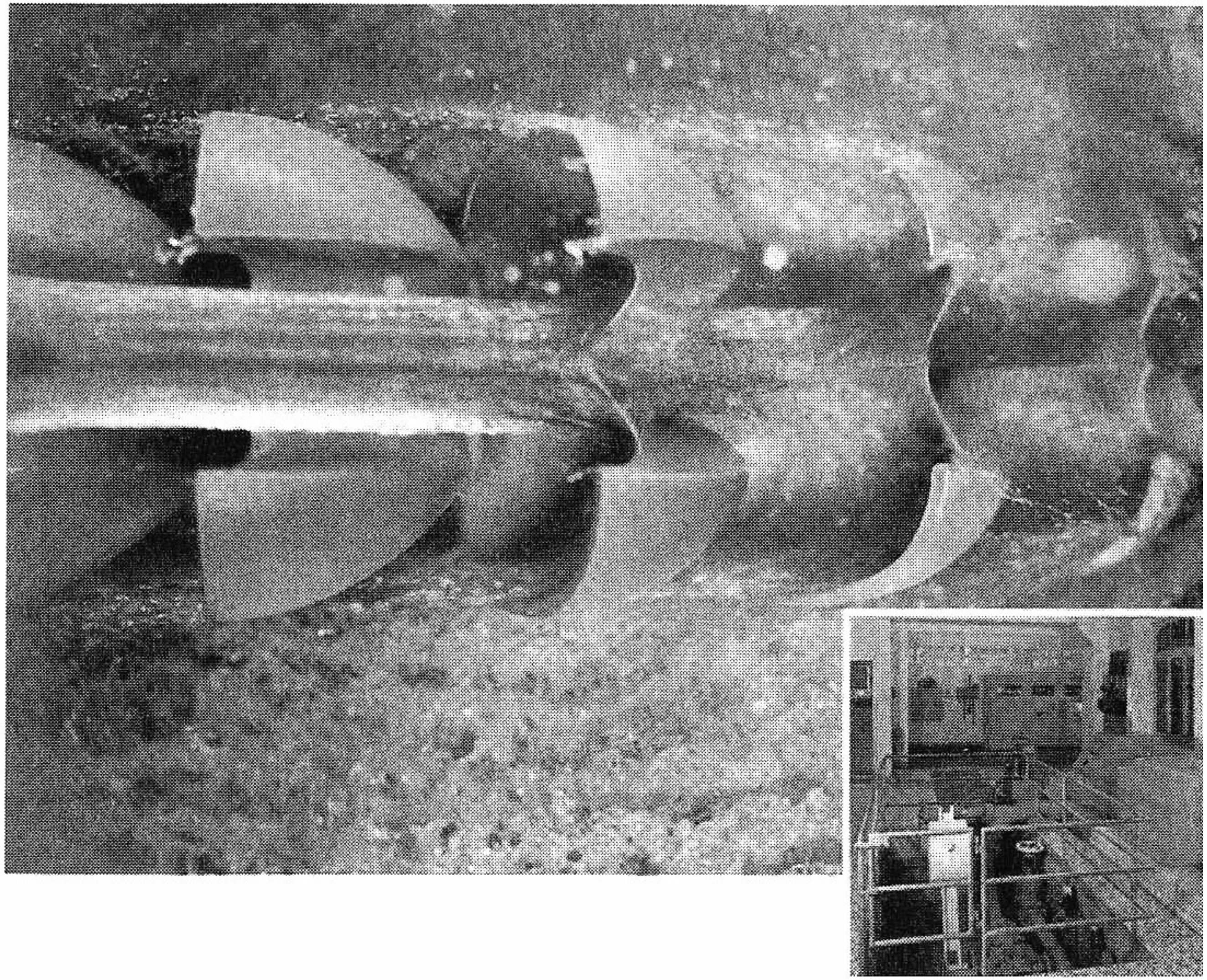

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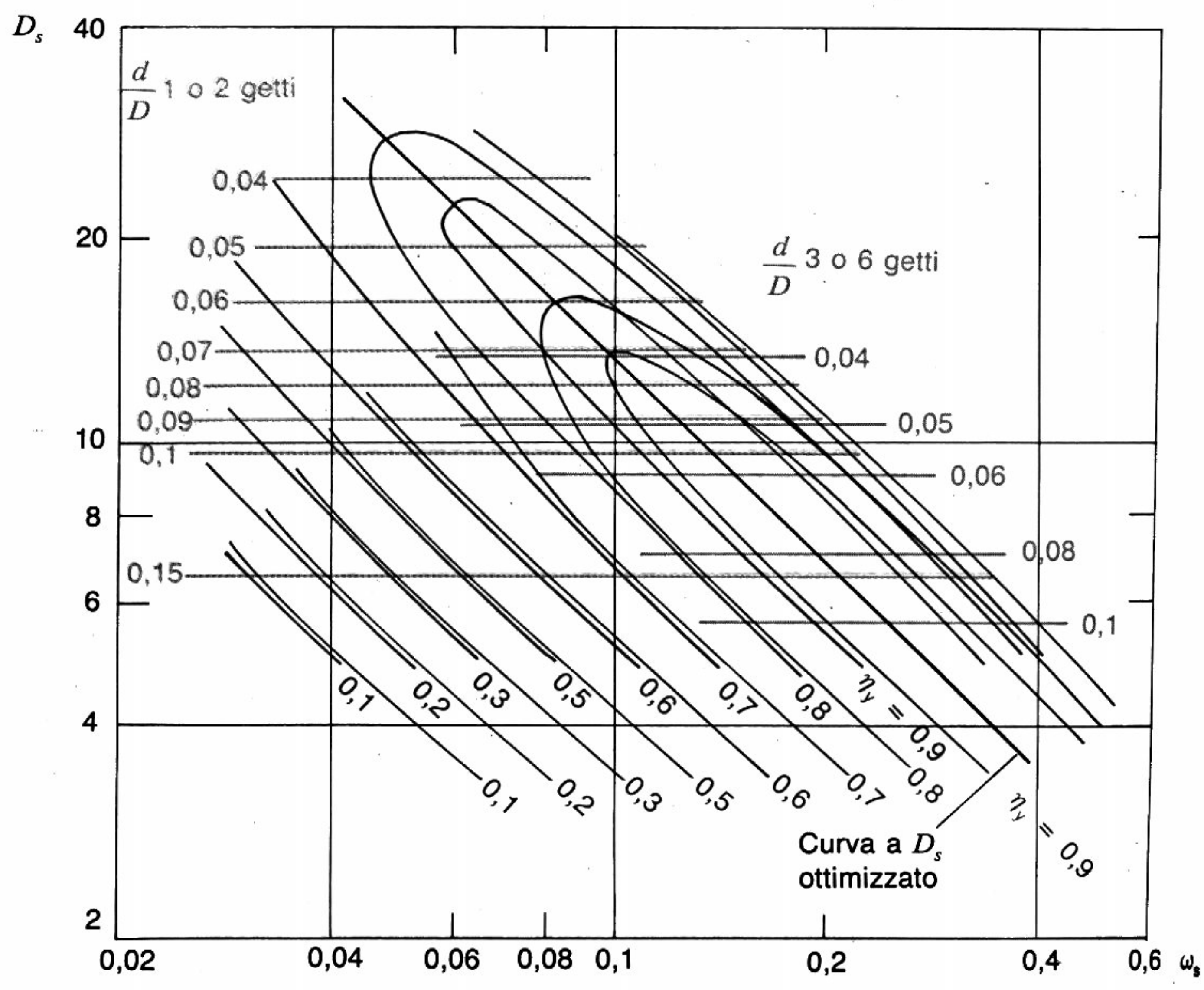

