ESERCIZI MACCHINE (PROF MANNA)

• TURBINA A GAS

① (lezione 13/11/2014)

IMT-TG a CIRCUITO CHIUSO

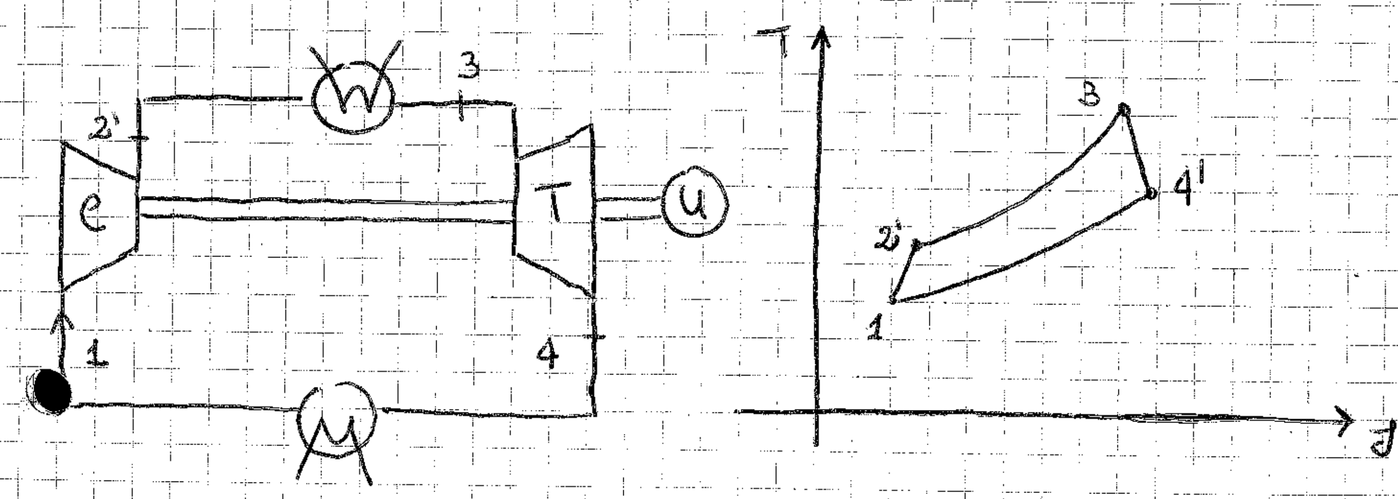
$\beta_c = \beta_T = 12$ $\quad \eta_{PC} = 0{,}8$ $\quad K = 1.4$ $\quad T_1 = 288\,K$

$\vartheta = 6$ $\quad \eta_{PT} = 0{,}9$ $\quad R = 287\ J/kgK$

Si trascurino la perdita di carico al COMBUSTORE $\frac{\Delta p}{p} = 0$

Calcolare $l_r = ?$ $\eta_r = ?$

SVOLGIMENTO



$l_r = l_{rT} - l_{rC}$

$l_{rC} = ?$

$$l_{rC} = h_{2'} - h_1 = \frac{K}{K-1} R T_1 \left(\beta^{\lambda/\eta_{PC}} - 1 \right) = \frac{1.4}{1.4-1} \cdot 0{,}287 \cdot 288 \left(12^{\frac{0{,}2857}{0{,}8}} - 1 \right)$$

$= 413\ KJ/kg.$

$l_{rT} = ?$

$\vartheta = \frac{T_3}{T_1} \Rightarrow T_3 = 6 \cdot 288\,K = 1728\,K$

$$l_{T_T} = h_3 - h_{4'} = \frac{k}{k-1} R T_3 \left(1 - \left(\frac{1}{\beta}\right)^{\lambda \cdot \eta_{PT}} \right) =$$

$$= \frac{1.4}{1.4-1} \cdot 0{,}287 \cdot 1728 \left(1 - \left(\frac{1}{12}\right)^{0{,}2857 \cdot 0{,}9} \right) = 819{,}5 \ \frac{kJ}{kg}$$

