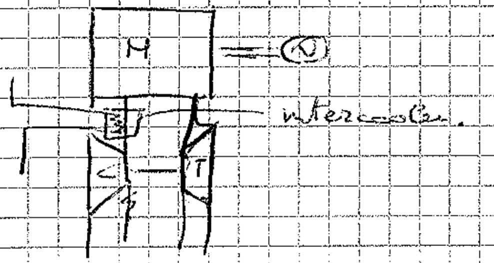
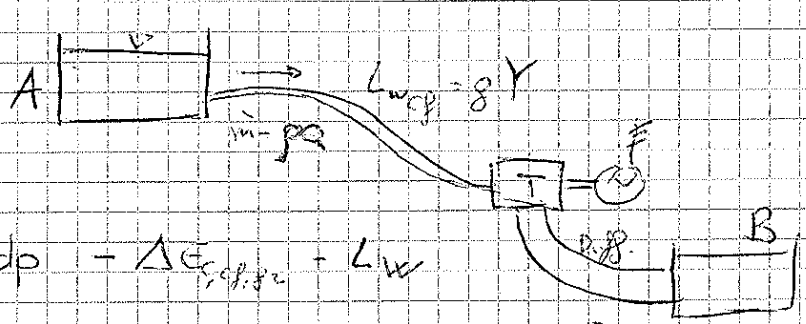


~~L'intercooler può essere fatto in più~~
In genere l'intercooler è il primo stadio di refrigerazione. Un secondo stadio viene fatto con un radiatore.

TURBINE IDRAULICHE



$$L_{i_{ott}} = -\int v\,dp - \Delta E_{c,ef,gz} + L_w$$

$$A-B] \quad L_{i_{ott}} = \frac{P_A - P_B}{\rho} + \frac{c_A^2 - c_B^2}{2} + g(z_A - z_B) - L_{w_{t,D}} - gY$$

$$L_{i_{ott}} = \underbrace{g\left(H_A^{\circ} - H_B^{\circ}\right)}_{H_d \text{ carico disponibile}} - L_{w_{t,D}} - gY$$

$H_d \simeq z_A - z_B = H_g \rightarrow$ caduta geodetica

$$L_{i_{ott}} = g\,\underbrace{(H_d - Y)}_{H_u \text{ caduta utilizzabile}} - L_{w_{t,D}}$$

$$\eta_y \hat{=} \frac{L_{i_{ott}}}{L_{i_{ott}} + L_{w_{t,D}}} = \frac{L_{i_{ott}}}{g H_u}$$

$$\eta_v = \frac{\dot m - \dot m_f}{\dot m} = \frac{\dot m_n}{\dot m}$$ $\dot m_n \rightarrow$ portata netta

$$\eta_o = \frac{P_u}{P_i} = \frac{P_i - P_m - P_{aux}}{P_i}$$

P_u: è potenza all'albero $= P_i - P_m - P_{Aux}$

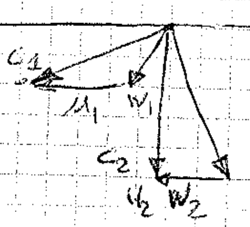
P_m: perdite meccaniche; P_{Aux}: perdite per ausiliari

$$\eta_g = \frac{P_{el}}{P_u}$$

$$P_u = \underbrace{\eta_o\,\eta_v\,\eta_y}_{\eta_t}\,\rho\,Q\,g\,H_u$$

Triangolo di Velocità

se $w_1 < w_2$ macchina a reazione



$$L_{i_{ott}} = u_1 c_{u1} - u_2 c_{u2}$$

se la macchina è motrice allora $c_{u1} > c_{u2}$ altrimenti è operatrice

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

Per queste macchine vale la similitudine fluidodinamica. Per le macchine idrauliche la similitudine è fondamentale!!!