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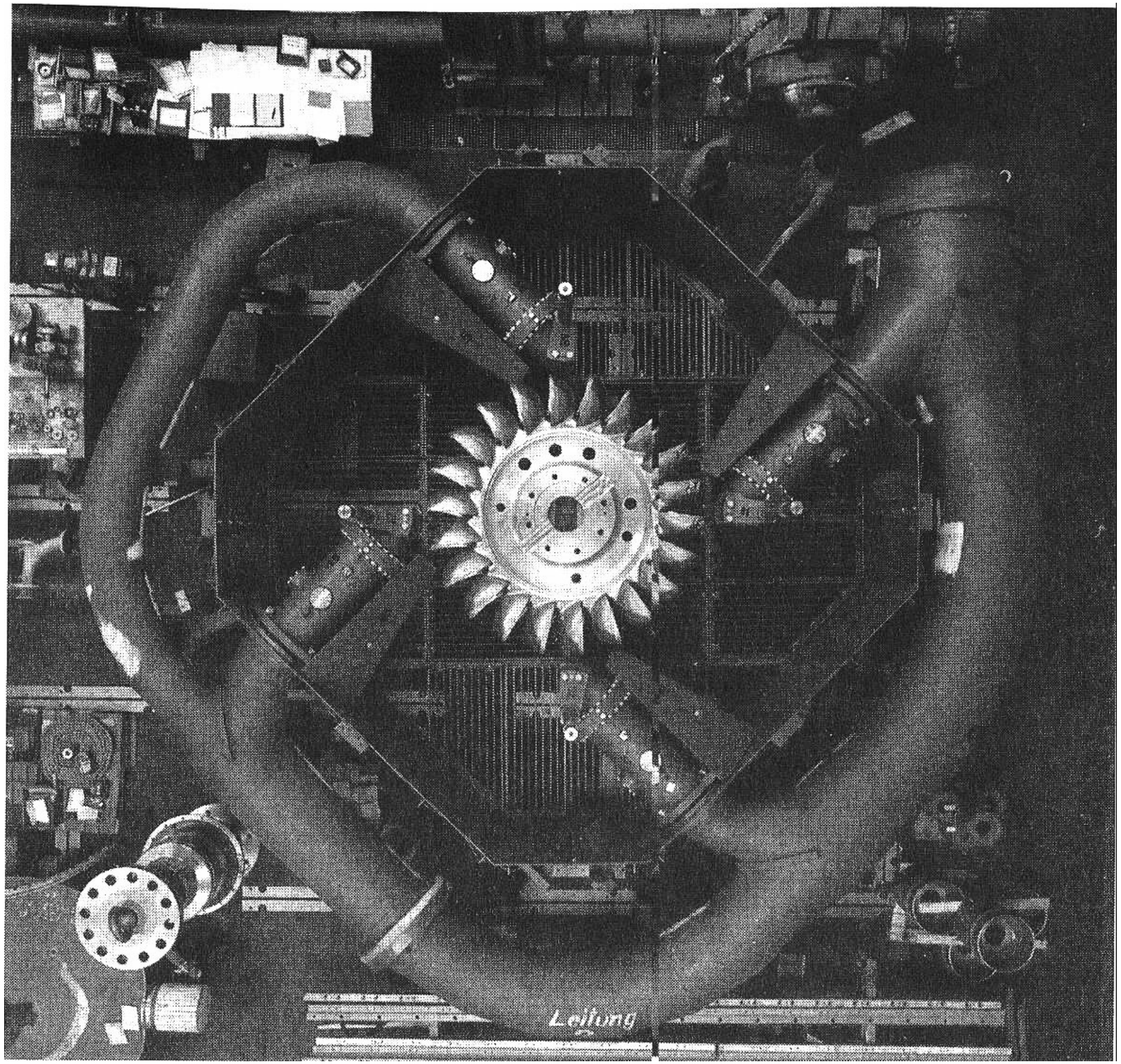
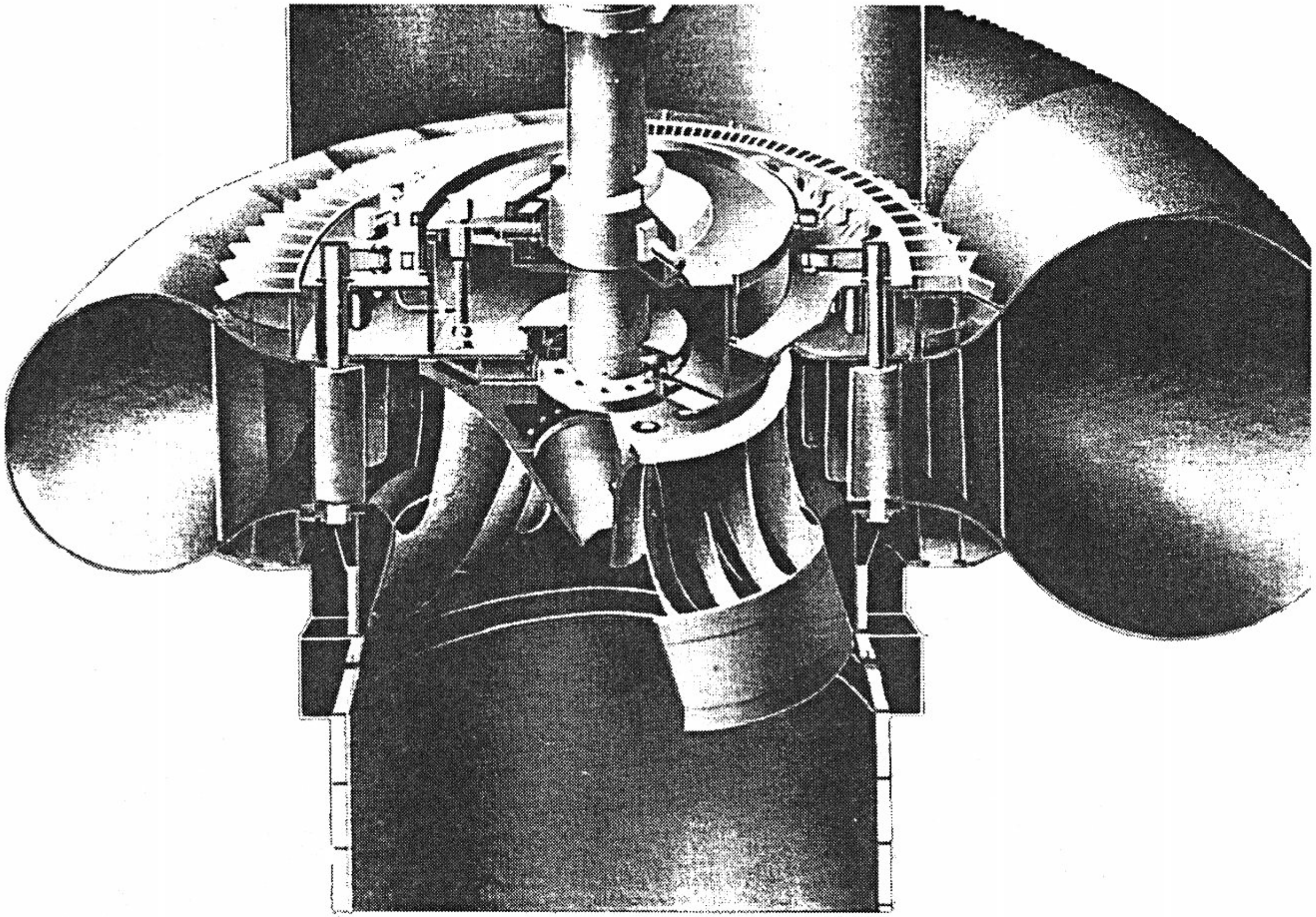
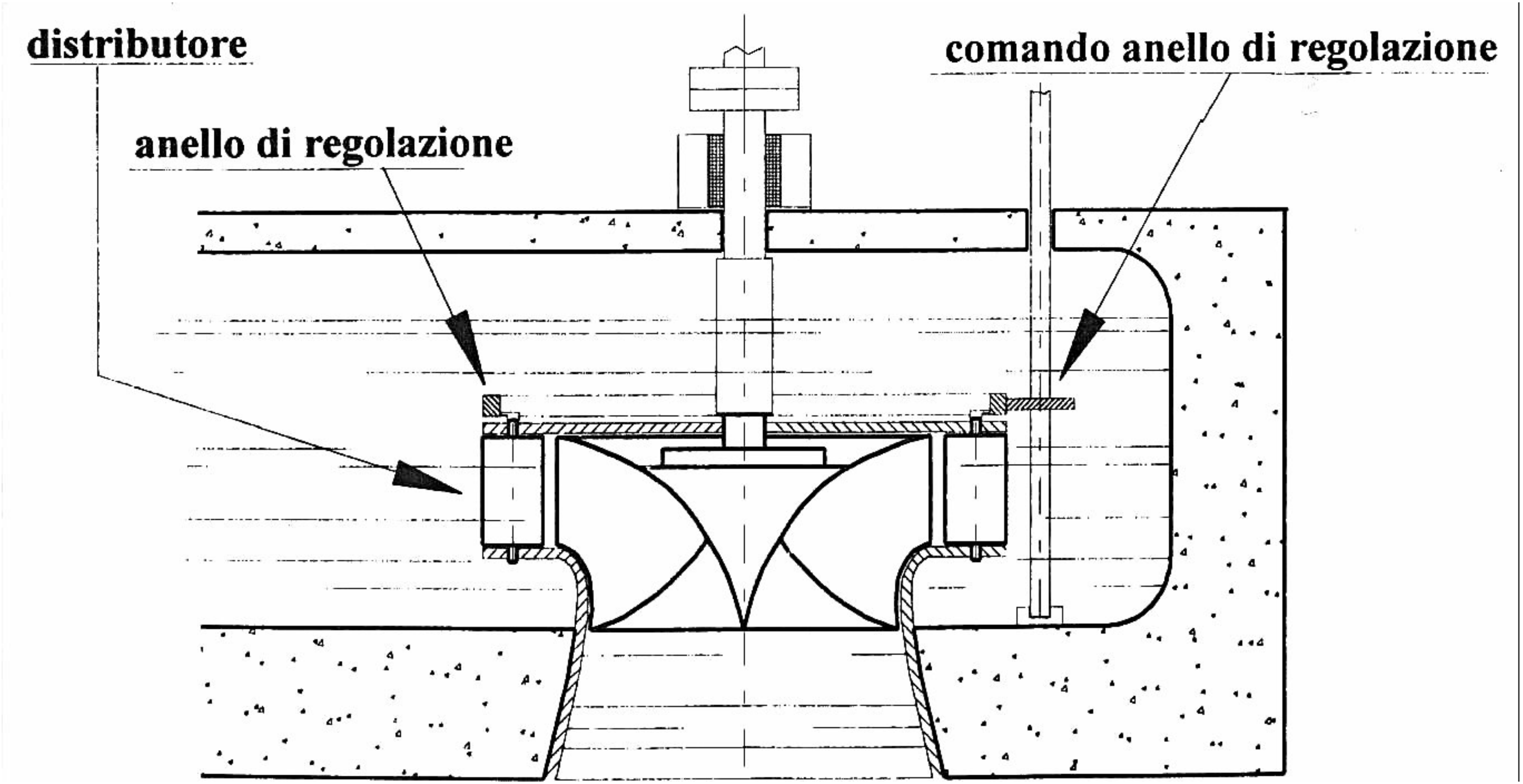