$$l_T = -413 + 819{,}5 = 406{,}5 \ kJ/kg.$$

$$\eta_T = \frac{l_T}{q_{aT}} = \frac{406{,}5}{1033} = 0{,}394$$

$$q_{aT} = h_3 - h_{2'} = \frac{k}{k-1} R \left(T_3 - T_{2'} \right) = \frac{1.4}{1.4-1} \cdot 0{,}287 \left(1728 - 699{,}5 \right)$$
$$= 1033 \ kJ/kg$$

$$T_{2'} = T_1 \, \beta^{\lambda / \eta_{PC}} = 288 \cdot 12^{0{,}2857/0{,}8} = 699{,}5 \ K$$

② (PROVA 25/01/2007) IHT-TG CHIUSA

$P_{min} = 1 bar$ | $k = 1.4$ | $T_1 = 15°C$

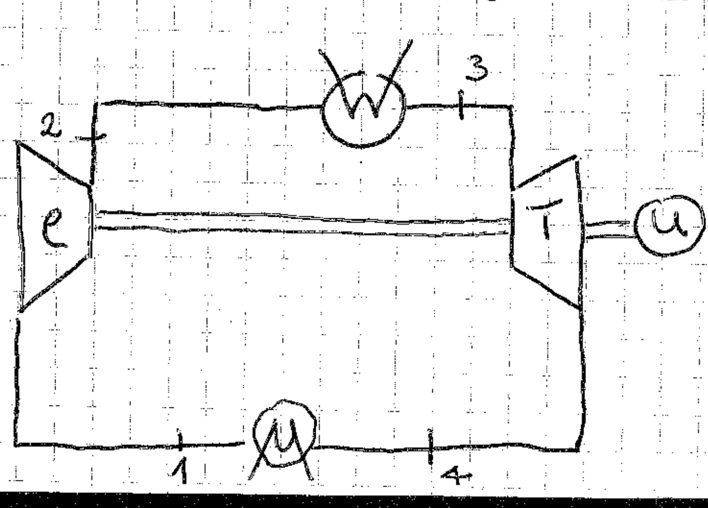
$\beta_C = \beta_T = 10$ | $R = 0{,}287 \ \frac{kJ}{kg K}$

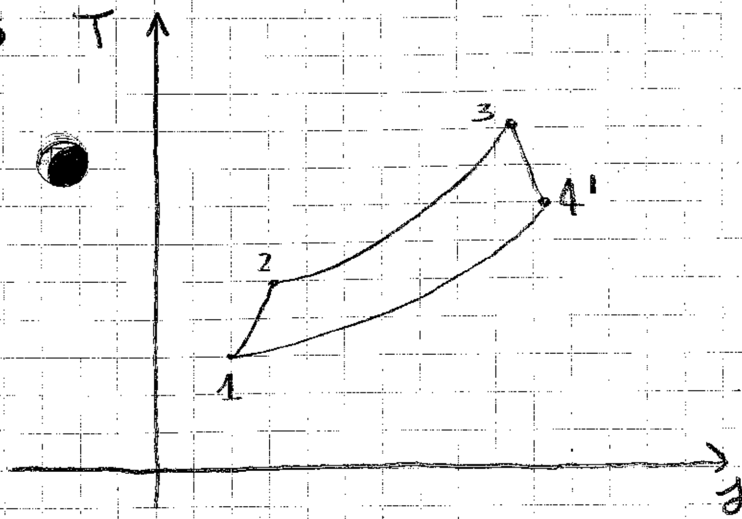
$\vartheta = 6$ | $\dot{m}_g = 100 \ kg/s$

