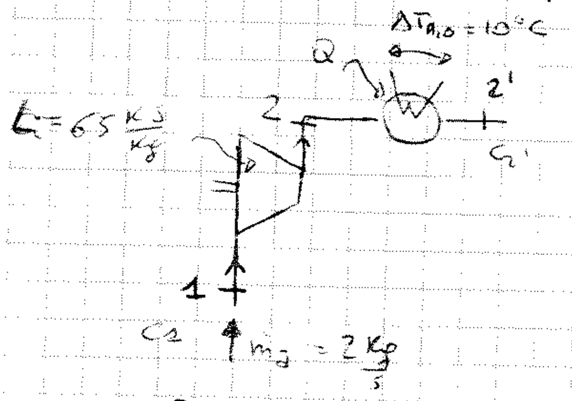
Esercitazione 1

21/03/2012

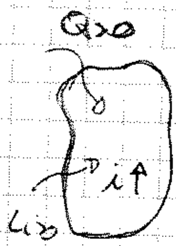
1) $\dot{m}_a = 2\ \text{Kg/s}$ $\quad T_1 = 288\ \text{K}$

comprime e poi scambiatore fino a $T_2' = 300\ \text{K}$



Sistema aperto da studiare con approccio euleriano

$$Q + L_i = \Delta i^* + \Delta E_c + \Delta E_g + \Delta E_{cg}$$



$$\Delta i^* \left\langle \begin{array}{l} \Delta i \\ \Delta i_{ch} \end{array} \right.$$ se si hanno reazioni chimiche nei sistemi

In questo caso non abbiamo reazioni chimiche

$$\Delta i_{ch} = 0 \qquad \Delta i^* = \Delta i$$

ΔE_g è trascurabile perché fluido è aria!!

ΔE_{cg} è ~~trascurabile~~ $= 0$ perché mi interessa solo ΔE_g tra 1 e 2'

ΔE_c è trascurabile perché non è il mio scopo variare la velocità dell'aria – suppongo quindi $c_1 = c_2'$

$$Q + L_i = \Delta i \Big|_1^{2'}$$ il lavoro è espresso riguardo kg di particella che passa

$$\Delta i = c_p \Delta T = c_p (T_{2'} - T_1)$$

$$Q = \Delta i - L_i = \left[1{,}005\,(300 - 288) - 65\right] \frac{\text{KJ}}{\text{Kg}} = \boxed{-52{,}9\ \frac{\text{KJ}}{\text{Kg}}}$$

$$c_{pa} = \frac{k}{k-1} R = 1{,}005\ \frac{\text{KJ}}{\text{Kg K}} \qquad k = 1{,}4 \quad R = 287\ \text{J/Kg K}$$

Per valutare T_2 devo cambiare volume di controllo

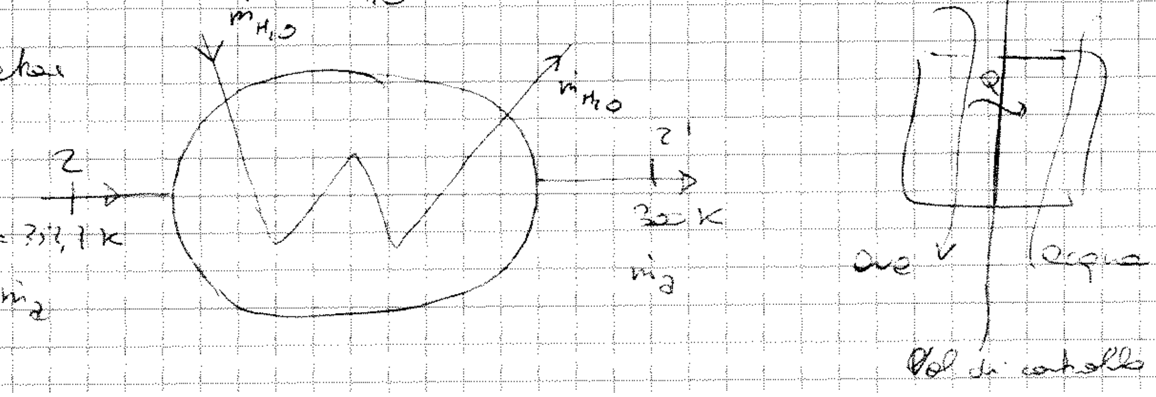
$$\Big/_1^2 \quad Q + L_i = \Delta i \Big|_1^2$$ Hp. la macchina è adiabatica $(Q = 0)$

$$L_i = \Delta i \Big|_1^2 \qquad \Delta i \Big|_1^2 = c_p (T_2 - T_1)$$

$l_i = c_p\,(T_L - T_2)$ $\qquad T_L = \dfrac{l_i + c_p T_1}{c_p} = 352{,}7\ K$

$\Delta T_{H_2O} = 10°C$

Refrigeratore



Q calcolato precedentemente è riferito all'~~acqua~~ aria

$\cancel{L_i} + Q_{H_2O} = \Delta i_{H_2O}$ $\qquad \dot m_a Q_a = \dot m_{H_2O}\, Q_{H_2O}$
$= 0$

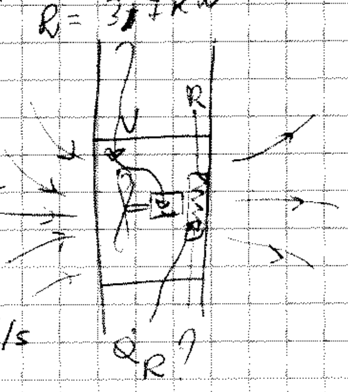
$\dot m_a Q_a = \Delta i_{H_2O}\, \dot m_{H_2O}$

$c_{p_{H_2O}}\, \Delta T\, \dot m_{H_2O} = \dot m_a Q_a \Rightarrow \dot m_{H_2O} = \dfrac{\dot m_a |Q_a|}{c_{p_{H_2O}} \Delta T} = 2{,}53\ \frac{Kg}{s}$

$4{,}1868$

Esercizio 2

$P_i = 3{,}7\,KW$



$p_e = 1\ bar$
$T_e = 5°C$
$\dot V_e = 1{,}5\ m^3/s$

$p_A = p_e = 1\ bar$
$T_A = 35°C$
$C_A = 0$

$\eta_M = 0{,}97$
$R_{aria} = 287\ \frac{J}{Kg\,K}$
$c_p = 1005\ \frac{J}{Kg\,K}$

$$Q + L_i = \Delta i \Big|_e^A + (\Delta E_c,\ \Delta E_g,\ \Delta E_{g})$$

$$Q_R = \Delta i \Big|_e^A - L_i \qquad \Delta i \Big|_e^A = c_{p_a}\,(\Delta T) = c_{p_A}\,(T_A - T_e)$$

$$P_i = \eta_M\, P_v = 0{,}97 \cdot 3{,}7 = 3{,}589\ KW$$

$$L_i = \frac{P_i}{\dot m_a}$$

$\dot m_a = \rho_E\, \dot V_E$ $\qquad \dfrac{P}{\rho} = RT$ $\qquad \rho_E = \dfrac{P_E}{R\,T_E} = \dfrac{10^5}{287 \cdot 278{,}15} = 1{,}253\ \frac{Kg}{m^3}$

$\dot m_a = 1{,}88\ \frac{Kg}{s}$

$$L_i = \frac{P_i}{\dot m_a} = \frac{3,535}{1,88} = 1,809 \ \frac{kJ}{kg}$$

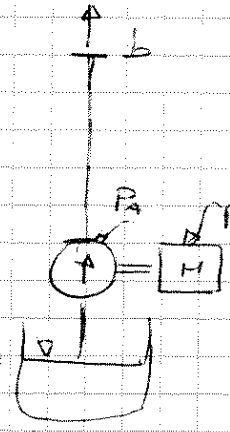
$$Q_R = c_p (T_A - T_E) - L_i = 1,005(35-5) - 1,809 = 28,241 \frac{kJ}{kg}$$

$$\dot Q_R = \dot m_a \, Q_R = 1,88 \cdot 28,241 = 53,1 \ kW$$

Esercitazione 2

22/03/2012

(1)



$z_b - z_a = 20 \ m$ $\quad d = 10 \ cm$ diametro condotto

$\eta_M = 0,87$ $\quad c_b = 2 \frac{m}{s}$

il sistema è aperto

$$Q + L_i = \Delta i + \Delta E_c + \Delta E_g + \underbrace{\cancel{\Delta E_{ch}}}_{=0}$$

$$\Delta E_g = g(z_b - z_A) \qquad \Delta E_c = \frac{c_b^2 - c_a^2}{2} \qquad c_a \simeq 0$$

$$L_i = \int_a^b v\,dp + L_w + \Delta E_c + \Delta E_g \qquad \int_a^b v\,dp = \int_a^b \frac{1}{\rho}\,dp = \frac{1}{\rho}\underbrace{(p_B - p_A)}_{=0}$$

perché $p_A = p_B = p_{atm}$

$$L_i = L_w + \Delta E_c + \Delta E_g = L_w + \frac{c_b^2}{2} + g\Delta z$$

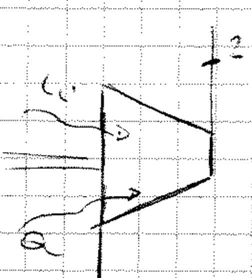
$$P_a = \frac{P_i}{\eta_m} = \frac{\dot m L_i}{\eta_m} \qquad \dot m = \rho_b A_b c_b = \rho \frac{\pi d^2}{4} c_b = 15,7 \frac{kg}{s}$$

Supponiamo che $L_w = 0$ $\quad L_i = 198,2 \frac{J}{kg} \Rightarrow P_a = 3,21 \ kW$

Supponiamo $L_w = 15\% L_i$ $\quad L_i (0,85) = \frac{c_b^2}{2} + g\Delta z \Rightarrow L_i = 233,2 \ J/kg$

$P_a = 3,77 \ kW$

(2)

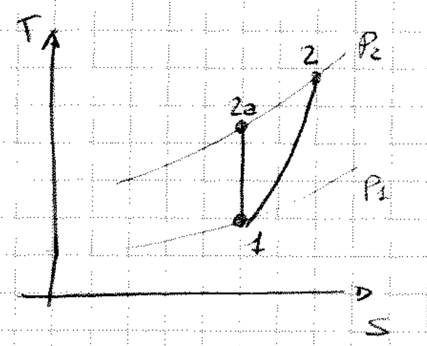


$T_1 = 17°C$ $\qquad P_2 = 200 \ kPa$

$P_1 = 100 \ kPa$

$\Delta E_c = 0$ $\qquad K = 1,4$ $\qquad c_p = 1004 \frac{J}{kg\,K}$

a) Ipotesi di trasformazione adiabatica reversibile



$$\frac{dT}{ds} = \frac{T}{c_p}$$

$$Q - L_i = \Delta i + \cancel{\Delta c} + \cancel{\Delta g z} + \cancel{\Delta c_g}$$

$$Q - L_i = c_p \Delta T$$

~~perdi trasf. adiabatica~~

Curva 1-2 è politropica con $m = 1,55$

~~L_i si ricava dalla~~

$$\frac{T_{2a}}{T_1} = \left(\frac{P_2}{P_1}\right)^{\frac{k-1}{k}} \qquad T_{2A} = T_1 \left(\frac{P_2}{P_1}\right)^{\frac{k-1}{k}} = 80,5\ °C$$

Poiché supponiamo trasf. adiabatica $Q = 0$ e quindi

$$L_i = c_p \Delta T = 63,8\ \frac{kJ}{kg}$$

b) Supponiamo trasf. adiabatica con attriti $(m = 1,55)$

$$\underbrace{\cancel{Q}}_{\substack{=0 \\ adiab}} + L_i = c_p \Delta T$$

$$T_{2b} = T_1 \left(\frac{P_2}{P_1}\right)^{\frac{m-1}{m}} = 370,9\ K \Rightarrow L_i = c_p \Delta T = 81,3\ \frac{kJ}{kg}$$

$$L_i = \int_1^{2b} v\,dp + L_w + \cancel{\Delta z} \Rightarrow \int_1^{2b} v\,dp = \frac{m}{m-1} R\,(T_{2b} - T_1)$$

$$\Downarrow$$

$$L_w = L_i - \frac{m}{m-1} R\,(T_{2b} - T_1) = 15,9\ \frac{kJ}{kg}$$

$$L_i = L_{is} + L_w + L_{CR} \Rightarrow L_{CR} = L_i - L_{is} - L_w = 1,6\ \frac{kJ}{kg}$$

$$\eta_{is} = \frac{L_{is}}{L_i} = 0,785 \qquad \eta_y = \frac{L_i - L_w}{L_i} = 0,804$$