Turbina Francis

$$\omega_s = 0.25 - 2.5 \qquad D_s = 0.5 - 1.8$$



Turbina Francis



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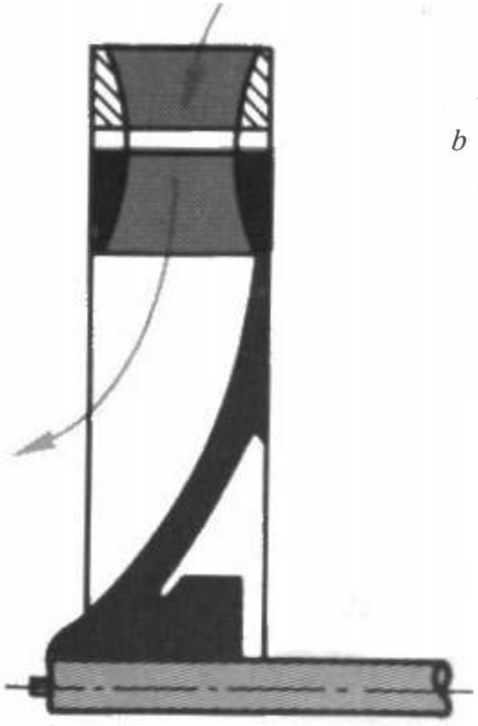
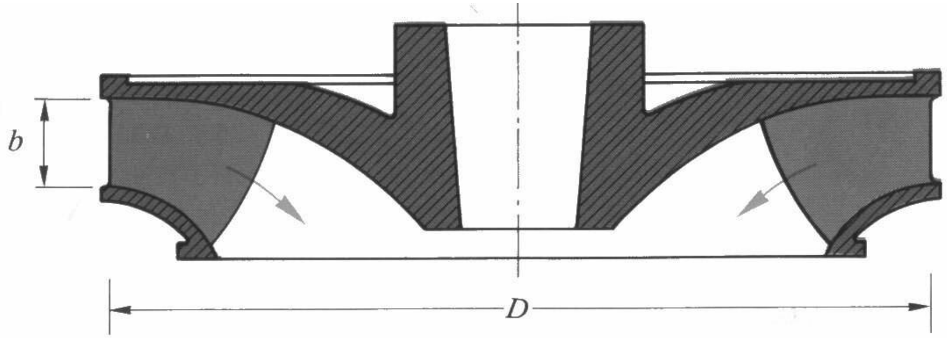
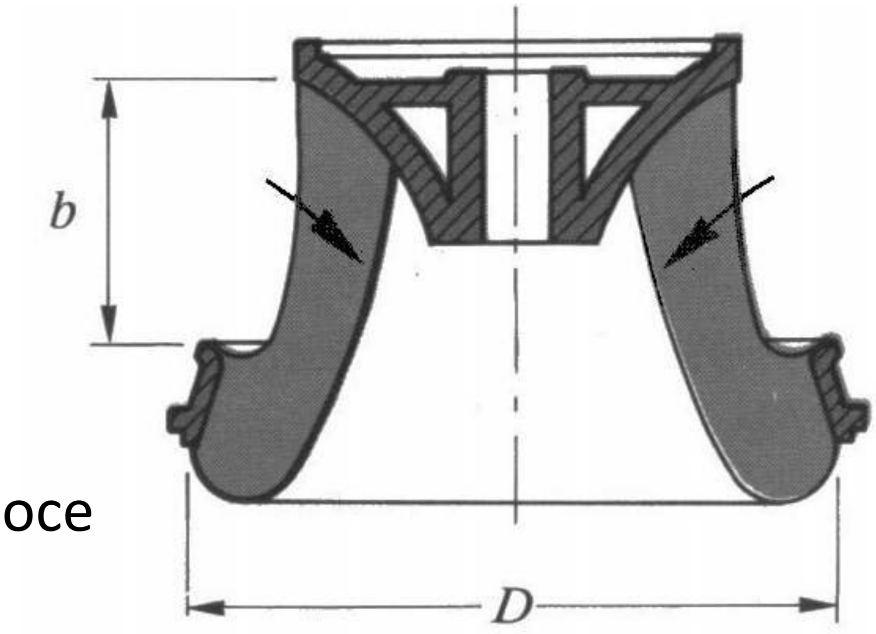


Lenta



Normale

Veloce



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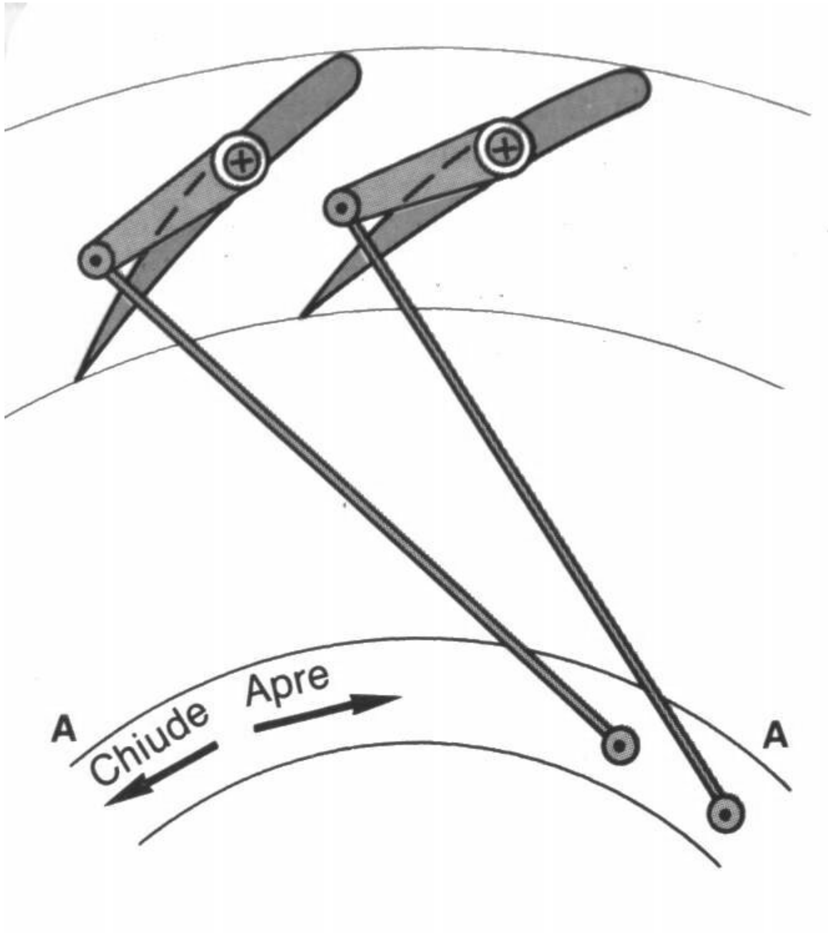