Similitudine
- geometrica
- similitudine dei triangoli } simil. fluidodinamica

$$L_i = u_1 c_{u1} - u_2 c_{u2} = u_1^2 (\quad)$$

costante in similitudine

$$L_i \propto u_1^2 \propto D^2 n^2$$

$$Q = \xi \pi D^2 \frac{e}{D} \frac{c_{\perp A}}{u_1} u_1 \Rightarrow Q \propto D^3 n$$

$$P_u = \eta_t \rho Q g H \propto Q H \propto D^5 n^3$$

$\simeq$ cost

$$\eta_y = \frac{L_i}{g H_u}$$ in similitudine $L_i \propto H_u \propto D^2 n^2 \propto u_1^2$

Definiamo $n \propto \frac{\sqrt{H_u}}{D}$

$$\frac{n'}{n''} = \frac{D}{D'} \sqrt{\frac{H_u'}{H_u}}$$

definiamo n_s (numero di giri specifico) ($D' = 1\,m$ $H_u' = 1\,m$)

$$n_s = \frac{n D}{\sqrt{H_u}}$$

$$Q \propto D^2 u_1 \propto D^2 \sqrt{H_u}$$

$$Q' \propto D'^2 \sqrt{H_u'}$$

$$\frac{Q'}{Q} \propto \left(\frac{D'}{D}\right)^2 \sqrt{\frac{H_u'}{H_u}}$$

Definiamo Q_s portata specifica ($D' = 1\,m$ $\quad H_u' = 1\,m$)

$$Q_S = Q / (D^2 \sqrt{H_u})$$

Q_s e n_s sono parametri rappresentativi per tutte le macchine in similitudine.

$$\boxed{\frac{n'}{n} = \sqrt{\frac{Q}{Q'}} \left(\frac{H_u'}{H_u}\right)^{\frac{3}{4}}}$$

Se $Q' = 1\,\frac{m^3}{s}$ e $H_u' = 1\,m$ possiamo definire n_q (numero giri caratteristico)

$$n_q = n \sqrt{Q} \frac{1}{(H_u)^{3/4}}$$

Possiamo definire un altro numero di giri caratteristico

$$n_c = \frac{n \sqrt{P_u}}{H_u^{5/4}}$$

Esiste un altra definizione $n_{qE} = \dfrac{n \sqrt{Q}}{(g H_u)^{3/4}}$

n_c^* = è il parametro principale che ci consente di definire la macchina da utilizzare nel campo desiderato

max rendimento

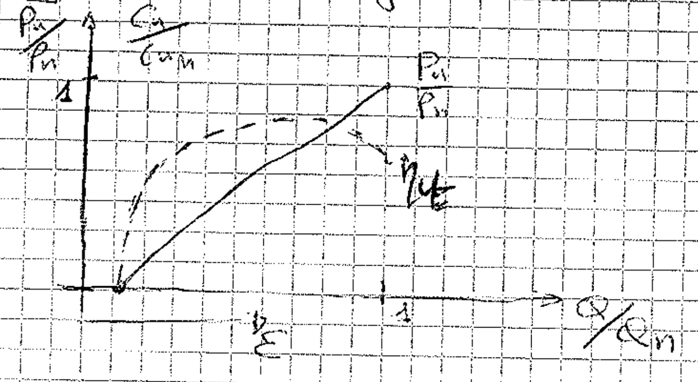
	n_c^*	$H_{u\,max}$
Pelton	5-60	1600-200
Francis lente	60-100	400
" normali	100-200	
" veloci	200-450	20
Elica - Kaplan	450-1000	40-4

$$n_c^* = \frac{n\,(rpm) \sqrt{P_u\,(CV)}}{(H_u^*\,[m])^{5/4}}$$

NOTA n_{qe} è fatto per non avere unità di misura se n [giri/s], Q [m^3/s] e H_u [m].