$\eta_{is} < \eta_y$ compressori

$\eta_y < \eta_{is}$ turbine

c) refrigerazione senza attriti $(m = 1,28)$

In questo caso $s < 0$ $\quad Q < 0$ $\quad$ e $L_w = 0$

$$Q + L_i = c_p (T_{2c} - T_1)$$

$$T_{2c} = T_1 \left(\frac{P_2}{P_1}\right)^{\frac{m-1}{m}} = 64,5\ °C \qquad L_i = \int_1^{2c} v\,dp = \frac{m}{m-1} R\,(T_{2c} - T_1) = 63,3\ \frac{kJ}{kg}$$

$$Q = c_p (T_{2c} - T_1) - L_i = -14,6\ \frac{kJ}{kg}$$

CE

d) Raffreddamento ~~isoentropico~~ isotermo senza attriti

$Q + L_i = c_p\,(T_{2d} - T_1)$ $\qquad T_{2d} - T_1 = 0$

$Q = -L_i$

$L_i = \int_1^{2d} v\,dp = R\,T_1 \int_1^{2d} \frac{dp}{p} = R\,T_1 \ln\left(\frac{P_2}{P_1}\right) = 57,7\ \frac{kJ}{kg}$

$\Downarrow$

$Q = -57,7\ \frac{kJ}{kg}$

e) raffreddamento isotermo con attriti $L_w = 15,9\ kJ/kg$

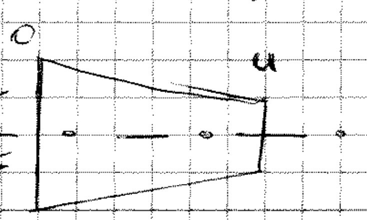
$T_{2d} = T_{2e} = T_1$

$Q = -L_i = -\int_1^{2e} v\,dp - L_w = -73,6\ \frac{kJ}{kg}$

Esercitazione 3

1) Ugello convergente, espansione isoentropica

2)



$P_0 = 5\ bar$

$T_0 = 150\ °C$

$c_0 \approx 0$

$P_2 = 2\ bar$ $\qquad P_2$ pressione nell'ambiente e nella nell'ugello

$\dot m = 3\ \frac{kg}{s}$ aria

$R = 287\ \frac{J}{kg\,K}$ $\qquad k = 1,4$

$\underbrace{\cancel{Q}}_{=0} + \underbrace{\cancel{L_i}}_{=0} = \Delta i + \Delta E_c + \underbrace{\Delta \cancel{E_g}}_{\approx 0} + \underbrace{\Delta \cancel{E_{g}}}_{\approx 0}$

supponendo sia adiabatico

$0 = \Delta i + \Delta E_c$

Dobbiamo valutare se siamo in condizioni critiche o meno.

$\frac{P_{u\,cr}}{P_0^\circ} = \left(\frac{T_{u\,cr}}{T_0^\circ}\right)^{\frac{k}{k-1}} = \left(\frac{2}{k+1}\right)^{\frac{k}{k-1}} = 0,528$

P_0° e T_0° sono le condizioni totali.

$P_0^\circ = P_0 \left(\frac{T_0^\circ}{T_0}\right)^{\frac{k}{k-1}} = P_0$

$T_0^\circ = T_0 + \frac{c_0^2}{2\,c_p} = T_0$

temperatura se fluido è fermo $\qquad c_0 \approx 0$

$\frac{T_{u\,cr}}{T_0^\circ} = \frac{2}{k+1} = \frac{2}{1,4+1}$

$\Downarrow$

$T_{u\,cr} = \frac{2}{k+1} \cdot T_0^\circ$

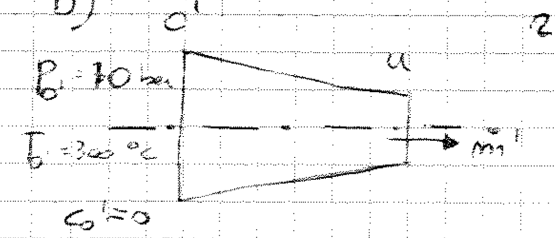
$$\frac{p_2}{p_0^\circ} = \frac{2}{5} = 0{,}4 < 0{,}528 \quad \text{siamo in condizioni critiche!!}$$

$$T_{u_{CR}} = \frac{2}{k+1} T_0^\circ = \frac{2}{2{,}4}(150+273) = 352{,}5\,K = 79{,}5\,°C$$

$$c_{u_{CR}} = \sqrt{k R T_{u_{CR}}} = \sqrt{1{,}4 \cdot 287 \cdot 352{,}5} = 376\ m/s$$

$$\dot m = \rho_{u_{CR}} \cdot c_{u_{CR}} \cdot S_u \qquad \rho_{cu} = \frac{p_{u_{CR}}}{R\,T_{u_{CR}}}$$

b)



$p_2' = 4$ bar

$$S_u' = S_u \qquad \frac{p_{u_{CR}}}{p_0^\circ} = f(k) = 0{,}528$$

$$\frac{p_{2_{CR}}'}{p_{0'}} = \frac{4}{10} = 0{,}4 < 0{,}528 \quad \text{condizioni critiche}$$

$$\dot m' = \rho_{u_{CR'}}\, c_{u_{CR'}} \cdot S_u$$

$$c_{u_{CR'}} = \sqrt{k R T_{u_{CR}}'} = \qquad \rho_{u_{CR'}} = \frac{p_{u_{CR'}}}{R\,T_{u_{CR}}'}$$

$$T_{u_{CR}}' = \frac{T_0'^\circ\, 2}{k+1} \qquad p_{u_{CR'}} = p_0^\circ \left(\frac{2}{k+1}\right)^{\frac{k}{k-1}}$$

$$\dot m_u' = \frac{p_{u_{CR}}'}{\sqrt{R\,T_{u_{CR}}'}} \cdot \sqrt{k \cancel{R T_{u_{CR}}}}\ S_u = \frac{p_{u_{CR}}'}{\sqrt{R\,T_{u_{CR}}'}} \sqrt{k}\ S_u =$$

$$= \frac{p_{0'}^\circ \left(\frac{2}{k+1}\right)^{\frac{k}{k-1}}}{\sqrt{R \cdot \frac{T_0'^\circ\, 2}{k+1}}} \sqrt{k}\ S_u = \frac{p_0^{\circ\prime}}{\sqrt{T_0^{\circ\prime}}}\ S_u\ \underbrace{f(k,R)}_{\text{tipo di gas}}$$

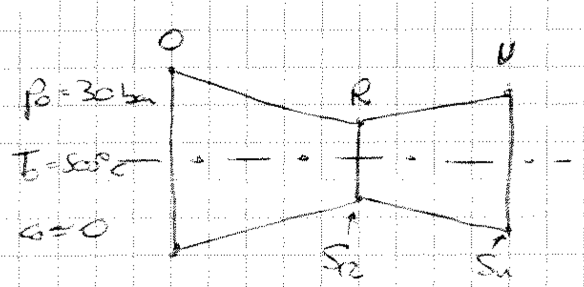
finchè l'ugello è critico la sua portata dipende solo dal rapporto $\frac{p_0^{\circ\prime}}{\sqrt{T_0^{\circ\prime}}}$

$$\dot m_u' = \frac{p_0^{\circ\prime}}{\sqrt{T_0^{\circ\prime}}}\ S_u\ f(k,R) \qquad \dot m_u' = \dot m_u \frac{p_0^{\circ\prime}}{p_0^\circ} \sqrt{\frac{T_0^\circ}{T_0^{\circ\prime}}}$$

$$\dot m_u = \frac{p_0^\circ}{\sqrt{T_0^\circ}}\ S_u\ f(k,R)$$

$$\dot m_u' = 3 \cdot \frac{10}{5} \sqrt{\frac{150+273}{300+273}} = 5{,}16\ \frac{kg}{s}$$

2) ugello convergente-divergente distributore di una turbina a vapore - Espansione isentropica

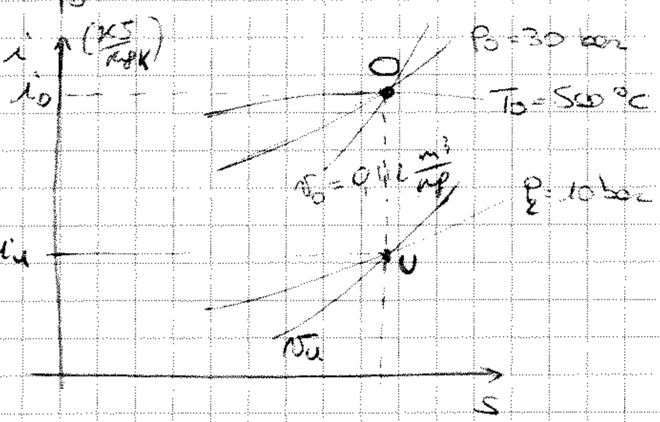


fluido vapore d'acqua

$$\left.\begin{array}{l} p_0^\circ = p_0 \\ T_0^\circ = T_0 \end{array}\right\} \rightarrow c_0 \simeq 0 \qquad \frac{P_2}{P_0} = \frac{10}{30} = 0,3\overline{3}$$

ipotesi $P_u = P_2$

$p_0 = 30$ bar $\quad T_0 = 500°C$



$i_0 = \cancel{3640}\ 3460 \ \frac{kJ}{kg}$

$i_u = 3120 \ \frac{kJ}{kg}$

$v_u = \frac{1}{\rho_u} = 0,260 \ \frac{m^3}{kg}$

$$0 = \Delta i + \Delta E_c$$

$$\Downarrow$$

$$0 = (i_u - i_0) + \frac{c_u^2 - c_0^2}{2}$$

$$\Downarrow$$

$$c_u = \sqrt{(i_0 - i_u) \cdot 2} = 824,6 \ m/s$$

$$\dot m = \rho_u c_u S_u \qquad S_u = \frac{\dot m}{\rho_u c_u} = \frac{\dot m v_u}{c_u} = 0,0011035 \ m^2$$

$$= 11,035 \ cm^2$$

So che R è tra O e U lungo l'espansione isentropica.

Possiamo fare della approx per valutare un kv.

$$p_0 v_0^{k_v} = p_u v_u^{k_v}$$

Kv è un k equivalente valido limitatamente all'espansione OU

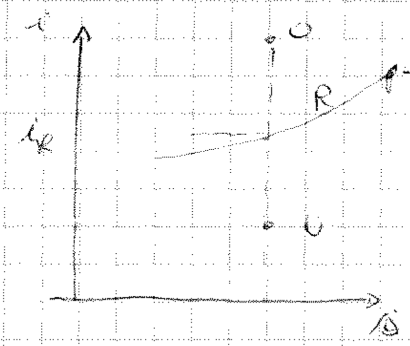
$$K_v = \frac{\ln\left(\frac{p_u}{p_0}\right)}{\ln\left(\frac{v_0}{v_u}\right)} = \frac{\ln\left(\frac{10}{30}\right)}{\ln\left(\frac{0,260}{0,112}\right)} \simeq 1,30$$

$$\frac{P_{R,cr}}{P_0} = \left(\frac{2}{1,3+1}\right)^{\frac{1}{1,3-1}} = 0,585 >> 0,585$$

molto prob. siamo in condizioni critiche

Quindi in R avremo sicuramente la pressione critica

$$P_R = P_{R_{cr}} = 0,585 \cdot P_0 = 17,55 \text{ bar}$$



$$i_R = 3280 \ \frac{kJ}{kg}$$

$$c_R = \sqrt{2(i_0 - i_R)} = 600 \ m/s$$

tra O e R $\quad 0 = \Delta i + \Delta E_c$

l'approx sta nel calcolo di i_R

se i_R è giusta allora c_R è corretto!!

Se avessimo scritto $c_R = \sqrt{k_v R_v \underbrace{T_{R_{cr}}}_{P_{R_{cr}} \cdot v_{R_{cr}}}} = \sqrt{1,3 \cdot 17,55 \cdot 10^5 \cdot 0,178} = 638,4 \ m/s$

sbagliato perché abbiamo considerato il vapore come un gas ideale!!!