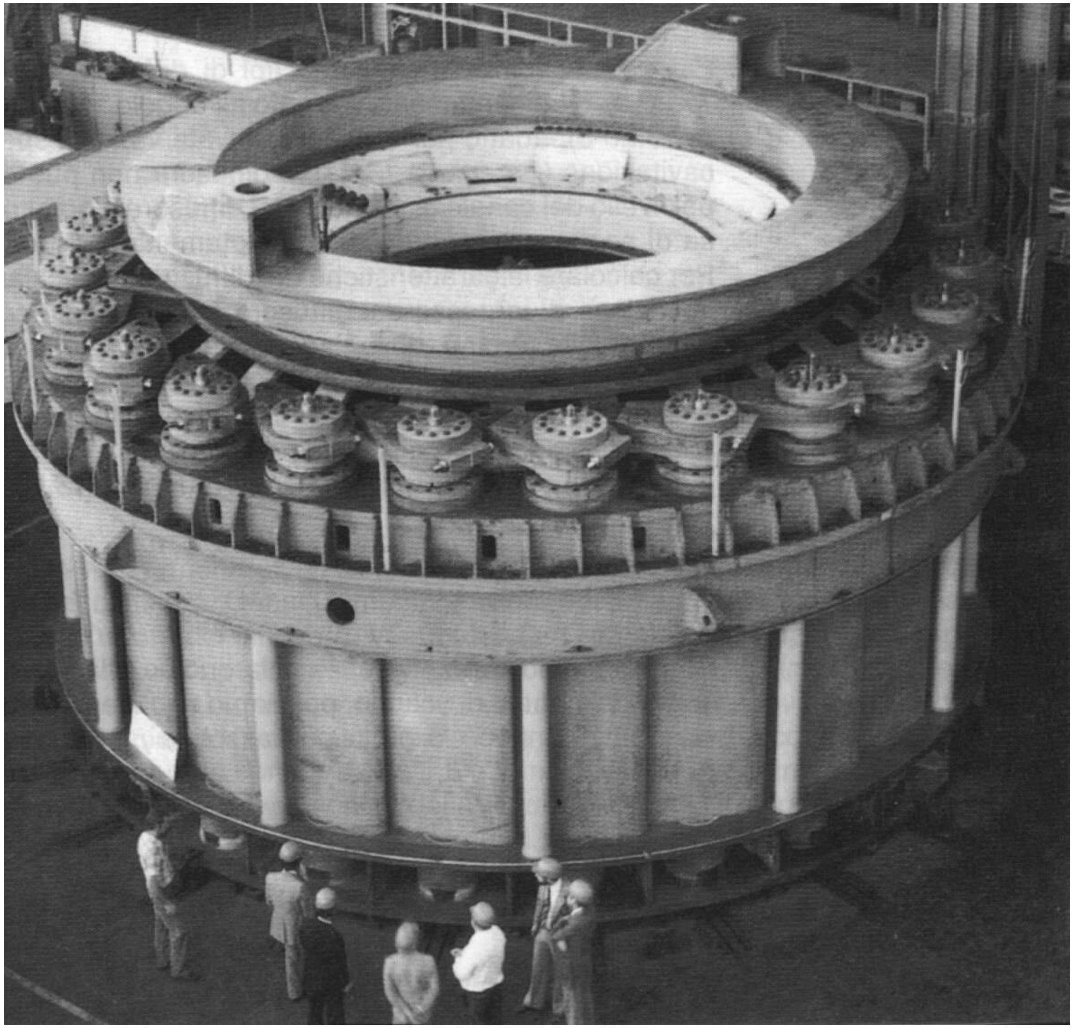

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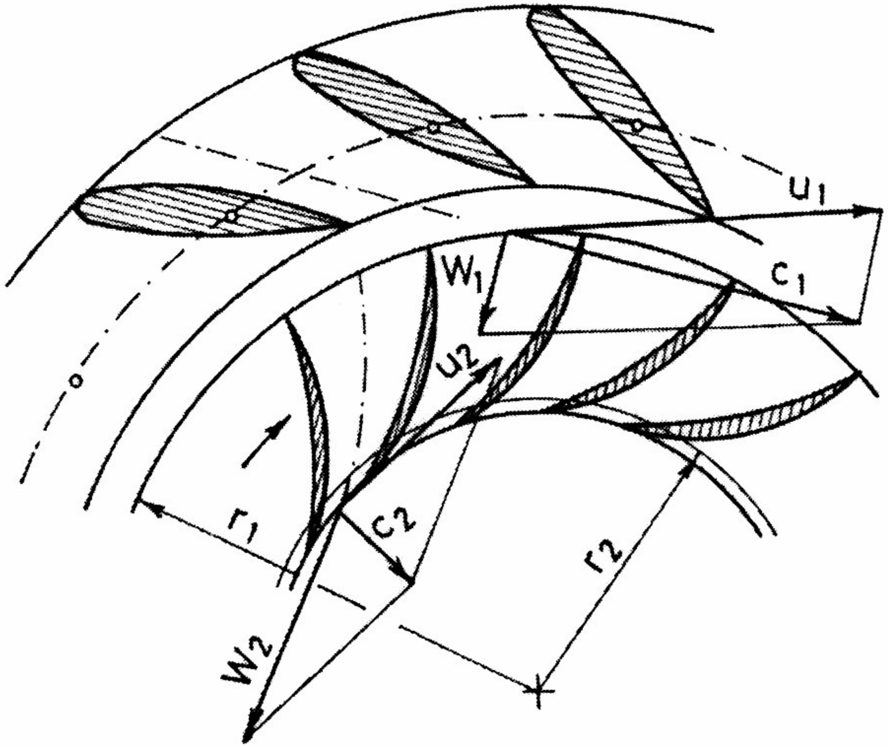
- La velocità dopo il distributore dipende dal grado di reazione:

$$c = \varphi \sqrt{2gH_u\left(1-R\right)}$$

$$L = u_1 c_{t1} - u_2 c_{t2}$$

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



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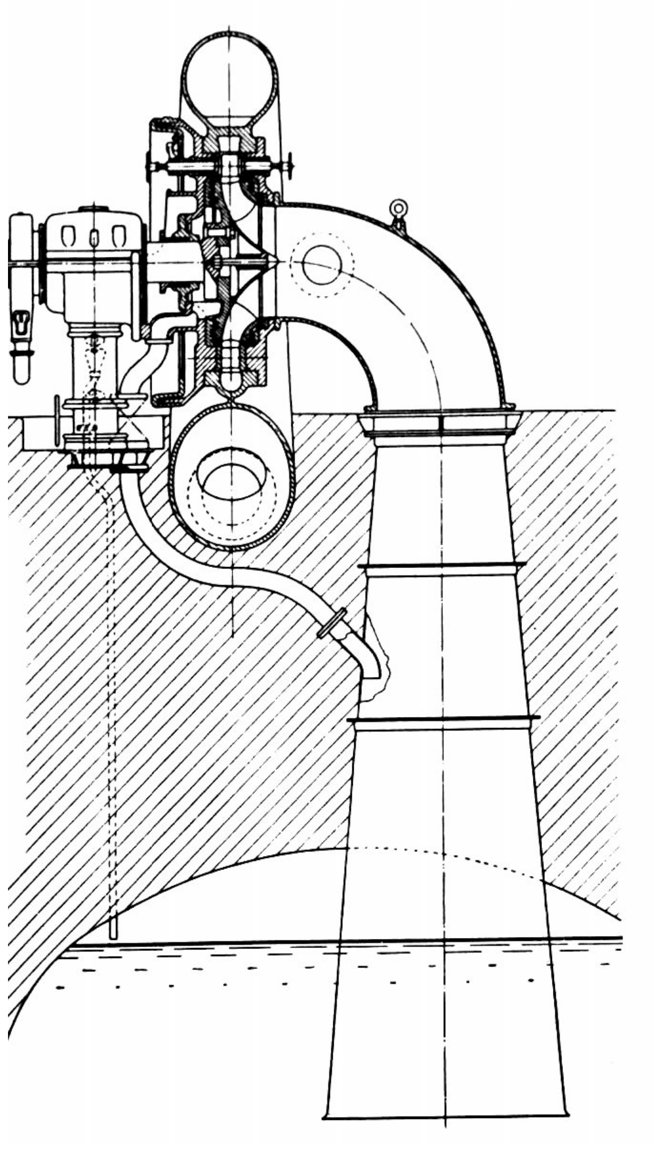