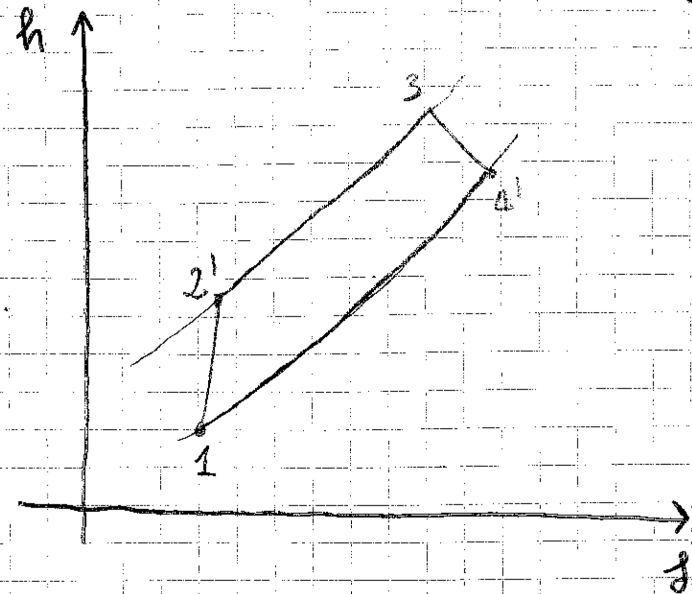
$\eta_{PC} = 0{,}8$

$\eta_{PT} = 0{,}9$ | P_T ? η_T ? | (CICLO SU PIANO T-S e h-S)

SVOLGO







$P_r = \dot{m}_g (l_{zT} - l_{zC})$

con $\frac{k}{k-1} R = 1{,}0045 \frac{kJ}{kgK}$

$l_{zC} = h_{2'} - h_1 = \frac{k}{k-1} R T_1 \left(\beta^{\lambda/\eta_{pc}} - 1 \right)$

$= 1{,}0045 \cdot 288 \cdot \left(10^{0{,}2857/0{,}8} - 1 \right) = 369\ kJ/kg$

$l_{zT} = h_3 - h_{4'} = \frac{k}{k-1} R T_3 \left(1 - \left(\frac{1}{\beta}\right)^{\lambda \cdot \eta_{pT}} \right) =$

$= 1{,}0045 \cdot \underbrace{6 \cdot 288}_{T_3 = \theta T_1 = 1728} \cdot \left(1 - \left(\frac{1}{10}\right)^{0{,}2857 \cdot 0{,}9} \right) = 776\ kJ/kg$

$P_r = \dot{m}_g (l_{zT} - l_{zC}) = 100 \cdot (776 - 369) = 40{,}7\ MW.$

$\eta_r = \frac{P_r}{Q_a} = \frac{l_r}{q_a} = \frac{40{,}7}{107{,}8} = 0{,}378$

$Q_a = \dot{m}_g (h_3 - h_{2'}) = \dot{m}_g \frac{k}{k-1} R (T_3 - T_{2'}) = 100 \cdot 1{,}0045 \cdot (1728 - 655)$
$= 107{,}8\ MW$

$T_{2'} = \beta^{\lambda/\eta_{pc}} \cdot T_1 = 288 \cdot 10^{0{,}2857/0{,}8} = 655\ K$

③ Turbina a gas con Rigenerazione

DATI: $T_{MIN} = 15°C = T_1$ $\quad \dot m_a = 100$ kg/s

$\beta_C = \beta_T = 5$ $\quad \alpha = 33$

$\eta_b = 0,98$ $\quad k = 1.4$

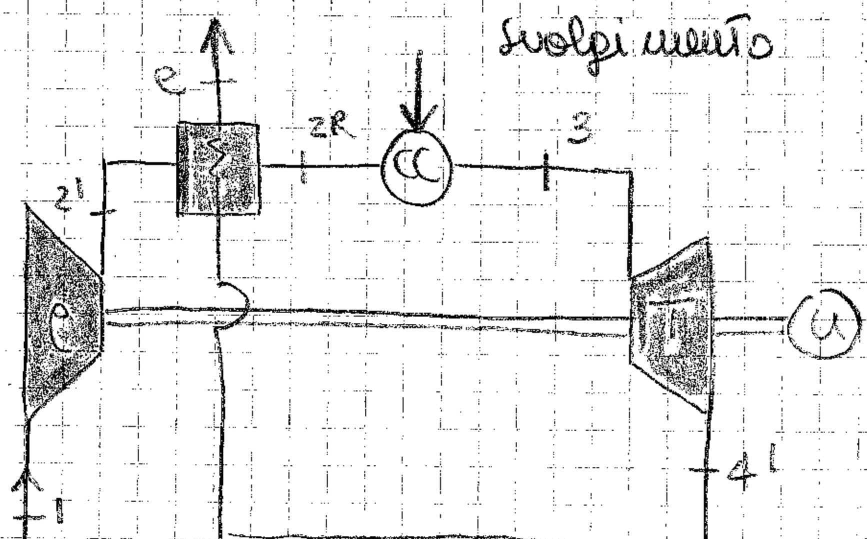
$\eta_{pc} = 0,8$ $\quad R = 0,287$ kJ/kgK