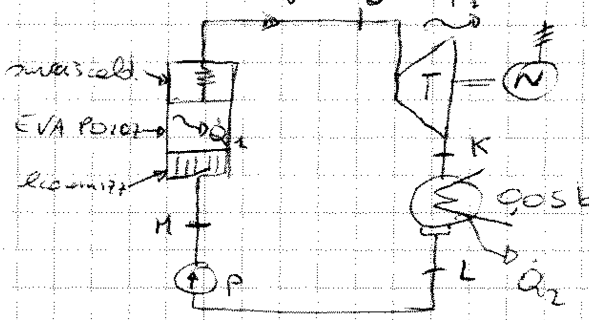
$$S_R = \frac{\cancel{3,5 \ kg/s} \ \dot{m}}{\rho_r \, c_r} \cong 10,4 \ cm^2$$

$\rho_r = \rho_u$

l'ipotesi è corretta perché ~~l'ugello~~ il vapore arriva in fondo all'ugello in condizioni di adattamento

ESERCITAZIONE 4

1) Impianto a vapore non rigenerativo e senza risurriscaldamento



$p_0 = 100$ bar $\quad T_0 = 550$ °C

$p_1 = p_K = 0,05$ bar

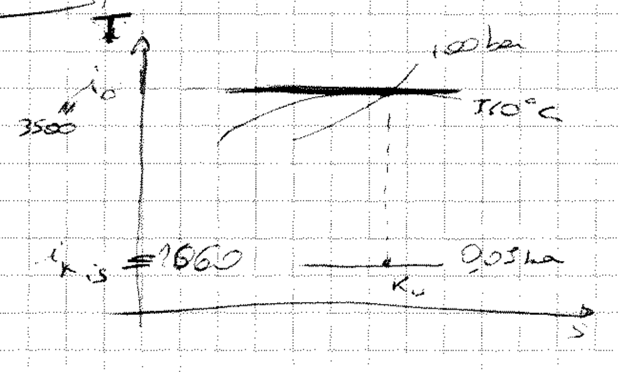
$\eta_{is} = 0,8 \qquad \eta_0 = 0,98$

$\boxed{\eta_u = ?}$

$$\eta_u = \frac{L_u}{Q_1} = \eta_0 \frac{L_i}{Q_1} = \eta_0 \, \eta_i$$

$$L_i = L_t - \underbrace{L_p}_{\cong 0} \cong L_t = i_0 - i_K$$

L_p trascurabile rispetto a L_t



$$L_t \simeq (i_0 - i_{K,is})\,\eta_{is} = 0{,}8\,(3500 - 2060) = 1152\ \frac{KJ}{Kg}$$

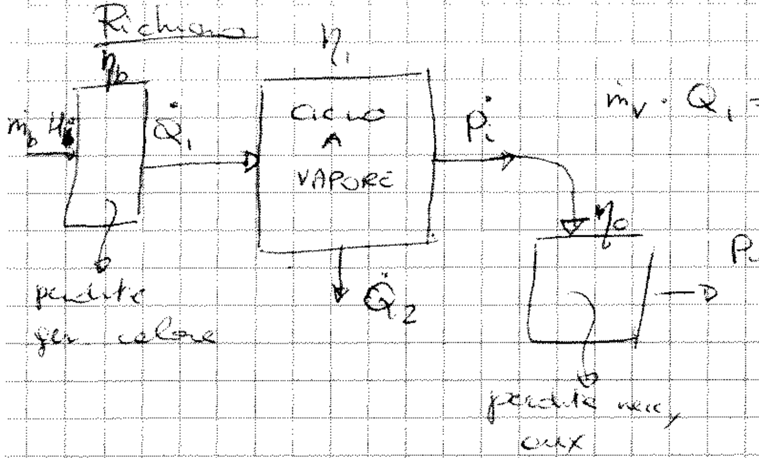
$$\begin{cases} L_p \simeq 0 \\ Q_1 = i_0 - i_M \end{cases} \Rightarrow \quad Q_1 \simeq i_0 - i_L = 3500 - 137{,}7 = 3362{,}3\ \frac{KJ}{Kg}$$

lo cerco su tabella di liquido-vapore saturo ($i_L = 137{,}7\ \frac{KJ}{Kg}$)

$$\eta_u = \eta_0 \frac{L_i}{Q_1} = \eta_0\,\eta_i = 0{,}98 \cdot 0{,}343 = \boxed{0{,}336 = \eta_u}$$

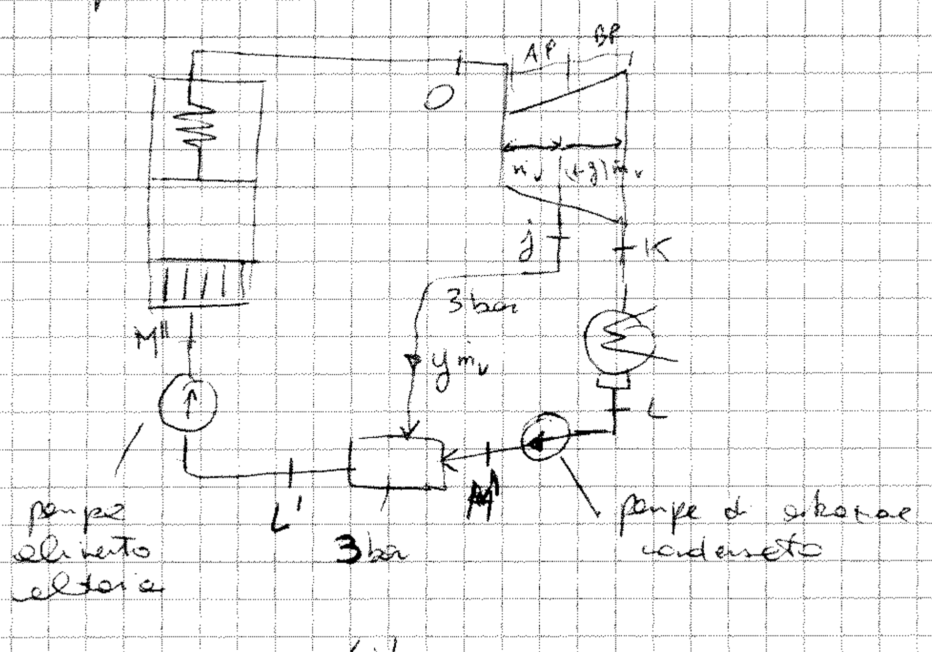
$$\eta_i = \frac{L_i}{Q_1} = \frac{1152}{3362{,}3} = 0{,}343$$

Richiamo



$$\dot m_v \cdot Q_1 = \dot Q_1 \qquad \eta_i = \frac{P_i}{\dot Q_1}$$

2) Con gli stessi dati calcolare η_u con ciclo rigenerativo e spillamento a 3 bar.

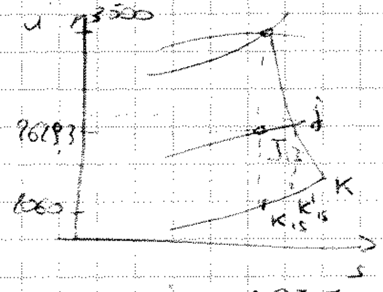


$$\eta_u' = \eta_o' \frac{L_i'}{Q_i'} \qquad \eta_o' \simeq \eta_o$$

$\dot m_v L_i'' = \dot m_v L_{i_{AP}} + \underline{(1-y)\dot m_v} L_{i_{BP}}$

$L_i' = L_{i_{AP}} + (1-y) L_{i_{BP}} = i_0 - i_j + (1-y)(i_j - i_k)$

$\underbrace{L_{i_{AP}}}_{i_0 - i_j} \qquad \underbrace{L_{i_{BP}}}_{i_j - i_k}$



$= \left(i_0 - i_{j_{is}} + (1-y)(i_j - i_{k'_{is}})\right)\eta_{is}$

$= \underbrace{0,80\,(3500 - 2629,3)}_{697,3\ \frac{kJ}{kg}} + (1-y)\underbrace{0,8\,(2802,7 - 2187,7)}_{482,1\ kJ/kg}$

$i_{K'_{is}} = 2187,7$

$i_j = i_0 - L_{i_{AP}} = 3500 - 697,3 = 2802,7\ kJ/kg$

$T_{M''}$: condizioni curve limite inferiore a 3 bar cioè 133,6 °C

bilancio allo scambiatore a miscela per trovare y

$y\,\dot m_v\, i_j + (1-y)\,\dot m_v\, i_{M'} = \dot m_v\, i_{L'}$

$i_{M'} \simeq i_L$ quindi

$i_{L'} \simeq i_{M''} \simeq i'$ (curve lim. inf. a 3 bar)

$$y = \frac{i'(\text{cli } 3\,bar) - i_L}{i_j - i_L} = \frac{561,6 - 137,3}{2802,7 - 137,3} = 0,16$$

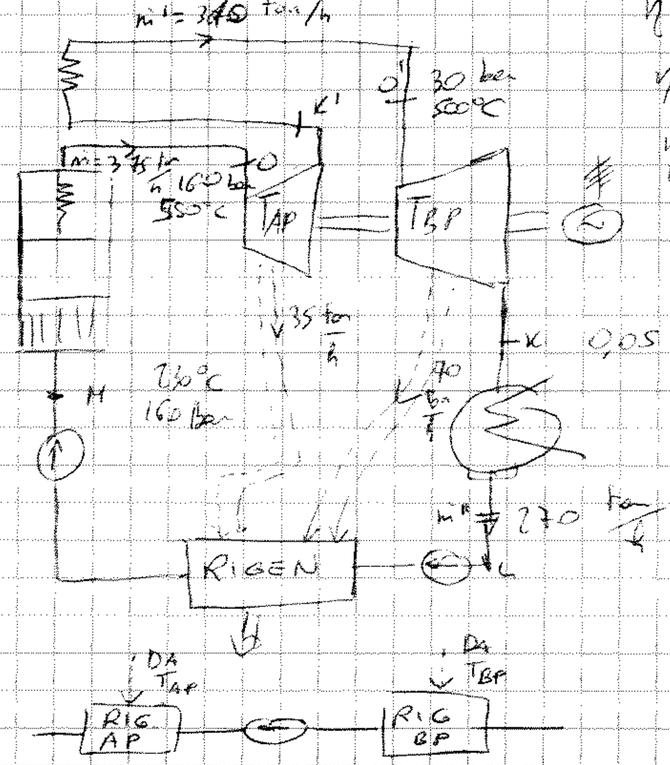
$L_i' = 697,3 + (1-0,16)\,482,1 = 1111,2\ \frac{kJ}{kg}$

$Q_1' = i_0 - i_{M''} = 3500 - 561,6 = 2938,4\ \frac{kJ}{kg}$

$\eta_u' = \eta_0 \frac{L_i'}{Q_1'} = 0,88\ \frac{1111,2}{2833,6} = 0,37$

ESERCITAZIONE 5

(1)



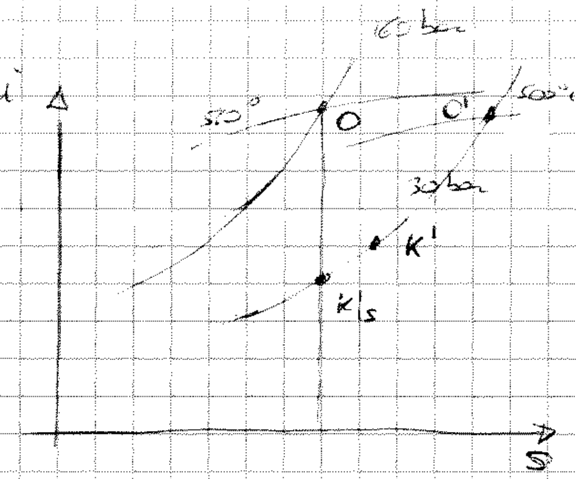
$\eta_{is} = 0,8$

$\eta_o = 0,97$

$\eta_b = 0,84$

$P_u = \eta_o P_i$

$P_i = \dot{Q}_1 - \dot{Q}_2$



$\dot{Q}_1 = \dot{m}\,(i_o - i_M) + \dot{m}'\,(i_{o'} - i_{k'})$

$\dot{Q}_2 = \dot{m}''\,(i_K - i_L)$

$i_o = 3438$ kJ/kg

$i_{k'_{is}} = 2960 \frac{kJ}{kg}$ $\qquad i_{k'} = i_o - \eta_{is} \cdot (i_o - i_{k'_{is}}) =$

$= 3438 - 0,8\,(3438 - 2960) = 3055,6 \frac{kJ}{kg}$

$i_{o'} = 3457 \frac{kJ}{kg}$

$i_M = \begin{pmatrix} cl_i \\ 230°C \end{pmatrix} = \cancel{2860}\ 991 \frac{kJ}{kg}$

$\dot{Q}_1 = \left[375 \frac{ton}{h} \left(3438 - \cancel{2860}\right) + 340 \frac{ton}{h} \left(3457 - 3055,6\right)\right] \frac{1}{3,6} =$

$991 \frac{kJ}{kg}$

$292,9$ MW

$i_K = i_{o'} - \eta_B\,(i_{k'} - i_{k_{is}}) = 2456$

$i_L = \left(\frac{cl_i}{0,05\,bar}\right) = 137,7$ kJ/kg

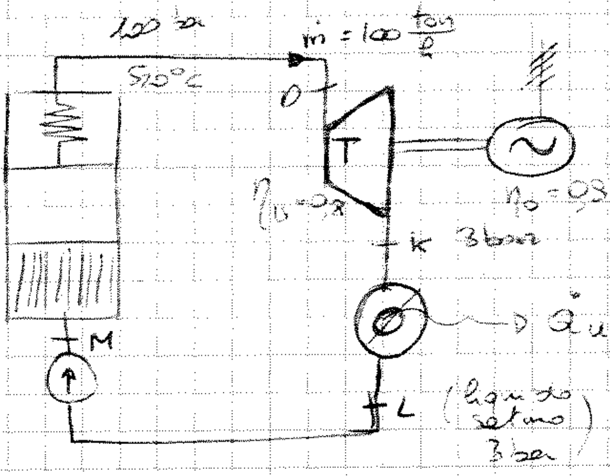
$\dot{Q}_2 = \frac{1}{3,6}\left(270\,(2456 - 137,7)\right) = 173,9$ MW

$P_u = \eta_o \cdot (\dot{Q}_1 - \dot{Q}_2) = 0,97\,(292,9 - 173,9) = 115,4$ MW

$$\eta_g = \eta_u \cdot \eta_b = \eta_b \frac{P_u}{Q_1} = 0{,}94 \frac{115{,}4}{291{,}9} = 0{,}370$$

2) impianti di cogenerazione e recupero totale.

a)



$$P_u = \eta_o P_i = \eta_o \dot m (i_0 - i_K) = \eta_o \eta_{is} \dot m (i_0 - i_{K_{is}})$$