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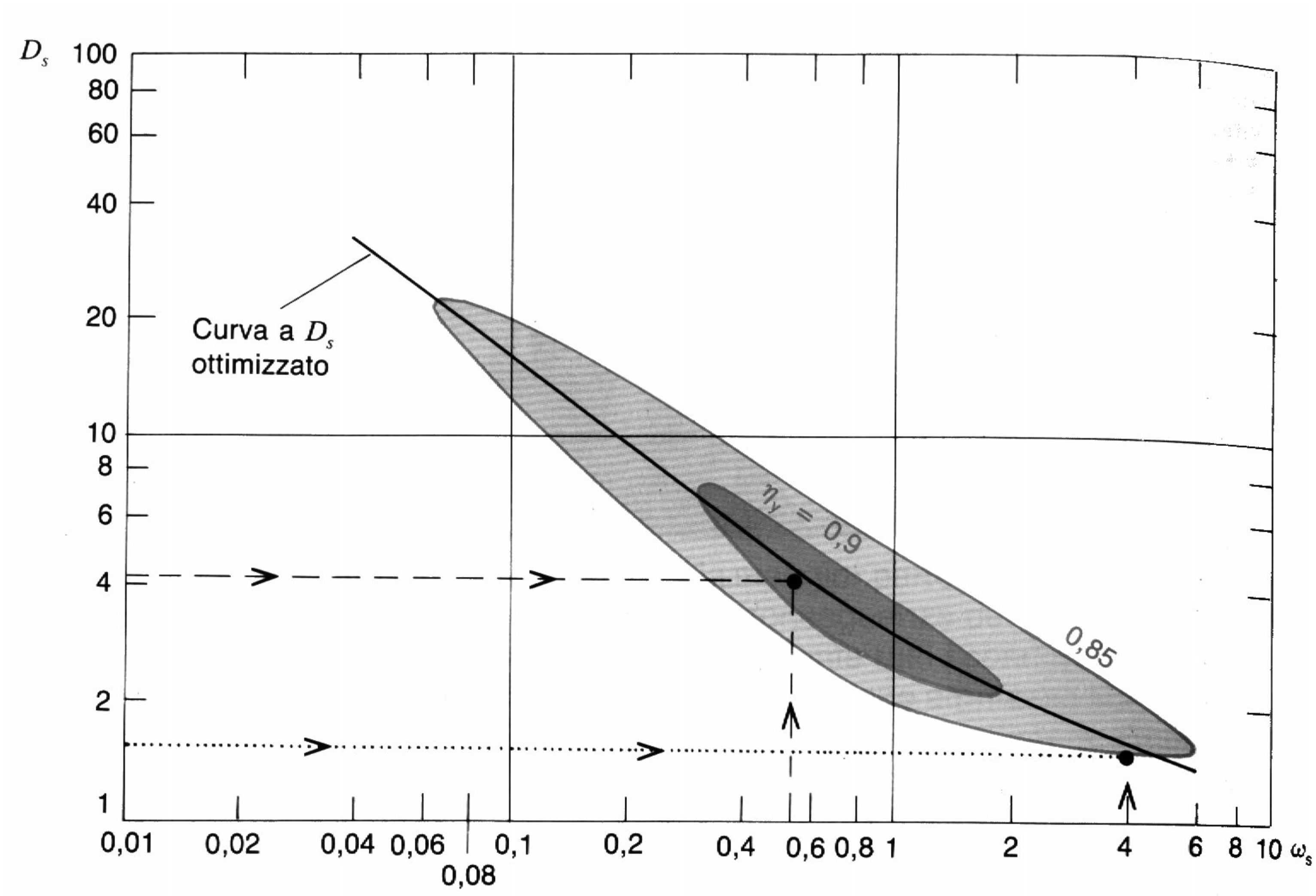
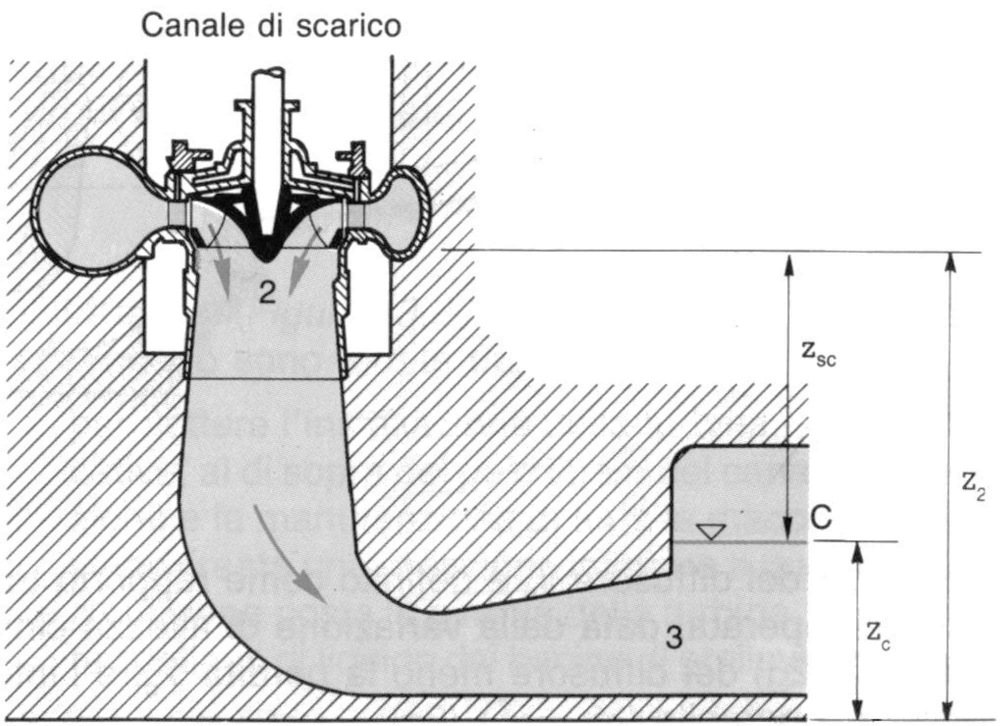


Cavitazione

- Si fa riferimento al parametro di Thoma

$$\sigma = \frac{\frac{p_{atm} - p_{vap}}{\rho g} - z_{sc}}{H_u}$$

$$z_{sc,\max} = \frac{p_{atm} - p_{vap}}{\rho g} - \sigma_{\min} H_u$$



Turbine Francis

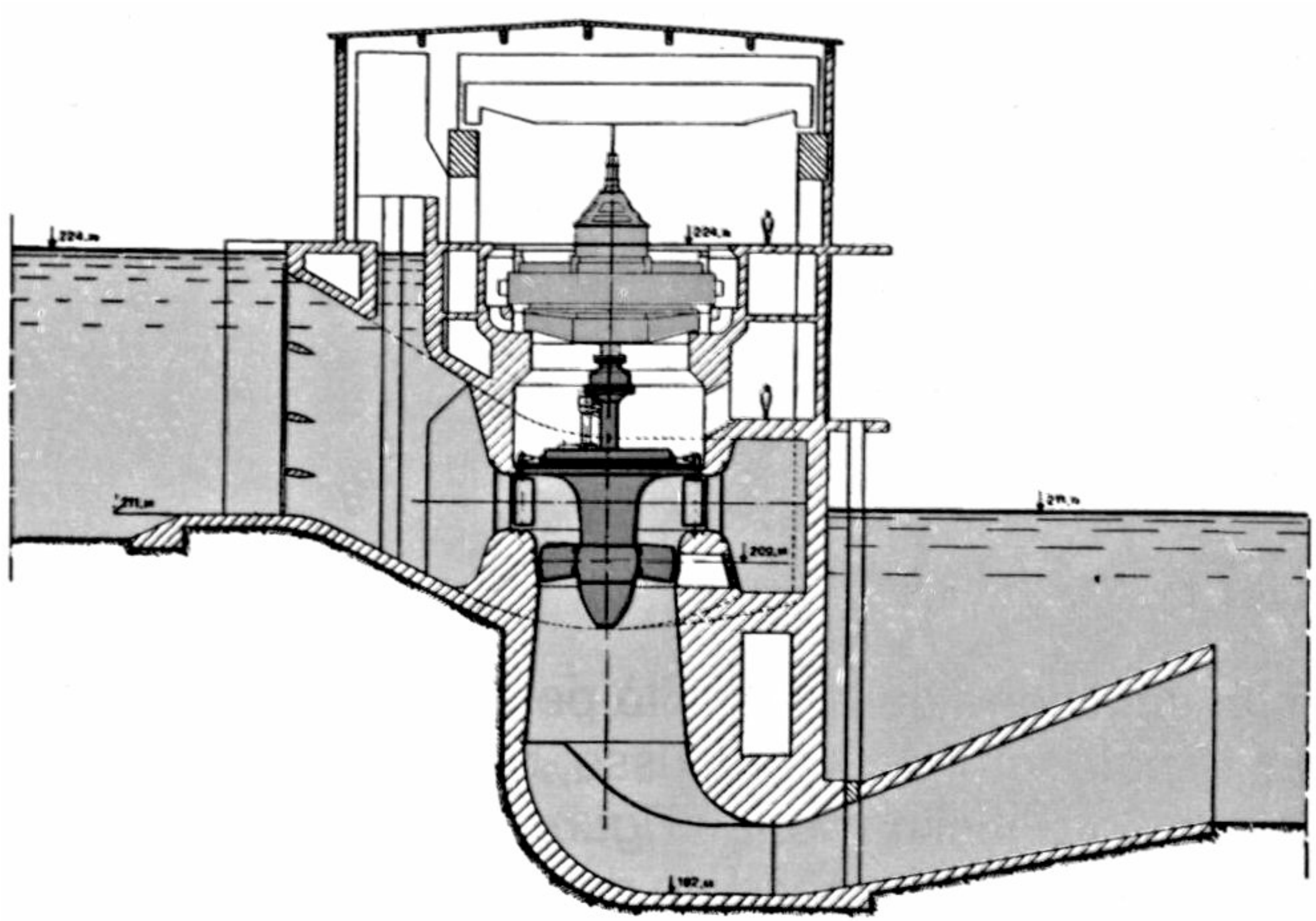
ω_s	0,45	0,5	1,0	1,5	2,0	2,3
σ^*	0,025	0,03	0,115	0,24	0,48	0,64