Caratteristiche delle turbine

1] Curva di regolazione



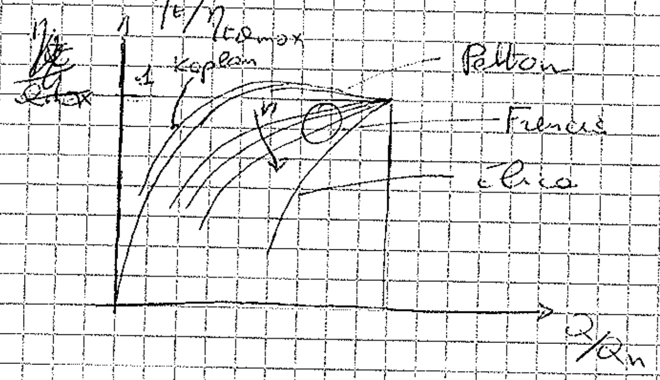
ε: apertura del sistema di regolazione

Non è detto che posizioni fisse di ε comportino una portata fissa

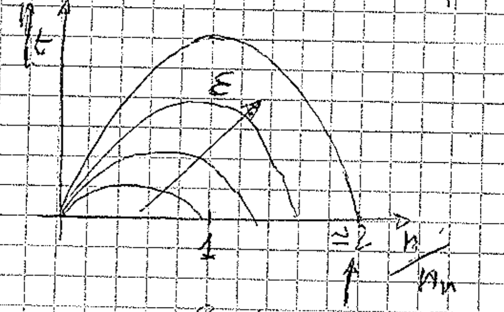
H_u = costante
n = costante

La potenza utile si annulla prima della portata perché ho bisogno di una certa portata per vincere gli attriti.

Andamento del rendimento per le varie macchine

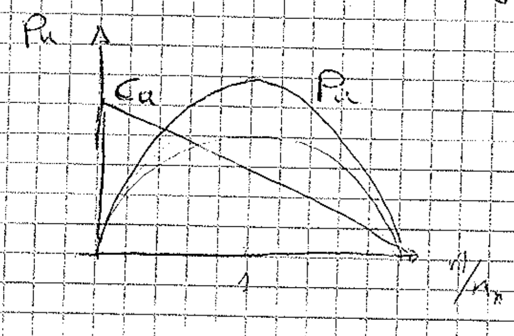


2] Caratteristica ad apertura costante (n variabile)



ε = cost
H_u = cost

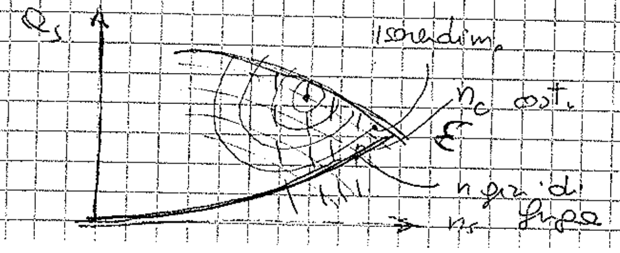
velocità di fuga



$P_u = \eta_t \rho Q g H_u$

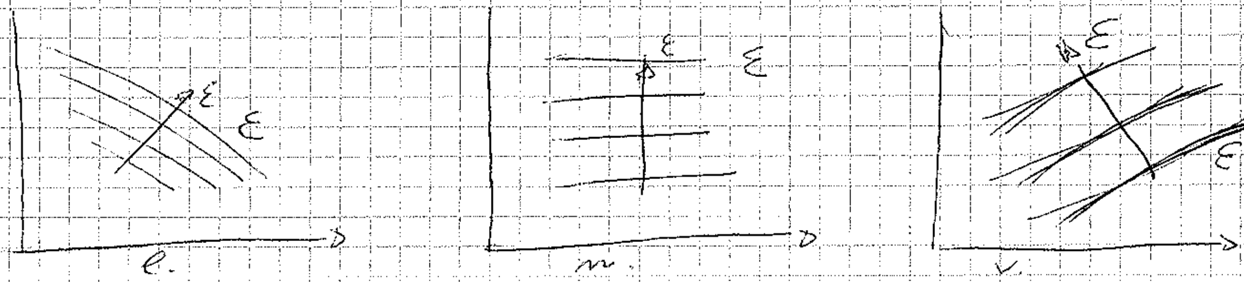
$C_u = \frac{P_u}{2\pi n}$

Diagramma collinare

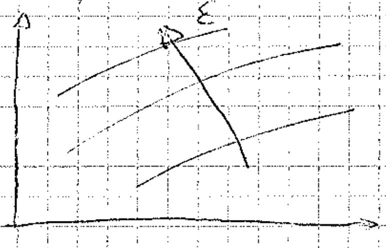


Se le macchine sono in similitudine fluidodinamica ho lo stesso diagramma collinare