$i_0 = 3425$ kJ/kg

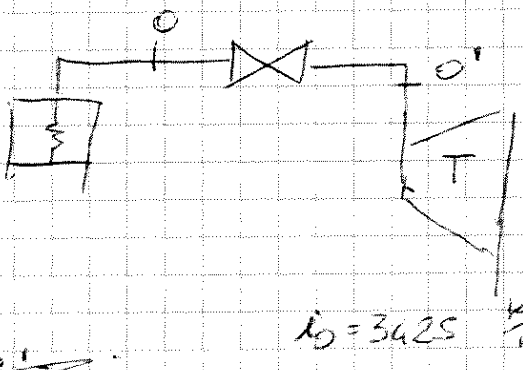
$i_{K_{is}} = 2591 \frac{kJ}{kg}$

$P_u = 17{,}98$ MW

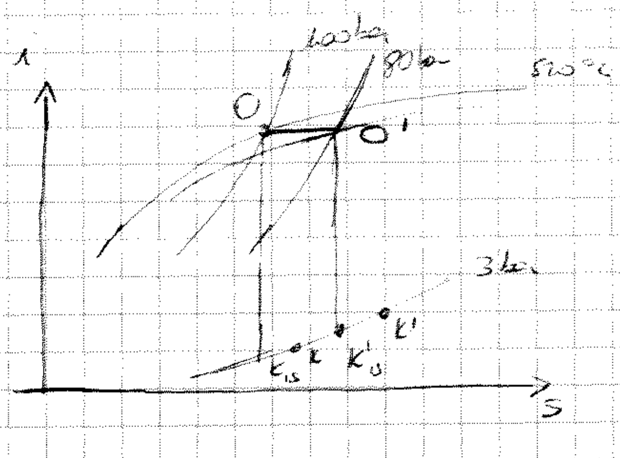
$$\eta_u = \eta_o \eta_i = \eta_o \frac{P_i}{Q_1} = \eta_o \frac{\eta_{is}(i_0 - i_{K_{is}})}{i_0 - i_M} = 0{,}97 \cdot 0{,}8 \frac{3425 - 2591}{3425 - 561{,}6} = 0{,}226$$

$i_M \simeq i_L \left(\begin{smallmatrix} l.s. \\ 3 bar \end{smallmatrix}\right) = 561{,}6 \frac{kJ}{kg}$

b)



lo scopo principale della valvola è regolare le richieste dell'utente



$i_0 = 3425 \frac{kJ}{kg}$

~~$\dot m' = \dot m$~~

$i_0' = 3425 \frac{kJ}{kg}$

$$\dot m' = \dot m \frac{\frac{p_0'}{p_0}}{\sqrt{\frac{T_0'}{T_0}} \simeq 1} = 100 \frac{80}{100} = 80 \frac{ton}{h}$$

$$P_u' = \eta_o \eta_{is} \dot m' (i_0' - \underbrace{i_{K'_{is}}}_{2630 \frac{kJ}{kg}}) = 13{,}71 \text{ MW} \qquad \eta_u = 0{,}215$$

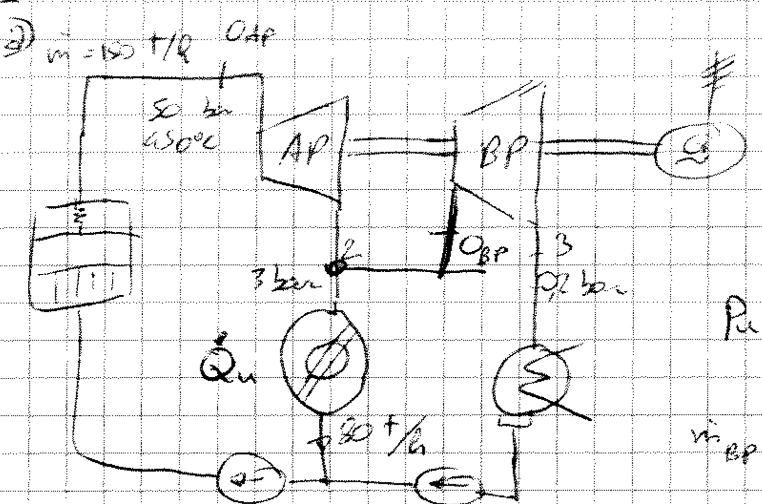
$$\dot m_b = \frac{P_u \cancel{\eta_b \eta_o \eta_{is}}}{\eta_b \eta_o \eta_{is} H_b} = \text{senza valvole } 7{,}25 \frac{kg}{s} = 8{,}09 \frac{t}{h}$$

$$\dot m_b' = \frac{P_u'}{\eta_b \eta_o \eta_{is} H_b} =$$

ESERCITAZIONE 6

1)

a) $\dot m = 150\ t/h$

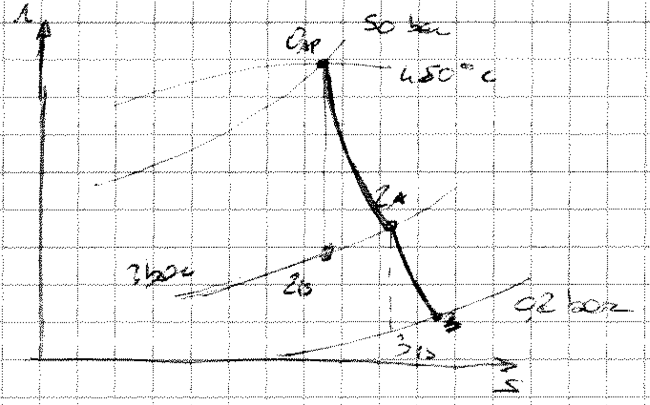


$\eta_o = 0{,}97$

$\eta_{AP} = \eta_{BP} = 0{,}8$

$$P_u = \eta_o P_i = \eta_o \left[\dot m_{AP} l_{i_{AP}} + \dot m_{BP} l_{i_{BP}}\right]$$

$$\dot m_{BP} = 150 - 80 = 70\ t/h$$



$$l_{i_{AP}} = \eta_{AP} (i_{0_{AP}} - i_{2is}) = 524{,}5\ kJ/kg$$

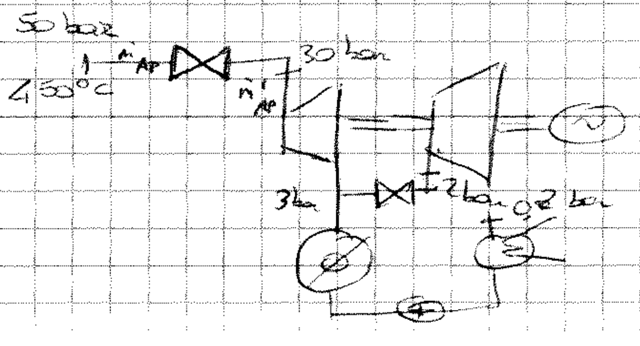
$$i_2 = i_{0_{AP}} - l_{i_{AP}} = 2786 \frac{kJ}{kg}$$

$$l_{i_{BP}} = \eta_{BP} (i_{0_{BP}} - i_{3is}) = 248{,}8 \frac{kJ}{kg}$$

$$i_3 \simeq 2350\ kJ/kg$$

$$P_u = \eta_o \left(\dot m_{AP} l_{i_{AP}} + \dot m_{BP} l_{i_{BP}}\right) = 27{,}76\ MW$$

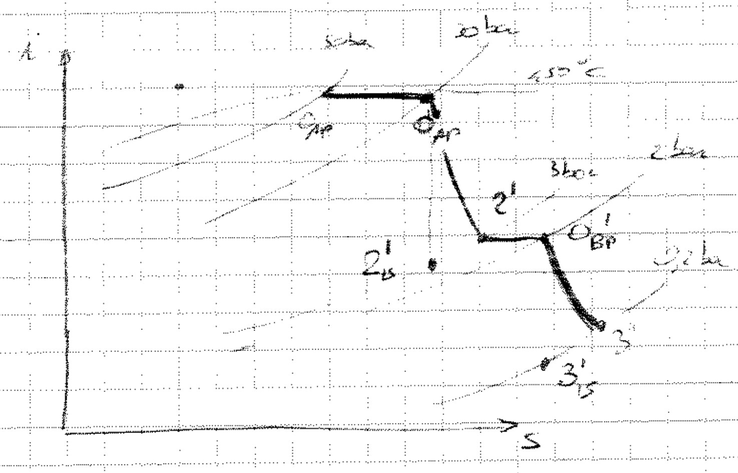
b) 2 valvole di laminazione



$$\dot{m}'_{AP} = \dot{m}^*_{AP} \frac{P'_{0_{AP}}}{P_{0_{AP}}} = 150 \, \frac{30}{50} = 90 \; t/h$$

$$\dot{m}'_{BP} = \dot{m}_{BP} \frac{P'_{0_{BP}}}{P_{0_{BP}}} = 70 \, \frac{2}{3} = 46{,}67 \; t/h$$

$$\dot{m}'_u = 43{,}33 \; t/h$$



$$l'_{i_{AP}} = \eta_{AP} \left(i_{0'_{AP}} - i_{2'_{is}} \right) = 428 \; \frac{kJ}{kg}$$

$$i_{2'} = 2882 \; \frac{kJ}{kg}$$

$$l'_{i_{BP}} = \eta_{BP} \left(i_{0'_{BP}} - i_{3'_{is}} \right) = 317{,}6 \; \frac{kJ}{kg}$$

$$i_{3'} = 2564{,}4 \; \frac{kJ}{kg}$$

$$P_u = \eta_0 \left(\dot{m}'_{AP} l'_{i_{AP}} + \dot{m}'_{BP} l'_{i_{BP}} \right) = 14{,}38 \; MW$$

$$\dot{Q}_u = \dot{m}_u \, \Delta i_u = \dot{m}_u \, (i_2 - i_j)$$

$$\dot{Q}'_u = \dot{m}'_u \, \Delta i'_u = \dot{m}'_u \, (i'_{2_{AP}} - i'_j)$$

Nota i_j è funzione della temperatura

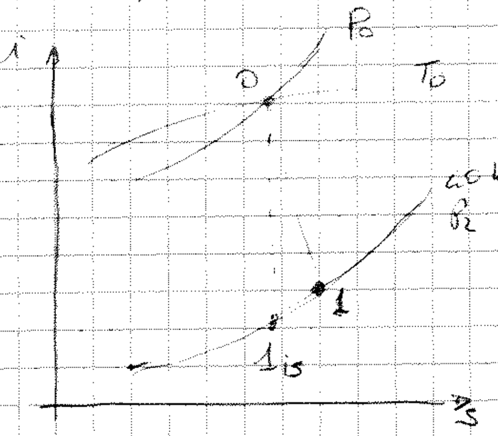
2) Analisi di uno stadio di turbina assiale ad azione semplice

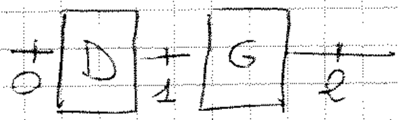
$\dot{m} = 150 \; \frac{kg}{s}$ $\quad p_0 = 80$ bar $\quad T_0 = 500°C$

$c_0 = 0$ $\quad p_1 = 40$ bar $\quad \alpha_1 = 30°$ $\quad \frac{u}{c} = \frac{1}{2} \cos \alpha_1$

palettatura metallica $\quad n = 3000$ rpm

$\varphi = 0{,}85$ $\quad \psi = 0{,}8$





Poiché macchina ad azione

$$p_1 = p_2$$

1° principio al distributore $\quad \cancel{Q} + l_i = \Delta i + \Delta E_c + \cancel{\Delta E_p} + \Delta \cancel{E_f} \quad \Delta i = -\Delta E_c$

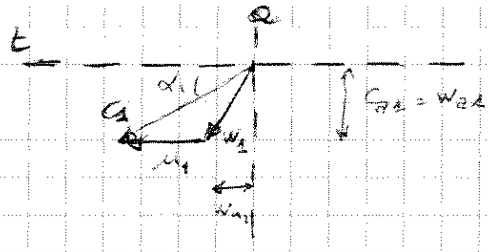
$\quad = 0 \quad = 0 \qquad = 0 \quad = 0$

Se esp. ... (ipotesi)

$$0 = \Delta i_{1s} - i_0 + \frac{c_{1s}^2 - c_0^2}{2} \Rightarrow i_0^0 = i_0 + \frac{c_0^2}{2} \simeq i_0$$

$$0 = i_{1s} - i_0^0 + \frac{c_{1s}^2}{2} \qquad c_{1s} = \sqrt{2(i_0 - i_{1s})} = 645 \ m/s$$

$$\varphi = \frac{c_{1r}}{c_{1s}} \Rightarrow c_1 = \varphi c_{1s} = 612,7 \ m/s$$



$$\frac{u}{c_1} = 0,5 \cos\alpha$$

$$u = \underbrace{\frac{c_1}{2}\cos\alpha_1}_{c_{u1}} = 265,3 \ m/s$$

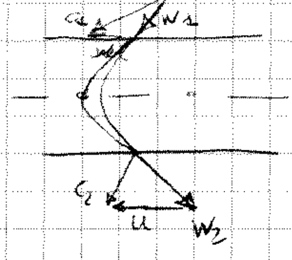
$$w_1 = \sqrt{w_{a1}^2 + w_{u1}^2} = 405,3 \ m/s$$