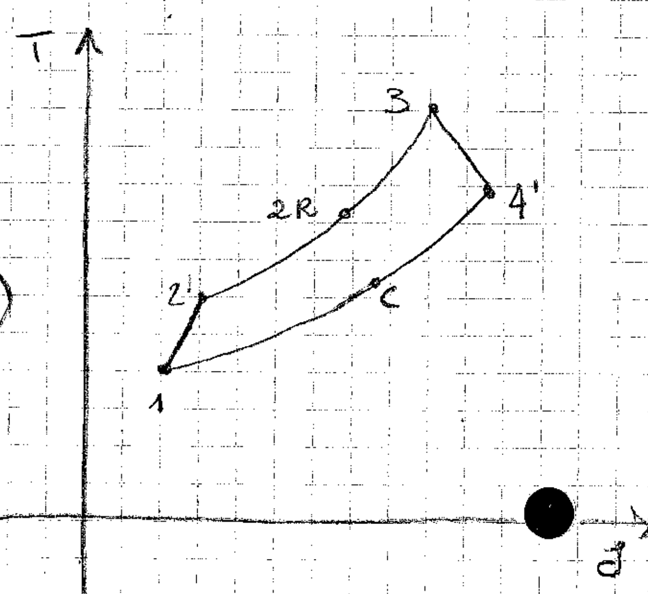
$\eta_{pT} = 0,9$ $\quad H_i = 42500$ kJ/kg

$R = 0,8$ (GRADO DI RIGEN)

Calcolare $\frac{\Delta\eta}{\eta}$ (VARIAZIONE (INCREMENTO) DI η) e T_C (Temperatura out gas)

Svolgimento





$$\frac{\Delta\eta}{\eta} = \frac{\eta_t^R - \eta_t}{\eta_t} \cdot 100$$

STUDIO anzitutto l'impianto NON Rigenerato e ne calcolo η_t

$$\eta_t = \frac{P_t}{Q_a}$$

$$P_t = \dot m_{gv}(l_{iT}) - \dot m_a(l_{ic})$$

$$l_{rc} = h_{2'} - h_1 = \frac{k}{k-1} R T_1 \left(\beta^{\lambda/\eta_{pc}} - 1 \right)$$

$$= 1{,}0045 \cdot 288 \left(5^{0{,}2857/0{,}8} - 1 \right) = 225 \text{ kJ/kg}.$$

$$l_{rT} = h_3 - h_{4'} = \frac{k}{k-1} R T_3 \left(1 - \left(\frac{1}{\beta}\right)^{\lambda \cdot \eta_{pT}} \right)$$

$T_3 = ?$ BILANCIO SUL COMBUSTORE (ENERGIA)

$$\dot{Q}_a = \eta_b H_i \dot{m}_c = \dot{m}_{gv} (h_3 - h_{2'})$$

$$T_3 = T_{2'} + \frac{\eta_b H_i}{(\alpha+1) \frac{k}{k-1} R} = 512 + \frac{0{,}98 \cdot 42500}{(33+1) \cdot 1{,}0045}$$

$$= 1732 \text{ K}$$

$$T_{2'} = \beta^{\lambda/\eta_{pc}} \cdot T_1 = 288 \cdot 5^{0{,}2857/0{,}8} = 512 \text{ K}$$