Turbine assiali

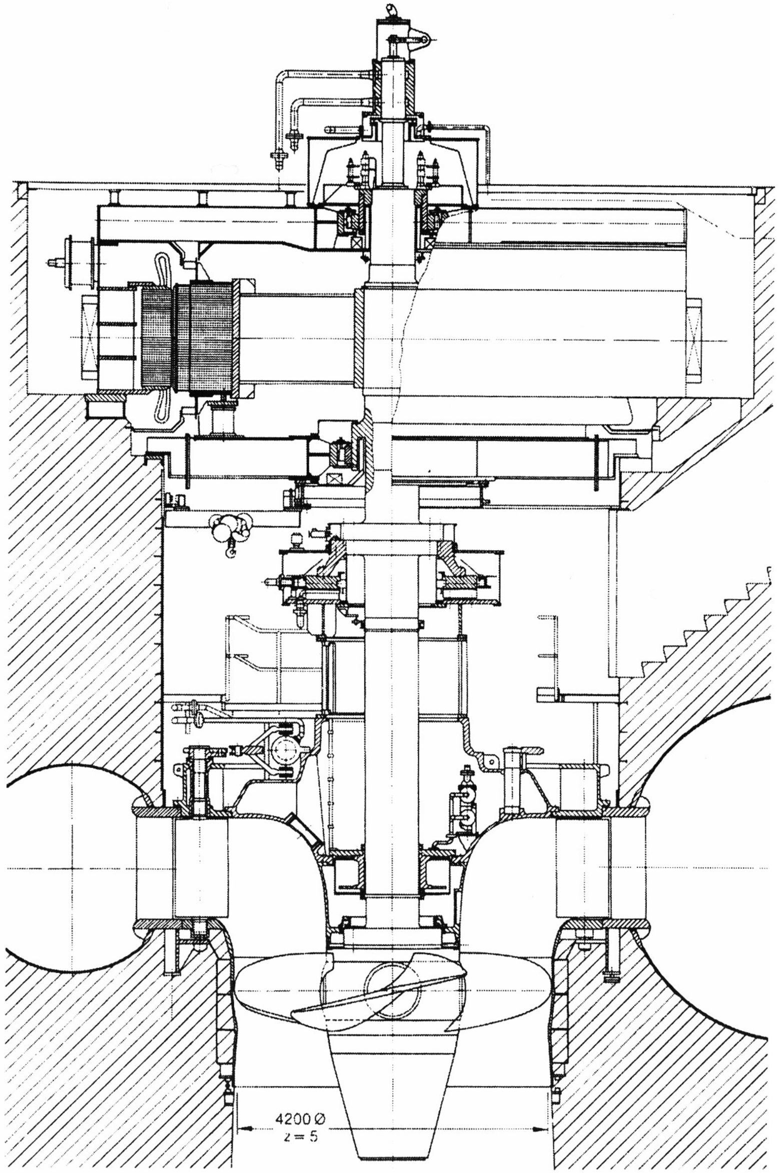
ω_s	2,3	2,5	3,0	3,5	4,0	4,6
σ^*	0,43	0,48	0,59	0,73	1,0	1,5