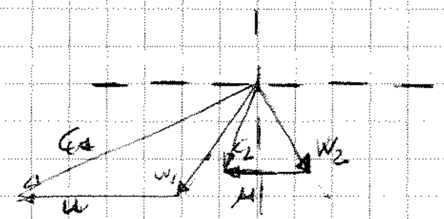
$$w_{a1} = c_{a1} = c_1 \sin\alpha_1 \qquad \beta_1 = \arcsin\left(\frac{w_{a1}}{w_1}\right) = 45,1^\circ$$

$$w_{u1} = c_{u1} - u$$

$$w_{2is} = w_1 \qquad w_2 = \varphi w_{2is} = \varphi w_1 = 364,8 \ m/s$$

Palettatura simmetrica

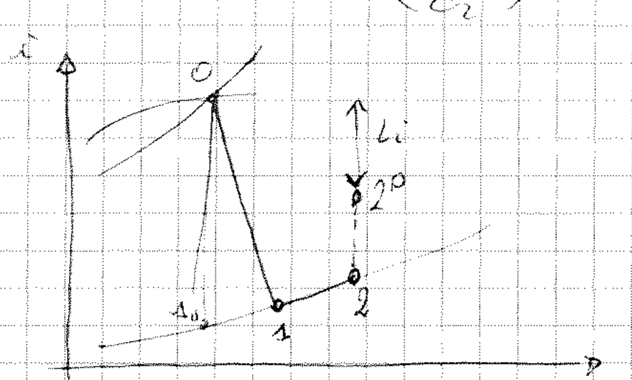




$$c_2 = \sqrt{c_{u2}^2 + c_{a2}^2} = 277 \ m/s$$

$$(w_{u2} - u_2)^2 \qquad w_{a2}^2$$

$$\alpha_2 = \arcsin\left(\frac{c_{a2}}{c_2}\right) = 86,5^\circ$$



intero stadio (D + G)

$$\underset{=0}{Q} + L_i = \Delta i + \Delta E_c$$

cambiamo segno a L_i perché vogliamo vederlo positivo fatto da turbina

$$L_i = -\Delta i - \Delta E_c =$$

$$= i_0 - i_2 + \frac{c_0^2 - c_2^2}{2} = i_0^0 - i_2 - \frac{c_2^2}{2}$$

$$L_i = (c_{u1} - c_{u2})\, u = 133,7 \ \frac{kJ}{kg}$$

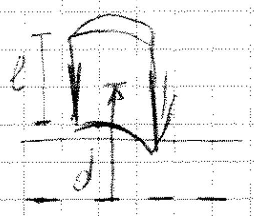
$$i_1 = l_i + i_0^0 + \frac{c_1^2}{2} = 3212 \ \frac{KJ}{Kg}$$

$$i_2 = i_1 + \frac{w_2^2}{2}\left(\frac{1}{\psi^2} - 1\right) = 3228 \ \frac{KJ}{Kg}$$

$$\eta_i = \frac{l_i}{i_0^0 - i_{1s}} = \frac{133{,}7 \cdot \frac{1000}{1000}}{\frac{612{,}7}{1095}} = 0{,}663$$

LUNGHEZZA SPIGOLO DI INGRESSO

$l \geq 10$ mm $\quad \frac{l}{d} \geq 0{,}01$



$$u = \pi d n = \frac{1}{2} c_{u1} = 265{,}3$$

$$d = \frac{265{,}3}{\pi \frac{3000}{60}} = 1{,}69 \ m$$

n va espresso in giri/secondo

$$v_1 = 0{,}070 \ \frac{m^3}{Kg}$$

$$\dot{m} = \frac{1}{v_1} \pi l d \underbrace{c_1 \sin\alpha_1}_{c_{a1}} \xi \quad , \quad \xi \text{ non ci è stato dato e quindi } \simeq 1$$

$$l = \frac{\dot{m}\, v_1}{\pi d \, c_1 \sin\alpha_1 \, \xi} = 6{,}8 \ mm$$

trovo il grado di parzializzazione per avere $l \geq 10$mm

$$\dot{m} = \frac{1}{v_1} \pi l d (1-\varepsilon) c_1 \sin\alpha_1 \quad \text{fissiamo } l = 10 \ mm$$

$$\varepsilon = 0{,}32$$

ma $\frac{l}{d} < 0{,}01$ $\quad$ voglio $l \geq 16{,}9$ mm

ne segue che $1 - \varepsilon = 0{,}4 \rightarrow \varepsilon = 0{,}6$

Bisogna parzializzare il 60% del passaggio

20/4/12 ESERCITAZIONE

1) Girante turbina assiale reazione (P_a, c, p_i)

aria $\begin{cases} k = 1{,}4 \\ R = 287 \frac{J}{kg\,K} \end{cases}$ $m = 1{,}35$ $p_1 = 10\,bar$ $T_1 = 750\,°C$

$c_1 = 450\ m/s$ $\alpha_1 = 20°$ $p_2 = 7\,bar$ $\ell_1 = \ell_2 = 25\,cm$ $\varphi = 0{,}95$

$n = 3000\ rpm$ $u = 300$

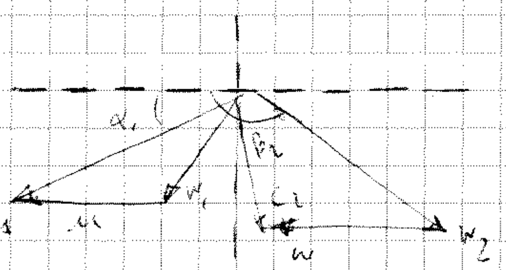
$P_i = L_i\,\dot m$ $\dot m = \rho_1\,\xi\,(\pi d \ell)\,c_1 \sin\alpha_1$

$$\rho_1 = \frac{p_1}{RT_1} = \frac{10 \cdot 10^5}{287\,(273+750)} = 3{,}41\ \frac{kg}{m^3}$$

$$d = \frac{u}{\pi n} = \frac{300}{\pi \frac{3000}{60}} = 1{,}91\ m$$

$$\dot m = 747\ \frac{kg}{s}$$

$$L_i = c_p\,(T_0 - T_2) = u\,(c_{u1} - c_{u2})$$



$$w_1 = \sqrt{(c_1 \cos\alpha_1 - u)^2 + (c_1 \sin\alpha_1)^2} = 180{,}5\ m/s$$

$$\beta_1 = \arcsin\left(\frac{c_{a1}}{w_1}\right) = 54{,}6°$$

Applichiamo il 1° principio in moto relativo con la girante.

$$0 = \Delta i + \Delta E_c + \dots$$

$$0 = c_p\,(T_2 - T_1) + \frac{w_2^2 - w_1^2}{2} \Rightarrow w_2 = 469{,}4\ m/s$$

$$T_2 = T_1 \left(\frac{p_2}{p_1}\right)^{\frac{m-1}{m}} = 937{,}6\ K$$

$$\dot m \propto \rho\, c_a \propto \rho\, w_a \Rightarrow \rho_1 c_{a1} = \rho_2 c_{a2}$$

$$w_{a2} = c_{a1} \frac{\rho_1}{\rho_2} = c_{a1} \left(\frac{p_1}{p_2}\right)^{\frac{1}{m}} = 200{,}5\ m/s$$

$$\beta_2 = \arcsin \frac{w_{a2}}{w_2} = 154{,}7°$$

$c_2 = \sqrt{(w_2 \cos\beta_2 + u_2)^2 + (w_2 \sin(\beta_2))^2} = 735,9 \ m/s$

$\alpha_2 = 171,8°$

$L_i = u\,(c_{u1} - c_{u2}) = 164,2 \ \frac{kJ}{kg}$

$P_i = \dot m L_i = 177,6 \ MW$

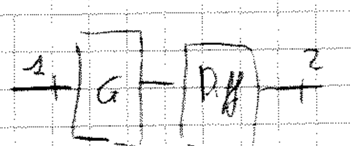
2) Turbocompressore

$\dot m = 75 \ kg/s \qquad p_1 = 1 \ bar \qquad T_1 = 15°C$

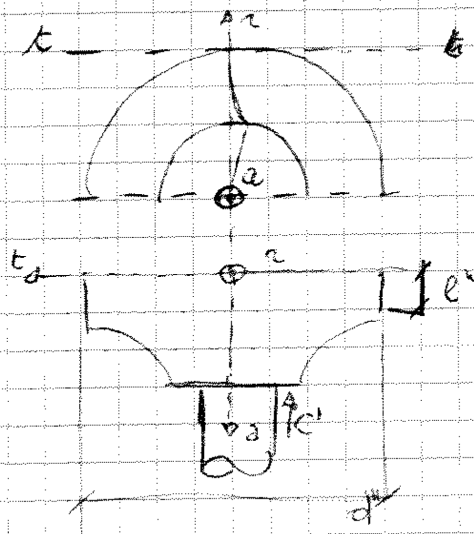
$p_2 = 3 \ bar \qquad \eta_{yc} = 0,75 \qquad \xi = 0,9$

$\frac{l''}{d''} = 0,7 \qquad \alpha'' = 20° \qquad m = cost$

$L_i = c_p\,(T_2 - T_1) \qquad T_2 = T_1 \left(\frac{p_2}{p_1}\right)^{\frac{m-1}{m}} = T_1 \left(\frac{p_2}{p_1}\right)^{\frac{1}{\eta_{yc}}\frac{k-1}{k}} = 164,7°C$

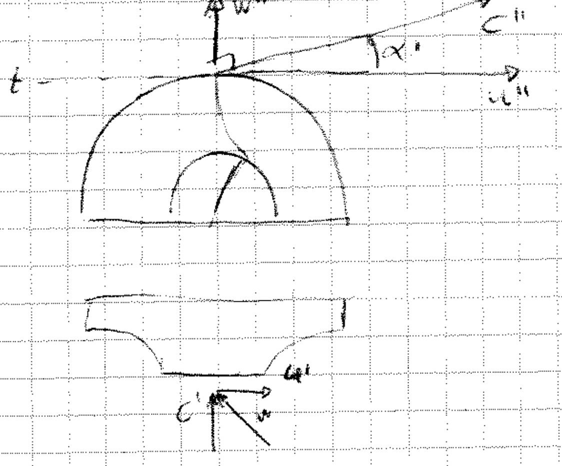


$L_i = 154,3 \ \frac{kJ}{kg}$



l'' è altezza delle palette in uscita della girante

l'ingresso delle palette è assiale



$L_i = -u'c_u' + u''c_u''$

$c_u' = 0 \qquad c_u'' = u''$

$L_i = (u'')^2$

$u'' = \sqrt{L_i} = 387,3 \ m/s$

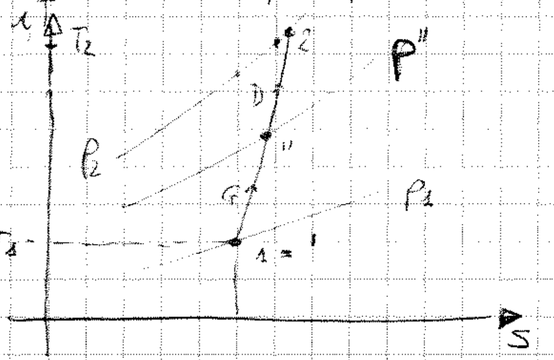
$w'' = u'' \tan(\alpha_2'') = 141,1 \ m/s$

$$c'' = \sqrt{u''^2 + w''^2} = 412,5 \ m/s$$

$$\dot{m} = \rho'' \xi (\pi d'' \ell'') w'' = \rho'' \xi \frac{\ell''}{d''} \pi d''^2 w''$$

componente di trasporto della velocità

$$d'' = \sqrt{\frac{\dot{m}}{\pi \xi \frac{\ell''}{d''} \rho'' w''}}$$



$$\rho'' = \frac{p''}{RT''}$$

Scriviamo il 1° principio al diffusore

$$0 = c_p (T_2 - T'') + \frac{c_2^2 - c''^2}{2}$$

$c' \ll w'$
$c' \ll c''$

Ma $c_2 \ll c''$ perché è la velocità del fluido nel condotto ad aria compressa

$$T'' = \frac{c_p T_2 - \frac{c''^2}{2}}{c_p} = 79,9 \ °C \qquad c_p = 1004 \ \frac{J}{kg K}$$

$$p'' = p' \left(\frac{T''}{T'}\right)^{\gamma_y = \frac{k}{k-1}} = 1,71 \ bar$$

$$\rho'' = \frac{p''}{RT''} = 1,684 \ \frac{kg}{m^3} \qquad R = 287$$

$\Downarrow$

$$d'' = \sqrt{\frac{\dot{m}}{\rho'' \pi \xi \frac{\ell''}{d''} w''}} = 0,61 \ m \Rightarrow \ell'' = \frac{\ell''}{d''} \cdot d'' = 61 \ mm$$

$$n = \frac{u''}{\pi d''} = 12\,137 \ rpm$$

Esercizio: due turbocompressori geom. simili e funzionanti in condizione di similitudine

$T_{1_I} = T_{1_{II}}$

	Compressore I		Compressore II
n	25000	rpm	30000
$\dot{m}$	2 kg/s		?
P_a	300 Hp		?