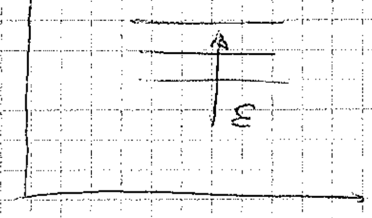
Francis



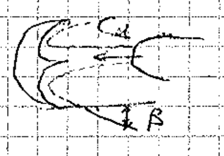
Kaplan

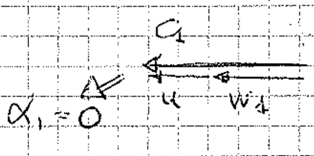


Pelton



Turbina Pelton

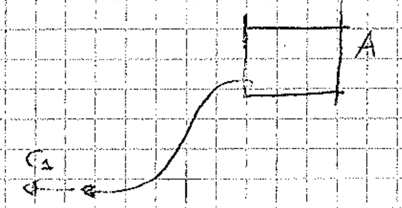




$p_1 = p_2$ aria

$u_1 = u_2 = u$

Calcoliamo la c_1



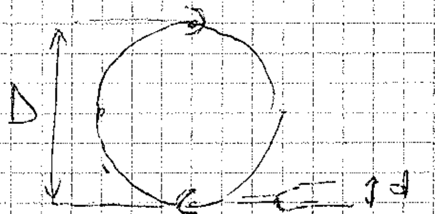
$p_A = p_{amb}$ $\quad p_1 = p_{amb}$

$z_A - z_1 = H_g$

$$0 = \frac{p_1 - p_A}{\rho} + \frac{c_{1id}^2}{2} + (z_1 - z_A)g + gY$$

$$c_{1id} = \sqrt{2g(H_g - Y)} = \sqrt{2g H_u}$$

$$\varphi = \frac{c_1}{c_{1id}} \Rightarrow c_1 = \varphi \sqrt{2g H_u}$$



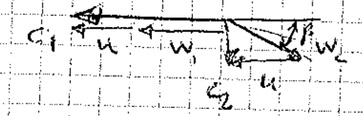
$u = \pi D n$

$w_1 = c_1 - u$

$$1\text{-}2_{id}] \quad 0 = \underbrace{\frac{p_1 - p_2}{\rho}}_{=0} + \frac{w_1^2 - w_{2id}^2}{2} + \cancel{g(z_1 - z_2)} + L_w$$

$w_1 = w_{2id}$

$$\psi = \frac{w_2}{w_{2id}} \Rightarrow w_2 = \psi\, w_{2id}$$



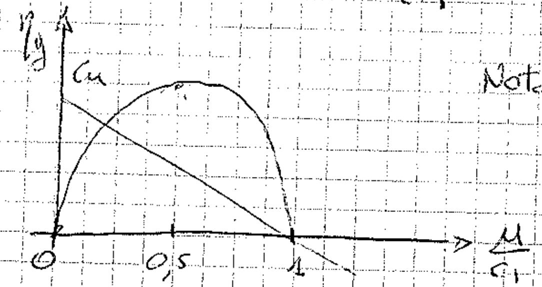
$$L_i = u\,(c_{u1} - c_{u2}) \qquad c_{u1} = c_1 \qquad c_{u2} = u - w_2\cos\beta$$

$$c_{u2} = u - \psi w_1 \cos\beta = u - \psi(c_1 - u)\cos\beta$$

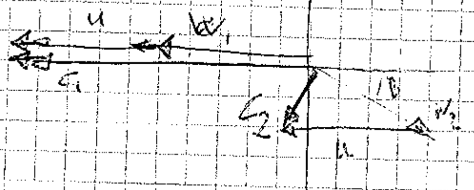
$$L_i = (1+\psi\cos\beta)\,u\,(c_1 - u)$$

$$\eta_y = \frac{L_i}{gH_u} \qquad gH_u = \frac{c_1^2}{2\varphi^2}$$

$$\eta_y = \frac{(1+\psi\cos\beta)\,u\,(c_1-u)}{c_1^2/2\varphi^2} = 2\varphi^2(1+\psi\cos\beta)\frac{u}{c_1}\left(1-\frac{u}{c_1}\right)$$