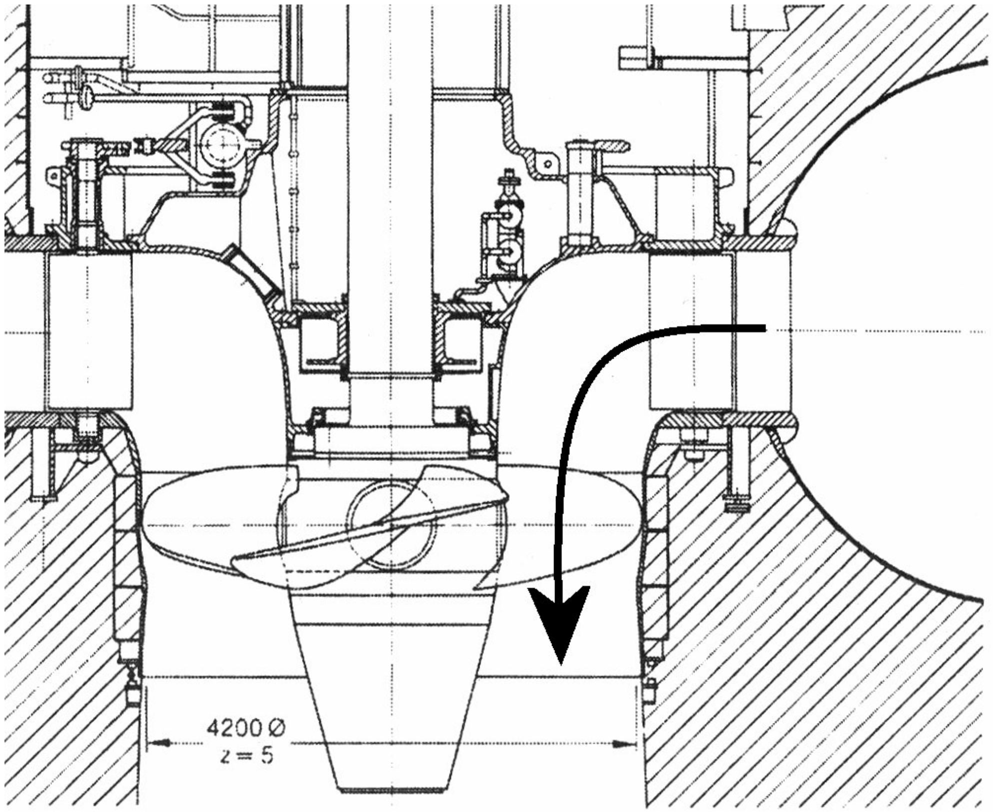
Turbina assiali

$$\omega_s = 1.7 - 6 \qquad D_s = 0.01 - 0.5$$

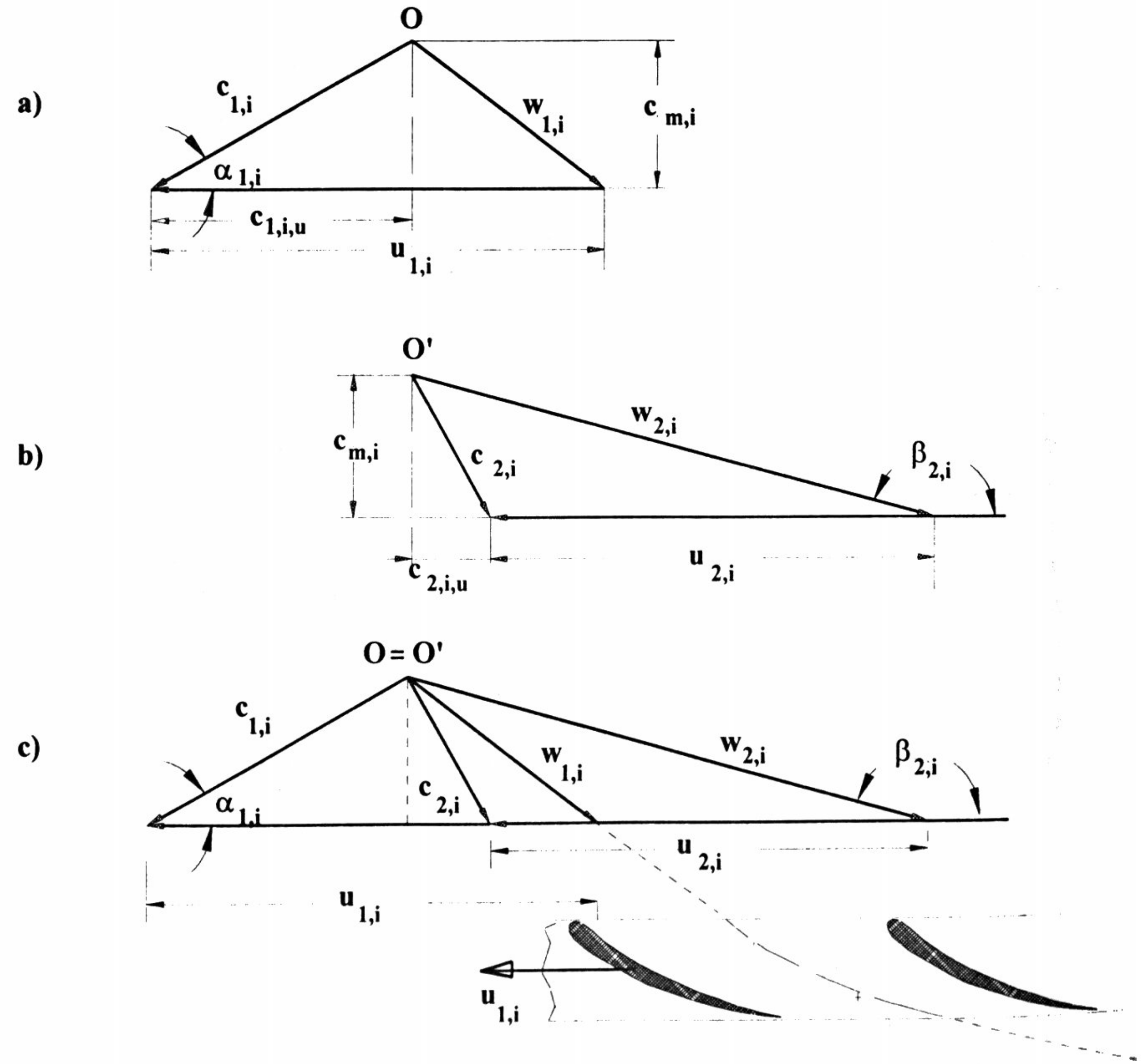


Turbina assiale

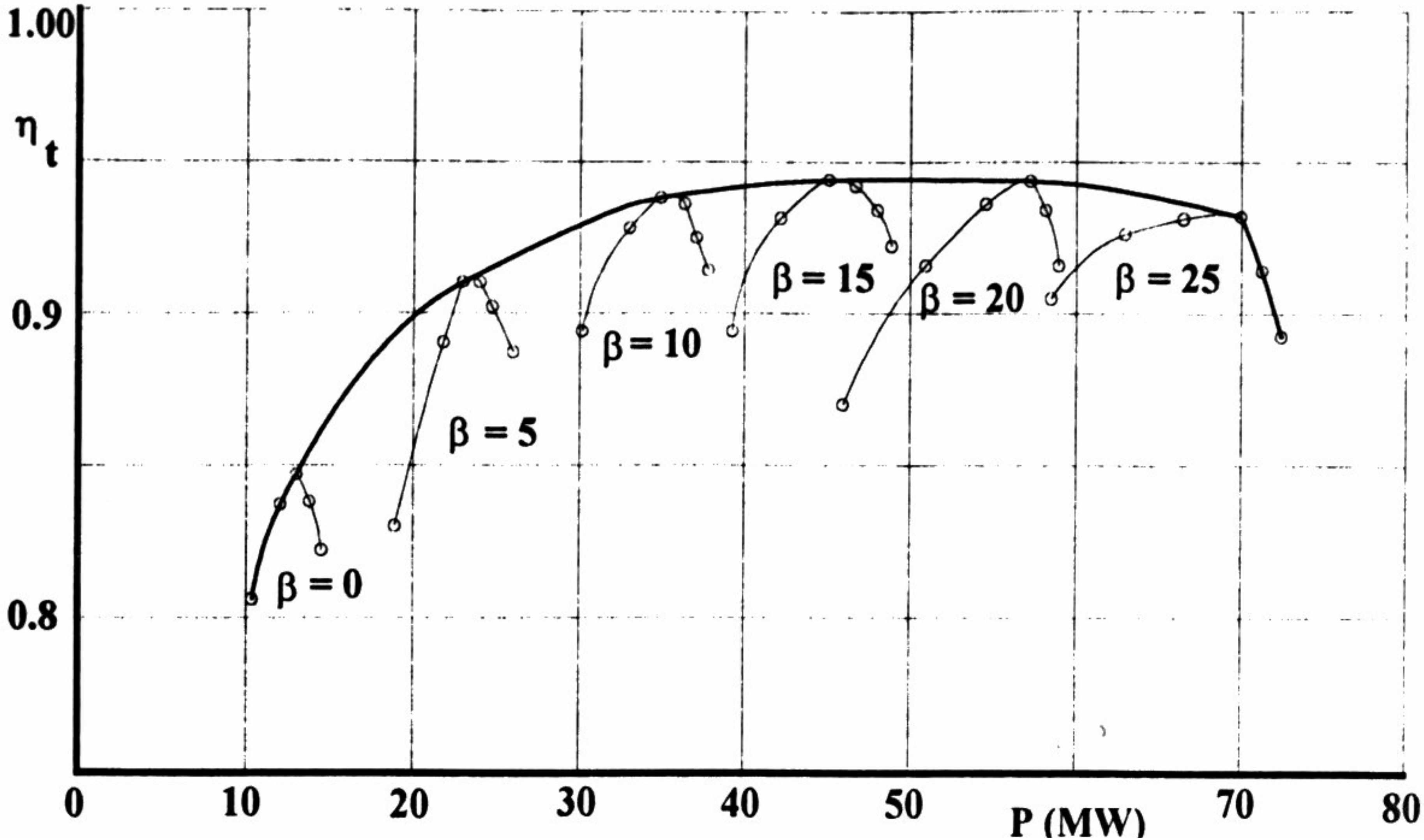




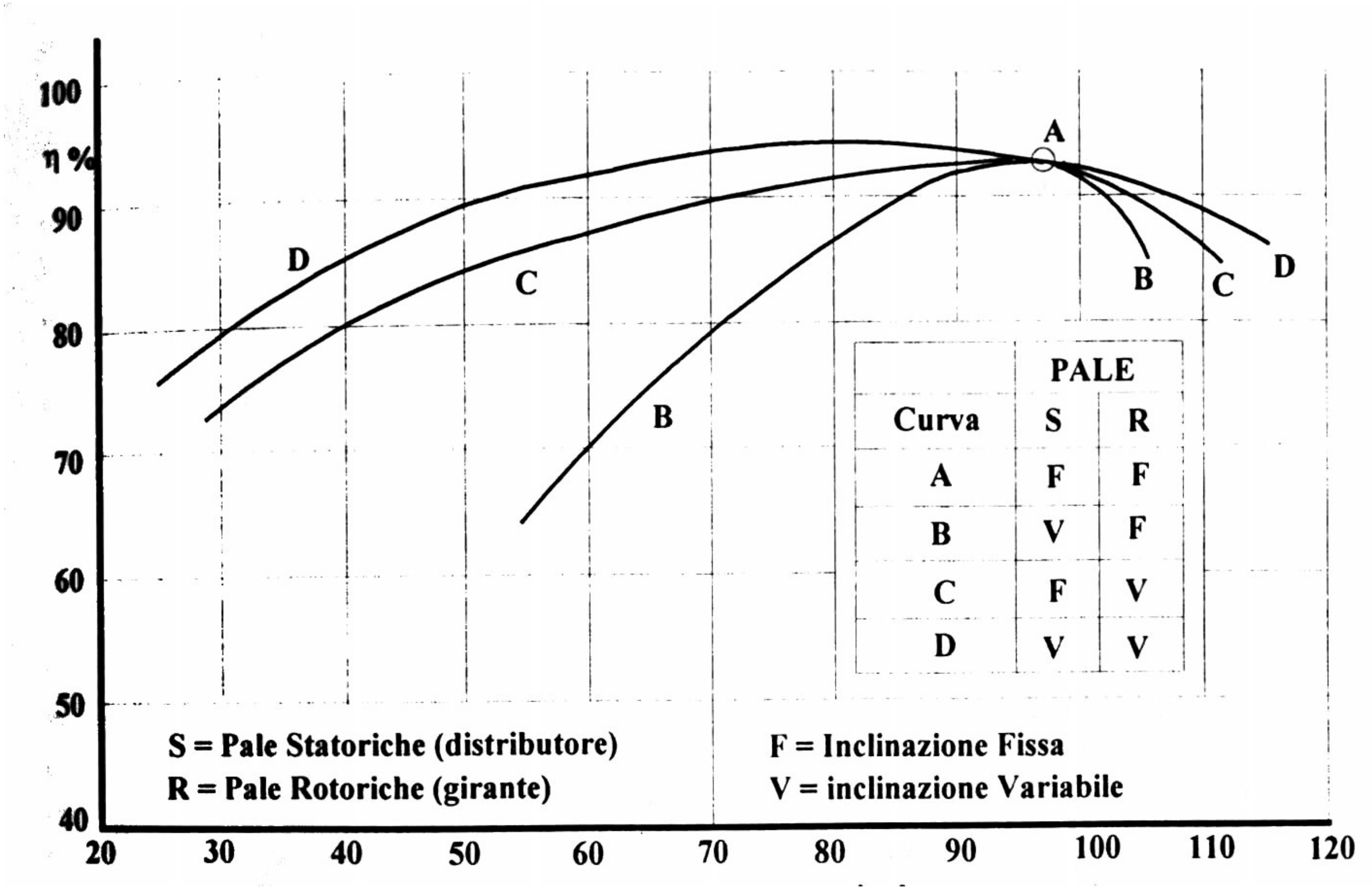
Turbina assiale