$\beta_I = \beta_{II}$

$\eta_m = 1$

$\eta_{yc_I} = 0{,}85$ ~~0,85~~ ?

$$P_{a_I} = \frac{\dot{m}_I \, L_{i_I}}{\eta_m} \Rightarrow L_i = \frac{P_{aI} \, \eta_m}{\dot{m}_I} = \frac{300 \cdot 0{,}736 \cdot 1}{2} = 110{,}3 \frac{kJ}{kg}$$

$$T_2^I = T_1^I + \frac{L_{i_I}}{c_p} = 129{,}1\,°C$$

$$R = 0{,}069 \frac{kcal}{kg\,K} \Rightarrow c_p = \frac{K}{K-1} R = \frac{1{,}4}{1{,}4-1} \, 0{,}069 \cdot 4{,}1868 = 1{,}011 \frac{kJ}{kg\,K}$$

$$\left(\frac{T_{2_I}}{T_{1_I}}\right) = \left(\beta_I\right)^{\frac{1}{\eta_{y_I}} \frac{K-1}{K}} \Rightarrow \beta_I = \left(\frac{T_{2_I}}{T_{1_I}}\right)^{\eta_{yc} \frac{K}{K-1}} = 2{,}565$$

$$L_{c_{II}} = c_p \, T_{1_{II}} \left(\beta_I^{\frac{1}{\eta_{yc_{II}}} \frac{K-1}{K}} - 1\right)$$

Poiché i 2 compressori lavorano in similitudine hanno lo stesso rendimento. Ne segue che il lavoro è lo stesso.

$$\frac{\dot{m}_I \sqrt{\cancel{R T_1}}}{\cancel{p_1} \, d_I''^2} = \frac{\dot{m}_{II} \sqrt{\cancel{R T_1}}}{\cancel{p_1} \, d_{II}''^2} \Rightarrow \frac{\dot{m}_I}{\dot{m}_{II}} = \left(\frac{d_I''}{d_{II}''}\right)^2$$

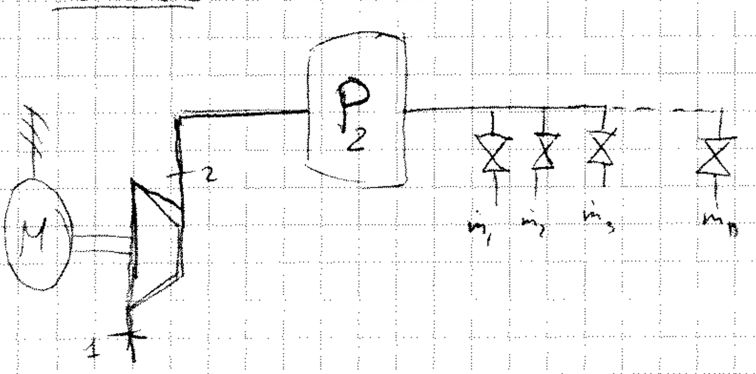
$$\frac{n_I \, d_I''}{\sqrt{RT_1}} = \frac{n_{II} \, d_{II}''}{\sqrt{RT_1}} \Rightarrow \frac{n_I}{n_{II}} = \frac{d_{II}''}{d_I''}$$

$$\Downarrow$$

$$\frac{\dot{m}_I}{\dot{m}_{II}} = \left(\frac{n_{II}}{n_I}\right)^2 \Rightarrow \dot{m}_{II} = \dot{m}_I \left(\frac{n_I}{n_{II}}\right)^2 = 1{,}39 \frac{kg}{s}$$

$$P_{a_{II}} = \frac{\dot{m}_{II} \, L_{i_{II}}}{\eta_m} = 153{,}2 \; kW$$

Esercizio

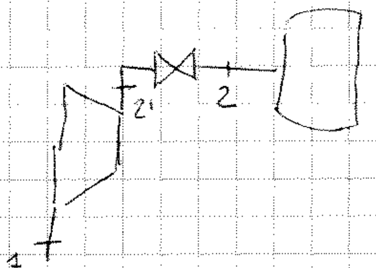


A portata variabile bisogna mantenere costante P_2

Le regolazioni da valutare sono

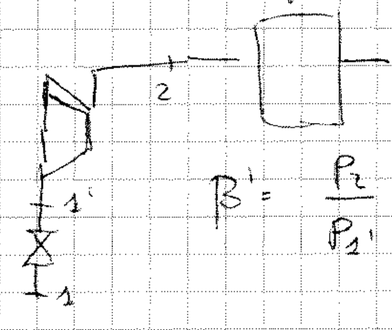
1) n° giri variabile (β = costante)

2) laminazione allo scarico



$$\beta' = \frac{P_2'}{P_1} > \beta$$

3) Laminazione all'aspirazione



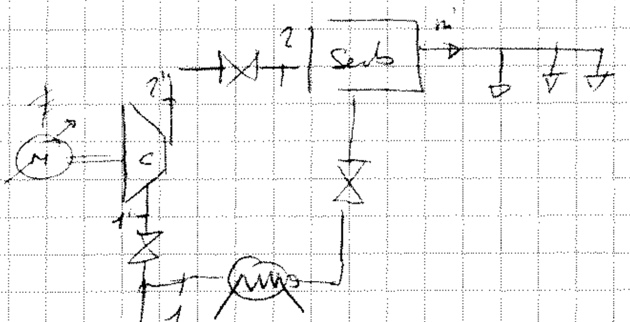
$$\beta' = \frac{P_2}{P_1'} < \beta \qquad P_1' < P_1$$

Esercizio

$$\frac{n}{n_0}\sqrt{\frac{T_0}{T_1}} = 1,00 \qquad \beta = 3,67$$

$$G\sqrt{\frac{T_1}{T_0}}\,\frac{P_0}{P_1} = 31,5\ \frac{kg}{s} \qquad \eta_c = 0,9$$

$T_1 = T_0 = 300$ K $\quad P_1 = P_0 = 1$ bar $\quad n_0 = n = 12000$ rpm



Analizzare i 3 casi di regolazione.

0) Ai limiti del pompaggio $G\sqrt{\frac{T_1}{T_0}}\frac{P_0}{P_1} = 27{,}6\ \frac{Kg}{s}$

Nel funzionamento iniziale

$L_i = c_p \frac{T_1}{\eta_{is}}\left(\beta^{\frac{k-1}{k}} - 1\right) = 108{,}5\ \frac{KJ}{Kg}$

Poichè $T_1 = T_0$ e $P_1 = P_0$

$\dot{m} = \cancel{27{,}6\ \frac{Kg}{s}}\ 33{,}15\ \frac{Kg}{s}$

$P_i = \dot{m}\ L_i = 3{,}6?\ MW$

1) $\dot{m} = 27{,}6\ \frac{Kg}{s}$ $\beta = 2{,}67$ $\eta_c \simeq 0{,}65$

$L_i = 150{,}1\ \frac{KJ}{Kg}$ $P_i = 4{,}14\ MW$

$\frac{n}{n_0}\sqrt{\frac{T_1}{T_0}} \simeq 0{,}865 = 11580\ rpm$

2) n = costante portata corretta = $28{,}5\ \frac{Kg}{S}$

$\dot{m} = 28{,}5\ Kg/s$ $\beta' = 2{,}82$ $\eta_c \simeq 0{,}65$

$P_2' = \beta' P_1 = 2{,}82\ bar$

$L_i = 158{,}8\ \frac{KJ}{Kg}$ $P_i = 4{,}56\ MW$

3) n = cost T/T_0 rimane 1 varia $\frac{P}{P_0}$

portata corretta $28{,}5\ \frac{Kg}{s}$ $\beta' = 2{,}82$ $\eta_c = 0{,}65$

$\frac{P_2'}{P_1'} = \beta' \Rightarrow P_1' = \frac{\overset{\beta P_1}{P_2}}{\beta'} = P_1 \frac{\beta}{\beta'} \Rightarrow \frac{P_1'}{P_1} = \frac{P_1'}{P_0} = \frac{\beta}{\beta'} =$

$\dot{m} = \frac{\text{portata corretta}}{\sqrt{T_1/T_0}}\frac{P_1'}{P_0} = \frac{P\ \text{corretta}}{\underbrace{\sqrt{T_1/T_0}}_{=1}}\frac{\beta}{\beta'} = 27\ Kg/s$

$L_i = 159{,}8\ \frac{KJ}{Kg}$

$P_i = 4{,}31\ MW$

Esercizio TURBOPOMPA CENTRIFUGA MONOSTADIO con diffusore palettato.

Pale girante rivolte in avanti $\beta'' = 60°$, $\alpha'' = 20°$

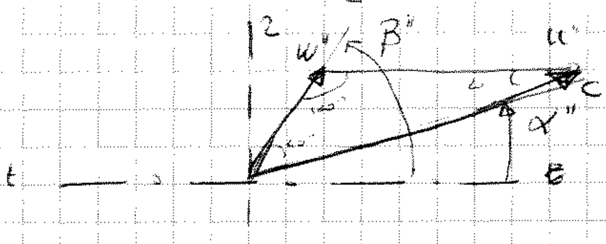
$d'' = 0{,}4$ m $n = 1500$ rpm $c_1 = 8$ m/s

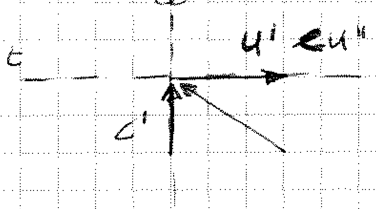
$\eta_y = 0{,}75$ perdite {40% girante, 60% diffusse

$P_1 = 1$ bar

$P_1'' = ?$ $c_1'' = ?$ $P_2 = ?$

trascurare $c_2 \simeq 0$





$$L_i = u'' c_u''$$

$$u'' = \pi d'' n = \frac{31{,}4}{1} \frac{m}{s}$$

$$\frac{u''}{\sin 40°} = \frac{c''}{\sin 120°} \Rightarrow c'' = u'' \frac{\sin 120°}{\sin 40°} = 42{,}3 \frac{m}{s}$$

$$l_i = u'' c_u'' = u'' c'' \cos\alpha'' = 1{,}25 \frac{kJ}{kg}$$

$$l_i = \frac{p'' - p'}{\rho} + \frac{c''^2 - c'^2}{2} + L_w$$

$$l_i = \int_1^{''} v\,dp + \Delta E_c\Big|_1^{''} + L_{w_g}\Big|_1^{''}$$

$$\eta_y = \frac{L_i - L_w}{L_i} = 0{,}75 \qquad L_w = (1 - \eta_y) L_i = 0{,}31 \frac{kJ}{kg}$$

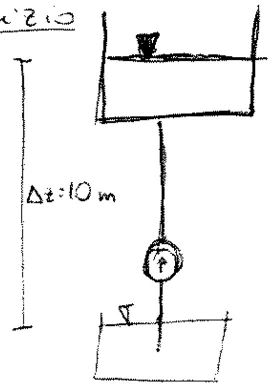
$$L_{w_g} = 0{,}125 \frac{kJ}{kg} \qquad L_{w_d} = 187{,}4 \; J/kg$$

$$\frac{p''}{\rho} = L_i - \frac{c''^2 - c'^2}{2} - L_{w_g} + \frac{p'}{\rho} = 359 \; J/kg$$

$$p'' = \frac{p''}{\rho} \cdot \rho = 3{,}59 \; bar$$

Esercizio

turbopompe centrifuga



$Y(Q = 17,5\ l/s) = 0,5\ m$

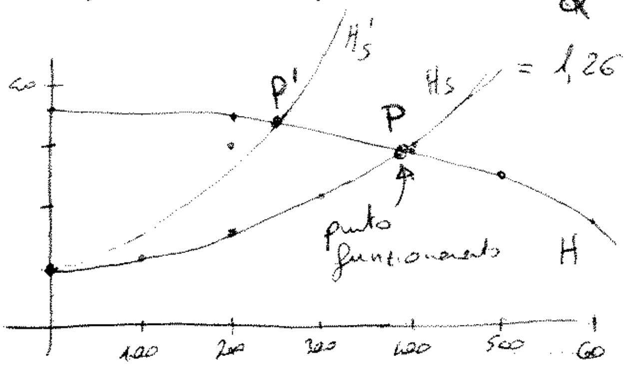
$\eta_o = 0,92 \qquad \eta_v \cong 1 \qquad n = 1500\ rpm$

$$P_a = \frac{\rho g H Q}{\eta_o \eta_y \eta_v}$$

$$H_s = \Delta z + Y = \Delta z + KQ^2$$

$$Y(Q = 17,5\ l/s) = KQ^2 = 0,5 \Rightarrow K = \frac{Y}{Q^2} = \frac{0,5}{(17,5 \cdot 3,6)} = 1,26 \cdot 10^{-4}$$

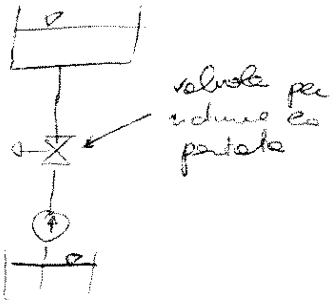
Q (m^3/h)	H_s (m)
0	10
100	11,26
200	15,04
300	21,34
400	30,16
500	41,50
600	55,35