$$l_{r2} = 1{,}0045 \cdot 1732 \left(1 - \left(\frac{1}{5}\right)^{0{,}2857 \cdot 0{,}9} \right) = 589{,}6 \text{ kJ/kg}$$

$$P_r = 103{,}03 \cdot 589{,}6 - 100 \cdot 225 = 38{,}25 \text{ MW}$$

- BILANCIO DI MATERIA AL COMBUSTORE:

$$\dot{m}_{gv} = \dot{m}_a + \dot{m}_c = 100 + 3{,}03 = 103{,}03 \text{ kg/s}.$$

$$\dot{m}_c = \frac{\dot{m}_a}{\alpha} = \frac{100}{33} = 3{,}03 \text{ kg/s}$$

$$\dot{Q}a = \dot{m}_{gv}(h_3 - h_{2'}) = \dot{m}_{gv}\frac{k}{k-1}R(T_3 - T_{2'})$$

$$= 103{,}03 \cdot 1{,}0045(1732 - 512) = 126{,}3\ MW$$

$$\eta_t = \frac{38{,}25}{126{,}3} = 0{,}303$$

Con Rigenerazione

$$\eta_t^R = \frac{P_t^R}{\dot{Q}_a^R} = \frac{38{,}25}{72{,}24} = 0{,}53$$

$$P_t^R \simeq P_t$$

$$\dot{Q}_a^R = \dot{m}_{gv}(h_3 - h_{2R}) < \dot{m}_{gv}(h_3 - h_2) = \dot{Q}a$$

$$\dot{Q}_a^R = 103{,}03(1732 - \underbrace{1034}_{T_{2R}}) \cdot 1{,}0045 = 72{,}24\ MW$$

$T_{2R} = ?$

Grado di Rigenerazione

$$R = \frac{\dot{m}_a(h_{2R} - h_{2'})}{\dot{m}_g(h_{4'} - h_{2'})} \simeq \frac{\dot{m}_a(T_{2R} - T_{2'})}{\dot{m}_g(T_{4'} - T_{2'})}$$

← sto ipotizzando che nei gas combusti vi sia lo pratica aria per cui $c_{p_g} \simeq c_{pa}$

$$T_{2R} = T_{2'} + \frac{R(T_{4'} - T_{2'})\dot{m}_g}{\dot{m}_a}$$

$$= 512 + \frac{0{,}8 \cdot (1145 - 512) \cdot 103{,}03}{100} = 1034\ K$$

$$T_{4'} = T_3 \cdot \left(\frac{1}{\beta}\right)^{\lambda \beta \eta_{pt}} = 1732 \cdot \left(\frac{1}{5}\right)^{0,2857 \cdot 0,9} = 1145\ K$$

$$\frac{\Delta \eta}{\eta} = \frac{0,53 - 0,303}{0,303} \cdot 100 = 74,92\ \%$$

- Calcolo temperatura T_C

Faccio un bilancio al Rigeneratore:

$$\dot{m}_{gv} (-h_e + h_{4'}) = \dot{m}_a (h_{2R} - h_{2'})$$

$$\dot{m}_{gv} \cancel{c_p} (T_{4'} - T_C) = \dot{m}_a \cancel{c_p} (T_{2R} - T_{2'})$$

$$T_C = T_{4'} - \frac{\dot{m}_a (T_{2R} - T_{2'})}{\dot{m}_{gv}} = 1145 - \frac{100 \cdot (1034 - 512)}{103,03}$$