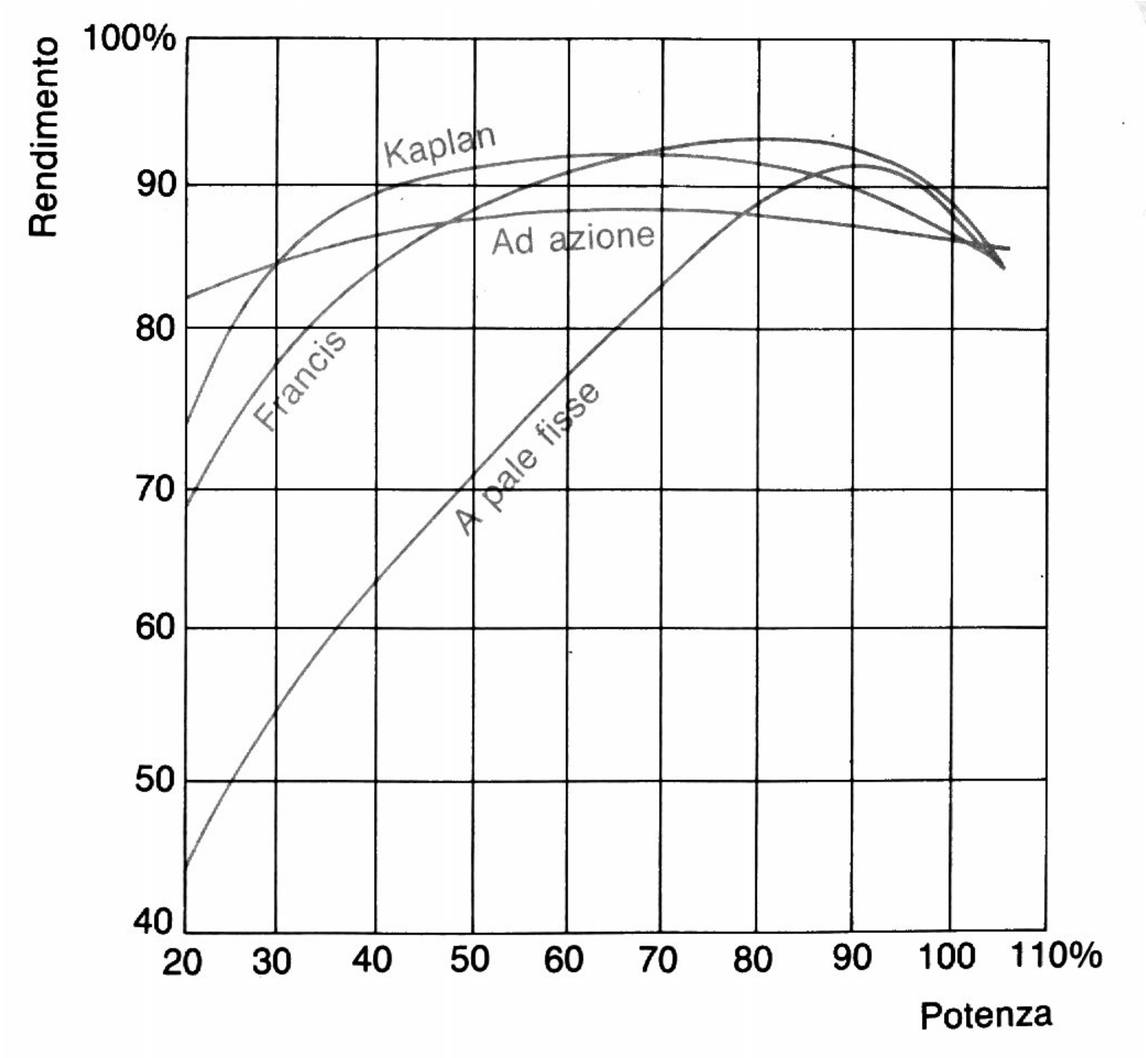
Turbina Kaplan



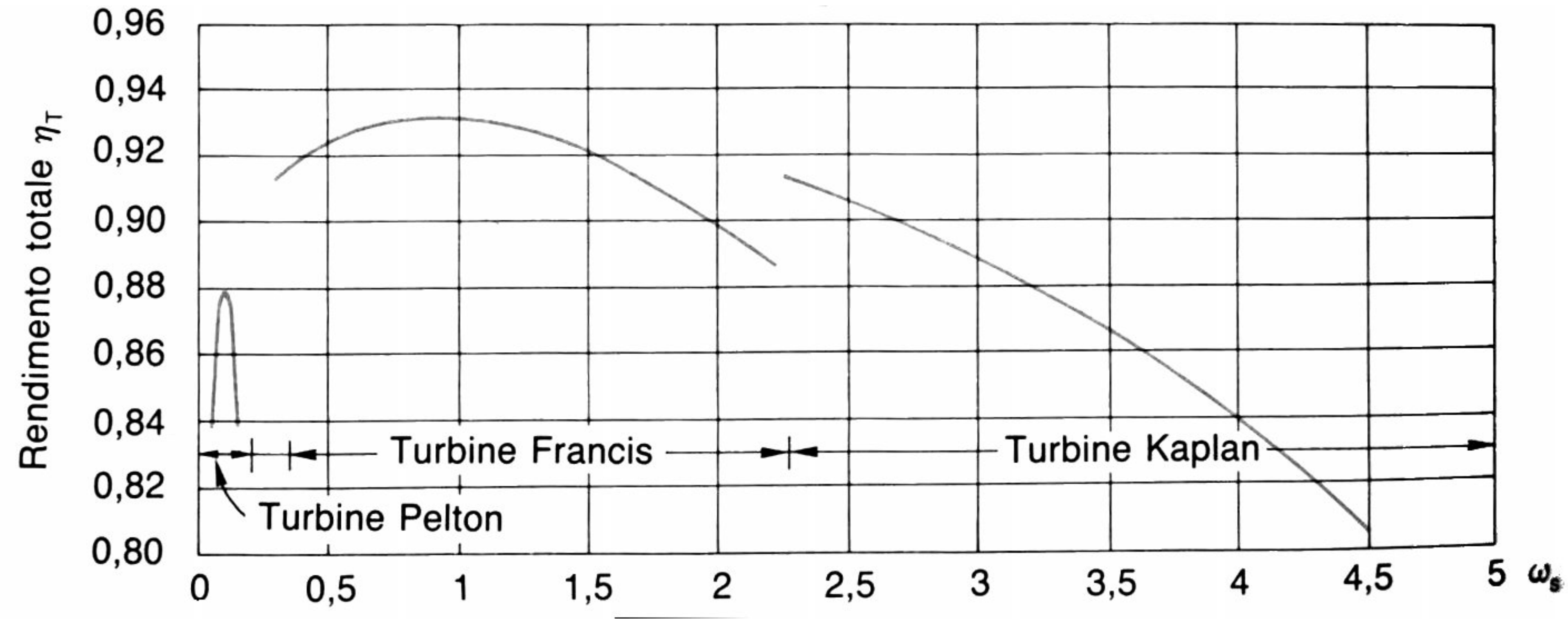
Turbina Kaplan



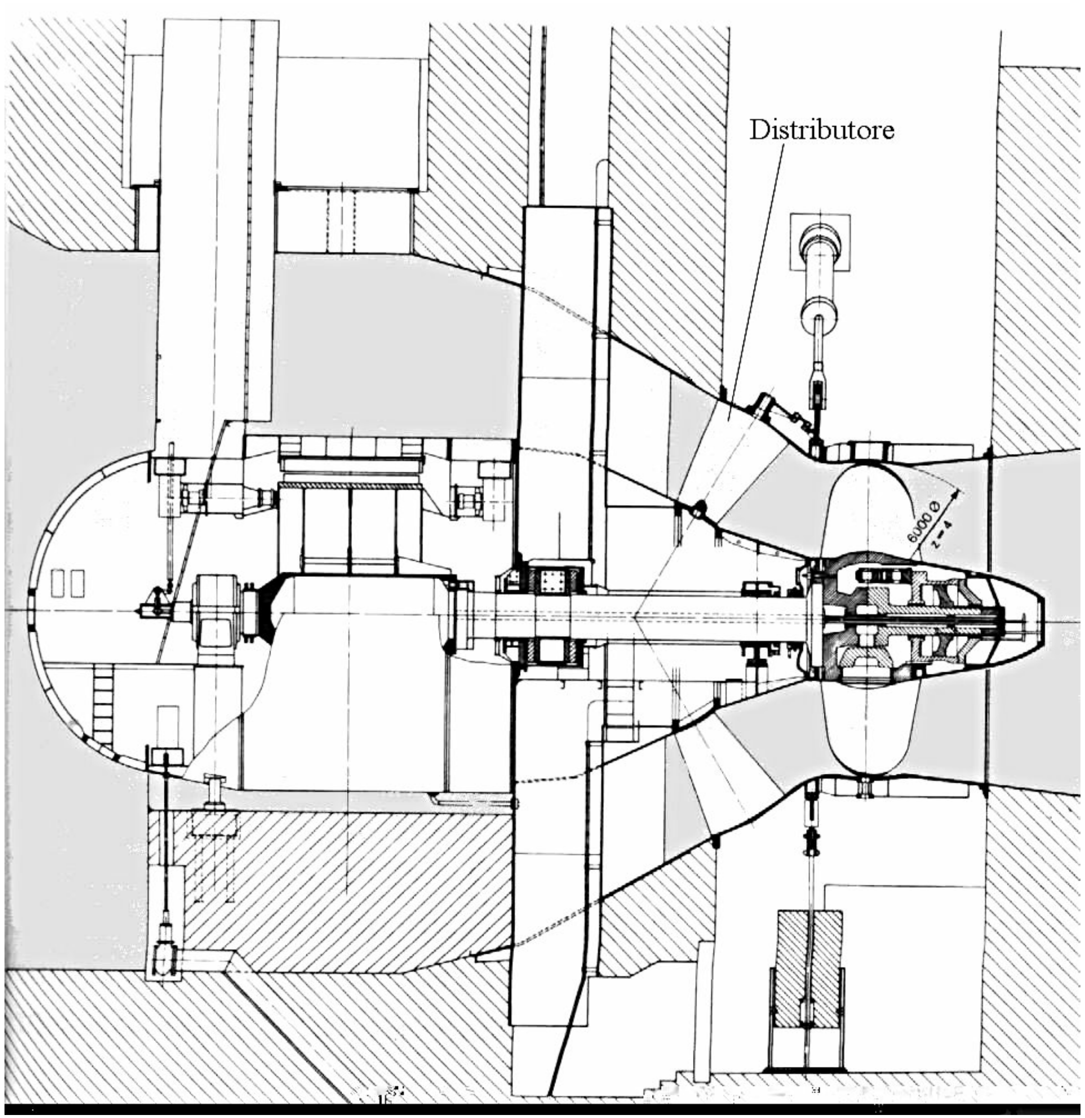
Confronto Turbine idrauliche



Confronto turbine idrauliche



Turbine a bulbo



Turbine a bulbo