$Q_p \cong 400\ m^3/h \qquad H_p = 30\ m \qquad \eta_y = 0,82$

$$P_a = \frac{1000 \frac{kg}{m^3} \cdot 9,81 \cdot 30 \cdot 400 \frac{m^3}{h}}{0,92 \cdot 1 \cdot 0,82} = 42,3\ KW$$

Riduzione portata ridotta ~~del~~ 40% : $Q' = 0,6\,Q = 240\ m^3/h$



$$P_a' = \frac{1000 \frac{kg}{m^3} \cdot 9,81 \cdot 240 \frac{m^3}{h} \cdot 34}{0,92 \cdot 1 \cdot 0,64} = 37,7\ KW$$

Di solito $\eta_o' < \eta_o$ dobbiamo calcolare le perdite

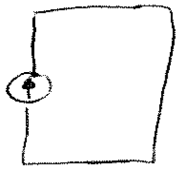
$P_{ass} = P_i + P_o$

$P'_{ass} = P_i' + P_o$

~~$P_{ass} = \frac{1}{\eta_o} \frac{P_i}{\eta_y \eta_v}$~~

Esercizio (3) Pompe centrifughe monostadio

$n = 1500$ rpm $\quad Q = 200$ l/s $\quad \eta_p = 0{,}75$



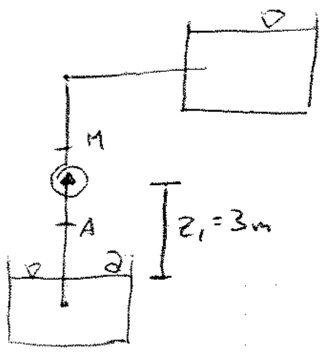
$Y = 40$ m $\quad Y \propto V^2 \quad \Delta z = 0$

$Q' = 150$ l/s $\qquad \frac{Q'}{Q} = \frac{n'}{n} \qquad \frac{H'}{H} = \left(\frac{n'}{n}\right)^2$

$$P_a' = \frac{\rho g H' Q'}{\eta_v \eta_m \eta_y'} =$$

Nota: $\eta_y' = \eta_y$ perché la curva di funzionamento è una parabola passante per l'origine come le curve isorendimento (perché siamo su circuito chiuso)

Esercizio (1)



$n = 800$ rpm $\quad Q = 80$ l/s $\quad Y \propto V^2$

$Y(Q = 100 \text{ l/s}) = 0{,}6$ m/m $\qquad p_{amb} = 1$ bar

$T_{amb} = 20°C$

$$Y_A\Big|_{Q=100\,l/s} = 0{,}6 \cdot z_1 = 1{,}8 \text{ m}$$

$NPSH_{disp} > NPSH_{min}$

$$\frac{p_a - p_v(T_a)}{\rho g} - z_1 - Y_a < NPSH_{min}$$

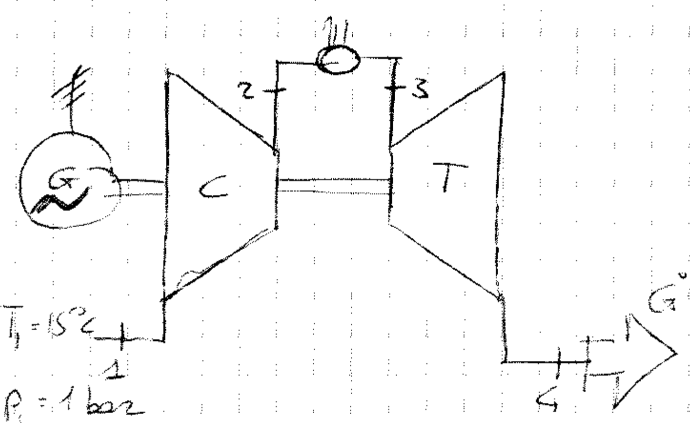
$$\frac{(1 - 23{,}4 \cdot 10^{-3})}{1000 \frac{kg}{m^3} \cdot 9{,}81 \frac{m}{s^2}} - 3\text{m} - Y_a\Big|_{Q=90\,l/s} = 5{,}50 \text{ m}$$

$$Y_a\Big|_{Q=90\,l/s} = Y_a\Big|_{Q=100\,l/s} \cdot \frac{90^2}{100^2} =$$

$NPSH_{min}(Q = 80 \text{ l/s}, n = 800) = 2$ m

$n' = 1750$ rpm

Esercizio: ciclo ~~a gas~~ combinato ENEL Livorno Ferraris



$T_1 = 15\,°C$

$p_1 = 1$ bar

$\beta_c = 14 = \beta_t \Rightarrow \eta_\pi = 1$

$\dot m_g = 1605\ t/h = 445{,}8\ \frac{kg}{s}$

$T_4 = 505\,°C$

$k_g = 1{,}333$

$c_{pg} = 1{,}147\ \frac{kJ}{kg\,K}$

$\eta_{yc} = 0{,}865 \qquad \eta_{yT} = 0{,}865$

$k_a = 1{,}4 \qquad c_{pa} = 1{,}005\ \frac{kJ}{kg\,K} \qquad H_i = 46700\ kJ/kg \qquad \eta_b = 0{,}995$

$\eta_{me} = 0{,}985$

Compressore

$$T_2 = T_1\, \beta^{\frac{1}{\eta_{yc}} \frac{k_a - 1}{k_a}} = 415{,}8\,°C$$

~~Turbina~~ Combustore

$$① \quad \eta_b H_i = (1+\alpha)\, c_{pg}\, (T_3 - T_2) \quad \text{form. approx}$$

$$① \quad \eta_b H_i + \alpha\, c_{pa}\, (T_1 - T_0) = (\alpha + 1)\, c_{pg}\, (T_3 - T_0) \quad \text{formula corretta}$$

$$\alpha = \frac{\eta_b H_i - c_{pg}\,(T_3 - T_0)}{c_{pg}(T_3 - T_0) - c_{pa}\,(T_1 - T_0)} = 53{,}6$$

$$2)\ \alpha = \frac{\eta_b H_i - c_{pg}\,(T_3 - T_2)}{c_{pg}(T_3 - T_2)} =$$

Turbina: $$T_3 = T_4\, \beta_t^{\eta_{yt} \frac{k_g - 1}{k_g}} = 1103{,}8\,°C$$

$$\dot m_f = \frac{\dot m_g}{\alpha + 1} = 8{,}16\ kg/s$$

$$\dot m_a = \dot m_g - \dot m_f = 437{,}6\ kg/s$$

$$P_{e,TG} = \eta_{me}\left[P_{iT} - P_{iC}\right] = \eta_{me}\left[\dot m_g\, c_{pg}\,(T_3 - T_4) - \dot m_a\, c_{pa}\,(T_2 - T_1)\right] =$$

$$= 127\,970\ kW$$

$$\dot{G} = \dot{m}_g\, c_{pg} (T_4 - \overset{25°C}{T_0}) = 245440 \text{ KW}$$

$$\eta_{el_{TG}} = \frac{P_{e_{TG}}}{\dot{F}} = 0,336 \qquad \dot{F} = \dot{m}_g \cdot H_i = 381,072 \text{ MW}$$

Generatore di vapore a recupero a 2 livelli di pressione

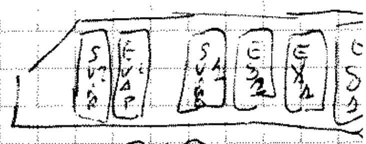
Dati: AP = 57,9 bar   BP = 6,78 bar

$$\Delta T_{AP_2} = T_4 - T_{e2} = 15°C \Rightarrow T_{e2} = T_4 + \Delta T_{AP_2} = 450°C$$

$$\Delta T_{PP,2} = T_{G2} - T_{c2} = 25°C \qquad T_{G2} = T_{c2} + \Delta T_{PP} = 292,5°C$$

$T_{c2} = 267,5°C$

p.to	p (bar)	T (°C)	i (KJ/kg)
e_2	57,9	450	3407
d_2	""	267,5°C	2791
c_2	""	267,5	1172
e_1	6,78	273	3004
d_1	""	160,7	2759
c_1	""	""	2758
b_1	6,78		220
a_1	0,14 bar	52,6°C	220



GVR

$$\dot{m}_{v2} = \frac{\dot{m}_g\, c_{pg} (T_4 - T_{G2})}{i_{e2} - i_{c2}} = 48,6 \text{ Kg/s}$$

$$\Delta T_{AP_1} = T_{G2} - T_{e1} = 19,5°C \qquad \Delta T_{PP} = T_{G1} - T_{c1} = 25°C$$

$$T_{G1} = 160,7 + 25 = 185,7°C$$

$$\dot{m}_g\, c_{pg} (T_{G2} - T_{G1}) = \dot{m}_{v1} (i_{e1} - i_{c1}) + \dot{m}_{v2} (i_{c1} - \underset{i_{c1}}{\underset{\parallel}{i_{b2}}})$$

$$\Downarrow$$

$$\dot{m}_{v1} = 13,2 \text{ Kg/s}$$

Nell'eco 1 passa $\dot{m}_{v1} + \dot{m}_{v2}$

$$\dot{m}_g\, c_{pg} (T_{G1} - T_S) = (\dot{m}_{v1} + \dot{m}_{v2})(i_{c1} - i_{b1})$$

$$\Downarrow$$

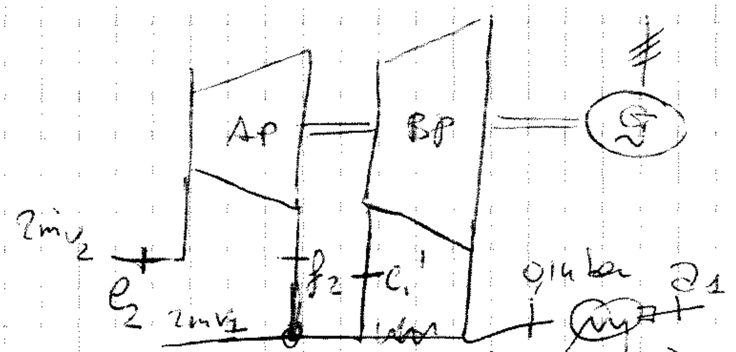
$$T_S = 130,3°C$$

$\dot{Q}_S = \dot{m}_g c_{pg} (T_5 - T_0) = 53,863$ MW potenza che potrei ancora recuperare

$\dot{Q}_V = \dot{G} - \dot{Q}_S = 191,597$ MW

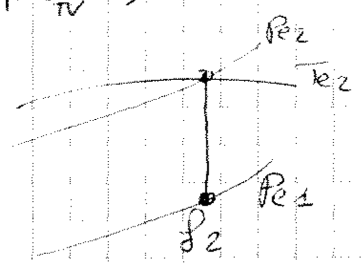
$\varepsilon_{GVR} = \frac{\dot{Q}_V}{\dot{G}} = \frac{191,597}{245,440} = 0,781$

<u>impianto a vapore</u> (conf. 2.1)



$\eta_{is_{AP}} = 0,8 = \eta_{is_{BP}}$

$\eta_{me_{TV}} = 0,98$



$P_{i2} = 2\dot{m}_{v_2} \eta_{is_{AP}} (i_{e_2} - i_{f_{2,is}})$

$i_{f_{2,is}} = 2438 \frac{kJ}{kg}$

$P_{i_2} = 75\,506$ kW $\qquad i_{f_2} = 2630$ kJ/kg

$(\dot{m}_{v_1} + \dot{m}_{v_2}) i_{e_1}' = \dot{m}_{v_1} i_{e_1} + \dot{m}_{v_2} i_{f_2} \Rightarrow i_{e_1}' = 2710 \frac{kJ}{kg}$

$i_{f_{1,is}} = 2105$ kJ/kg

$P_{i,1} = 2(\dot{m}_{v_1} + \dot{m}_{v_2}) \eta_{is,BP} (i_{e_1}' - i_{f_{1is}}) = 59,427$ MW

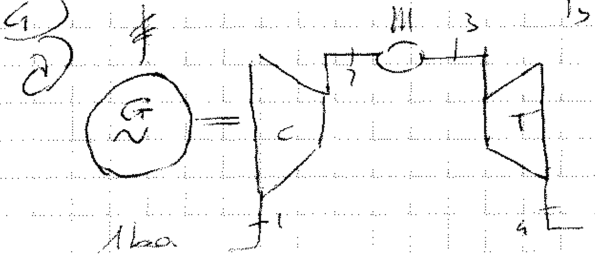
$P_{eTV} = \eta_{me_{TV}} (P_{i,1} + P_{i,2}) = 132\,232$ kW

$\eta_{cc} = \frac{2 \cdot P_{eTG} + P_{eTV}}{\cancel{2 H_i \dot{m}_g}\ 2\dot{F}} = 0,50$

Esercizi turbine a gas

a)

$T_3 = 1000 K$



1 bar

300 K $\beta_c = 18$

$\eta_{yc} = 0,85$

$\eta_{is\,t} = 0,88$

$\eta_b = 0,93 \quad \eta_o = 0,97$

$H_i = 42,7 \frac{MJ}{kg}$

$k = k' = 1,4$

$P_u = 10\ MW \qquad \dot m_a = ?$

$P_u = \eta_o P_i = \eta_o \dot m_a L_i = \eta_o \dot m_a \left[\frac{\alpha+1}{\alpha} L_t - L_c\right]$