Nota: è una caratteristica ad apertura costante



situazione di max rendimento ($u = c_1/2$)

$$\omega = 2\pi n = \frac{2u}{D} \qquad C_u = \frac{P_u}{\omega} = \frac{\eta_v \dot m L_i}{2u/D} = \frac{\eta_v \dot m (1+\psi\cos\beta)\frac{u c_1}{c_1}\left(1-\frac{u}{c_1}\right)}{\cancel{2}u/D}$$

$$C_u = \eta_v \dot m (1+\psi\cos\beta)\left(1-\frac{u}{c_1}\right) c_1 \frac{D}{2}$$

Numero giri caratteristico: $n_c = \frac{n\sqrt{P_u}}{H_u^{5/4}} \propto \frac{n\sqrt{Q}}{H_u^{3/4}} \propto \frac{\frac{u}{D}\sqrt{Q}}{H_u^{3/4}}$

$n \propto \frac{u}{D}$ $\qquad Q = \zeta\frac{\pi d^2}{4} i c$ $\qquad i$: numero di getti ($1 \div 6$)

$$n_c \propto \frac{\frac{u}{D} d\sqrt{i c_1}}{H_u^{3/4}} \qquad H_u \propto c_1^2 \text{ infatti } c_1 = \varphi\sqrt{2gH_u}$$

$$n_c \propto \frac{\frac{u}{D} d\sqrt{i c_1}}{c_1^{3/2}} = \underbrace{\frac{u\, d\sqrt{i}}{c_1 D}}_{0,5 \text{ max rend}} = 0,5\frac{d}{D}\sqrt{i}$$

$$n_c \propto \frac{d}{D}\sqrt{i} \qquad i = 1 \div 6$$

$$\frac{1}{50} < \frac{d}{D} < \frac{1}{8}$$

$$n_c = 256 \frac{d}{D}\sqrt{i} \qquad n_c = 5 \div 60$$

Salto max elaborabile

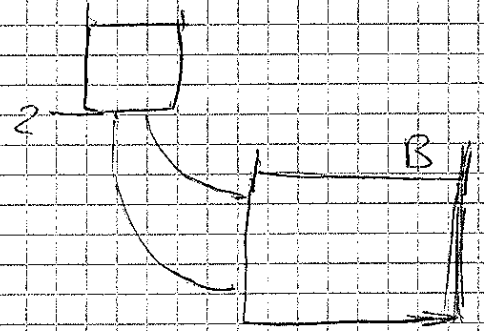
$$H_u = \frac{c_1^2}{2g\,\underbrace{\varphi_{1}^2}_{0{,}96}} \frac{u^2}{u^2} \qquad \frac{u}{c_1} = 0{,}5$$

$$H_u = \frac{1}{0{,}5^2}\frac{1}{2g}\frac{1}{0{,}96} \cdot u^2$$

limite sulla u dovuto alla σ ammissibile. Per queste macchine $u_{max} \cong 100$ m/s.

$$H_u \cong 2'000 \text{ m}$$

~~Esercizio~~ Cavitazione



$$\frac{p_2 - \Delta p}{\rho g} > \frac{p_v}{\rho g}$$

$$0 = \frac{p_2 - p_B}{\rho} + g(z_2 - z_B) - L_{wD} + \frac{c_2^2}{2} - \frac{c_B^2}{2}$$

$$\begin{cases} \dfrac{p_2}{\rho g} = \dfrac{p_B}{\rho g} - \dfrac{c_2^2}{2g} + (z_B - z_2) + \dfrac{L_{wD}}{g} + \dfrac{c_D^2}{2g} \\ \dfrac{\Delta p}{\rho g} = \lambda \dfrac{w_2^2}{2g} \end{cases}$$

$$\frac{p_{atm} - p_v}{\rho g} - (z_2 - z_B) \geq \underbrace{\frac{c_2^2}{2g} - \frac{\lambda w_2^2}{2g} - \frac{L_{wD}}{g} - \frac{c_D^2}{2g}}_{h_0 \text{ fornito dal costruttore}}$$

$$\sigma = \frac{h_0}{H_u}$$

Da valutazioni statistiche $\ln \sigma = 1{,}67 \cdot \ln n_c - 10{,}76$