$L_c = c_p T_1 \left(\beta^{\frac{1}{\eta_{yc}}\frac{k-1}{k}}\right) = 1,0045 \cdot 300 \cdot 18^{\frac{1}{0,85}\frac{1,4-1}{1,4}} = 304,9\ kJ/kg$

$T_2 = T_1 + \frac{L_c}{c_p} = 603,5\ K$

$\eta_b H_i = (1+\alpha) c_p (T_3 - T_2) \Rightarrow \alpha = 99,7$

$L_T = \eta_{is\,t} c_p T_3 \left(1 - \beta_c^{-\frac{k-1}{k}}\right) = 396 \frac{kJ}{kg}$

$T_4 = T_3 - \frac{L_T}{c_p} = 605,8\ K$

$L_i = \frac{\alpha+1}{\alpha} L_t - L_c = 95,1 \frac{kJ}{kg}$

$\dot m_a = \frac{P_u}{\eta_o L_i} = 108,4 \frac{kg}{s} \qquad \eta_g = \frac{P_u}{\dot m_b H_i} = \eta_o \eta_b \frac{L_i}{Q_1}$

$Q_1 = c_p (T_3 - T_2) = 398,3 \frac{kJ}{kg} \qquad \eta_g = 0,97 \cdot 0,93 \frac{95,1}{398,3} = 0,215$

b) $T_3' = 900\ K$

$L_T' = \eta_{is\,t} c_p T_3' \left(1 - \beta_t^{-\frac{k-1}{k}}\right) = 356,4 \frac{kJ}{kg}$

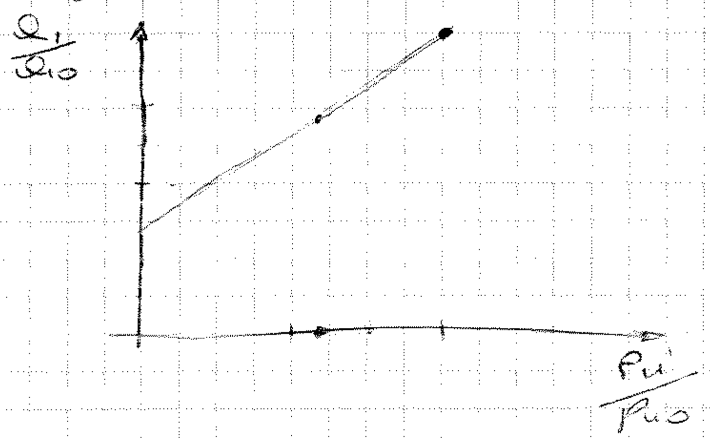
$\alpha' = \frac{\eta_b H_i}{c_p (T_3' - T_2)} = 132,9$

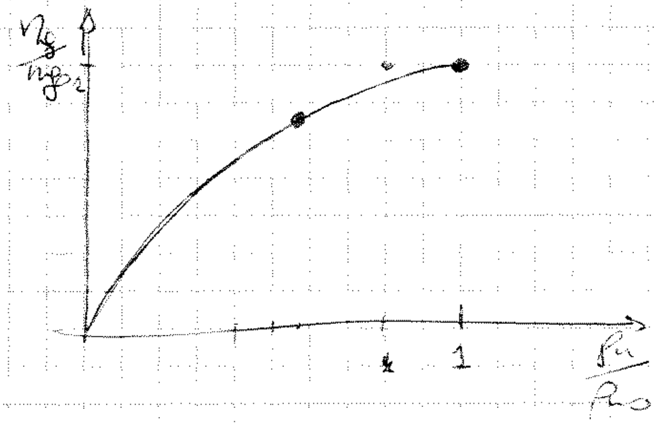
$Q_1' = c_p (T_3' - T_2) = 297,8 \Rightarrow \frac{Q_1'}{Q_1} = 0,748$

$\frac{\dot m_b'}{\dot m_b} = \frac{Q_1'}{Q_1} = 0,748$

$$L_i' = \frac{\alpha'+1}{\alpha} L_t' + L_c = 54,2 \frac{KJ}{Kg}$$

$$\eta_g' = \eta_b \eta_b \frac{L_i'}{Q_1'} = 0,164$$





$\Delta Q_1 \propto \Delta T_3$

$\Delta P_u \propto \Delta L_i \propto \Delta L_t \propto \Delta T_3$

Prima si cercava di ridurre la potenza abbassando T_3. Oggi si cerca di ridurre ma senza far diminuire T_3. (lavorare ad α costante)

Esercitazione motori alternativi

1)

$$pme = \frac{P_u}{i_{tot} V \frac{n}{m}} = 13,06 \text{ bar}$$

$d = 2c$

$$u = 2cn \qquad \frac{i_{tot} V}{i_{tot}} = \pi \frac{d^2}{4} c$$

$$c^3 = \frac{4}{\pi 4} \frac{i_{tot} V}{4} \Rightarrow c = \sqrt[3]{\frac{i_{tot} V}{}} = 45,7 \text{ mm}$$

$u = 27,4$ m/s

3)

$$\frac{P_u}{i_{tot}} = 2000 \text{ kW} \qquad V = \pi \frac{d^2}{4} c \qquad d = 640 \text{ mm}$$

$u = 10$ m/s

$$u = 2cn \Rightarrow c = \frac{u}{2n} = 900 \text{ mm}$$

$$V = 0,29 \text{ m}^3 \qquad pme = \frac{P_u}{i_{tot} V \frac{n}{m}} = 24,85 \text{ bar}$$

5) $i_{tot_O} V_O = 1600\ cm^3$ $\qquad i_{tot_D} V_D = 1300\ cm^3$

$n = 3000$

$C_d = 98\ Nm$ $\qquad C_O = 120\ Nm$

$q_{b_D} = 260\ g/kWh$ $\qquad q_{b_O} = 270\ g/kWh$

$\dot m_{a_D} = 160\ kg/h$ $\qquad \dot m_{a_O} = 140\ kg/h$

$p_a = 1\ bar$ $\qquad T_a = 20°C$

$pme = ?$ $\qquad \alpha = ?$ $\qquad \lambda = ?$ coeff. di riempimento

$$pme = \frac{C_u\ 2\pi\ m}{i_{TOT}\ V} \Rightarrow \quad pme_D = 6{,}48\ bar \quad pme_O = 9{,}42\ bar$$

$$q_b = \frac{\dot m_b}{P_u} \qquad P_u = C_u \cdot 2\pi\, n \Rightarrow \quad P_{u_D} = 30{,}79\ kW \quad P_{u_O} = 37{,}70\ kW$$

$\Downarrow$

$$\dot m_b = P_u\ q_b \Rightarrow \quad \dot m_{bD} = 7{,}389\ \frac{kg}{h} \quad \dot m_{bO} = 10{,}179\ \frac{kg}{h}$$

$$\alpha = \frac{\dot m_a}{\dot m_b} \Rightarrow \quad \alpha_D = 21{,}65 \quad \alpha_O = 13{,}75$$

$$\lambda_v = \frac{\dot m_a}{\rho\ i_{tot} \frac{n}{m} V} \Rightarrow \quad \lambda_{vD} = 0{,}79 \quad \lambda_{vO} = 0{,}82$$

$$\rho = \frac{p_a}{RT}$$

b) $q_b' = q_b$ $\qquad q_b' = 1{,}1\ q_b$ $\qquad \alpha' = \alpha_{st} = 14{,}6$ $\qquad n' = n$

$$pme' = \frac{P_u'}{i_{TOT} V \frac{n}{m}} = \frac{C_u'\ 2\pi\ m}{i_{TOT}\ V} \Rightarrow \quad pme'_D = 3{,}24\ bar \quad pme'_O = 4{,}71\ bar$$

$$\dot m_b = P_u'\ q_b' \qquad P_u = C_u'\ 2\pi\ n' \Rightarrow \quad P'_{uD} = 15{,}385\ kW \quad P'_{uO} = 18{,}85\ kW$$

$\Downarrow$

$\dot m'_{bD} \simeq 3{,}69$

$\dot m'_{bO} \simeq 0{,}55\ \dot m_b$

$$\alpha' = \frac{\dot m_a'}{\dot m_b'} \Rightarrow \quad \alpha'_D = \frac{\dot m_a}{0{,}5\ \dot m_b} = 43{,}2 = 2\alpha$$

$$\alpha'_O = \alpha_{st} = 14{,}6 \Rightarrow \dot m_a' = 81{,}7\ \frac{kg}{h}$$

Turbine idrauliche

1) modello

$n^* = 300$ giri/min $\quad \eta^*_{T_{max}} = 0,87 \quad Q_S = 1,1\ m^3/s$

$P_u^* = 35\ KW \quad\quad D^* = 0,8\ m$

reale $Q_e = 100\ m^3/s \quad P_u = 30\ MW$

$$n_c = \frac{n\sqrt{P_u}}{H^{5/4}} = n_{c\,modello} = \frac{n^*\sqrt{P_u^*}}{H^{*\,5/4}}$$

$$P_u^* = \eta^*_{T_{max}}\,\rho g\, H^* Q^* = \quad\quad Q_S = \frac{Q^*}{D^{*2}\sqrt{H^*}}$$

$$P_u^* = \eta^*_{T_{max}}\,\rho g\, H^{*\frac{3}{2}}\, D^{*2}\, Q_S \Rightarrow H^* = 3,137\ m$$

$n_c = 476,5$ giri/min (NOTA P_u in cavalli $1KW \simeq 736\ CV$)

$$P_u = \eta^*_{T_{max}}\,\rho g\, H\, Q \Rightarrow H = 41\ m$$

$$Q_S = Q_S^* = \frac{Q}{D^2\sqrt{H}} \Rightarrow D = \sqrt{\left(\frac{Q_S\sqrt{H}}{Q}\right)^{-1}} = 3,768\ m$$

$$n_c = \frac{n\sqrt{P_u}}{H^{5/4}} \Rightarrow n = \frac{n_c\, H^{5/4}}{\sqrt{P_u}} = 226,7\ rpm$$

$$n_s = n_s^* = \frac{n^* D^*}{\sqrt{H^*}} = 133,4\ rpm$$

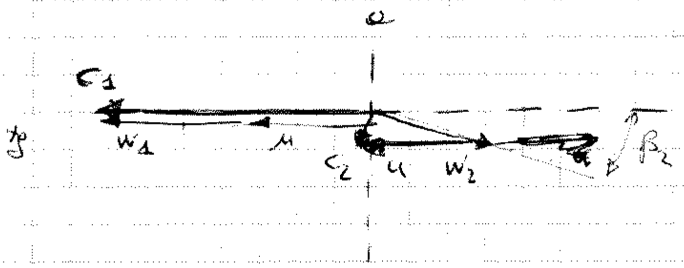
2) $Q = 8,88\ m^3/s \quad H = 721\ m \quad n = 300\ rpm \quad D = 3,54\ m$

$P_u = 55175\ KW \quad \eta_m = 0,97 \quad \psi = 0,94 \quad \beta_1 = 10°$

$$P_u = \eta_T\,\rho g H Q = \eta_m\,\underset{=1}{\eta_v}\,\underbrace{\eta_y\, g H}_{L_i}\,\rho Q$$

$$L_i = \frac{P_u}{\eta_m\,\rho Q} = 6405,6\ J/kg \simeq 6,4\ kJ/kg$$

$$L_i = u\,(c_{u_1} - c_{u_2})$$



$c_{u1} = c_1$

$w_2 = \psi w_{2is}$

$w_{2is} = w_2$

$w_1 = c_1 - u \qquad w_2 = \psi (c_1 - u)$

$c_{u2} = u - \underline{w_2 \cos\beta_2}$

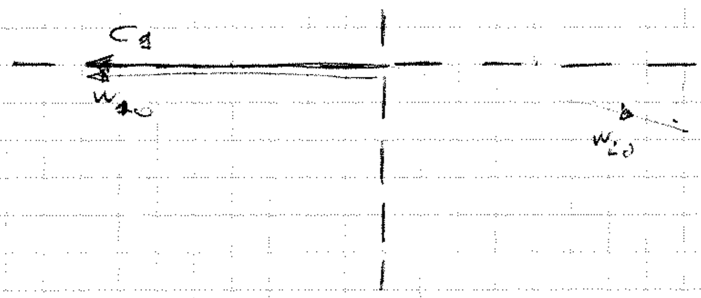
$$l_i = u\,(c_1 - u)\,(1 + \psi \cos\beta_2)$$

$$c_1 = u + \frac{l_i}{u\,(1+\psi\cos\beta_2)} = \qquad u = \pi D n = 55{,}61 \text{ m/s}$$

$$= 115{,}63 \text{ m/s}$$

$$Q = \frac{\pi d^2}{4} c_1 \Rightarrow d = 0{,}313 \text{ m}$$

b)



$c_1 = w_{10}$

$u = 0$

$w_{20} = \psi w_{10}$

$w_{20} = c_2$

$c_{u20} = w_{u20} - \psi c_1 \cos\beta_2$

$$M = \frac{D}{2}(c_{u1} - c_{u20})\,\rho Q =$$