$$T_C = 638\ K$$

④ Turbina a gas RISCALDAMENTO RIPETUTO

DATI: $\dot{m}_a = 10000\ kg/h = 2,78\ \frac{kg}{s}$ $\eta_{at} = 0,8726$

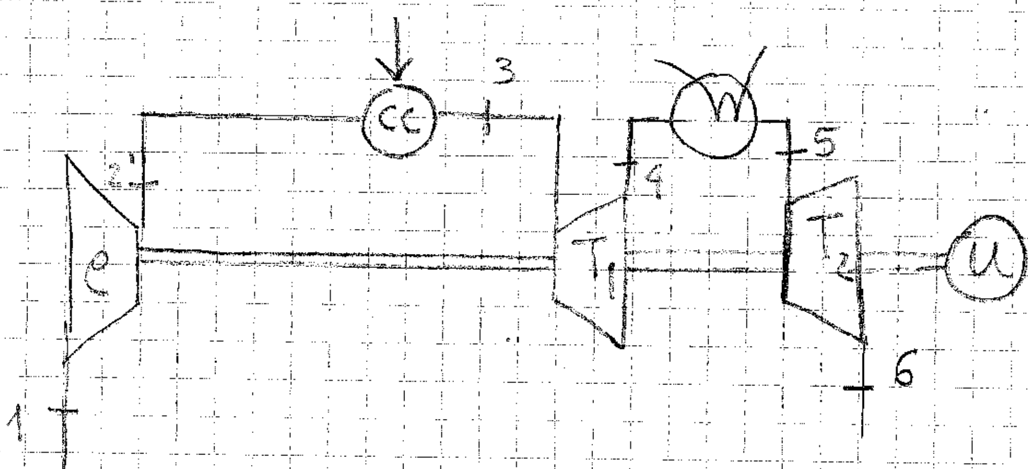
$\bar{\beta} = 36$ $R = 287\ J/kgK$

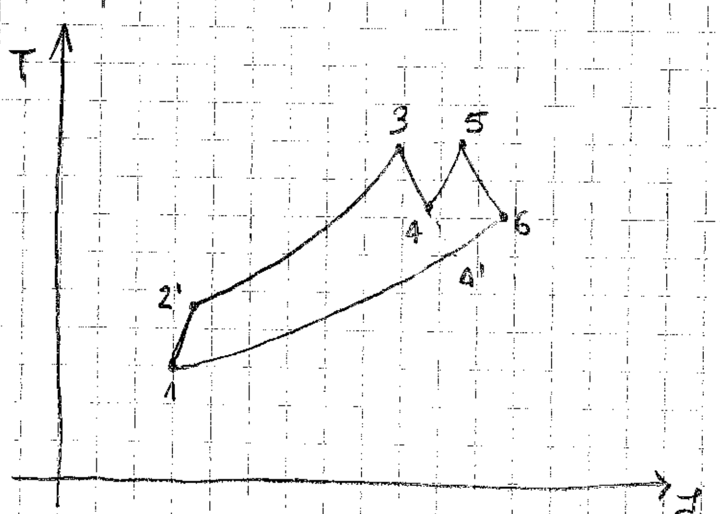
$T_3 = T_{IN} = 1000°C$ $k = 1.4$

$\frac{\Delta P_r}{P_r} = 0,1721$ $\frac{l_{rt1}}{l_{rt2}} = 1,951$

(Si trascuri l_r compress.)

Calcolare $\eta_{at}^{RR} = ?$





$$\frac{\Delta P_r}{P_r} = \frac{P_r^{RR} - P_r}{P_r} = 0,1721$$

$P_r = ?$ Potenza Reale senza RR

$$P_r = \dot{m}_a (l_{rT} - \cancel{l_{rC}}) = \dot{m}_a\, l_{rT}$$

$$l_{rT} = h_3 - h_{4'} = \frac{k}{k-1} R T_3 \left(1 - \left(\frac{1}{\beta}\right)^{\lambda \cdot \eta_{pt}} \right) = \frac{k}{k-1} R T_3 \left(1 - \left(\frac{1}{\beta}\right)^{\lambda} \right) \eta_{at} \quad (1)$$

Dal momento che $\eta_{at} = \frac{l_{rT}}{l_{isoT}} \Rightarrow l_{rT} = \eta_{at} \cdot l_{isoT}$ e quindi uso la (1)

$$l_{rt} = 0{,}8726 \cdot 1{,}0045 \cdot 1273 \cdot \left(1 - \left(\frac{1}{36}\right)^{0{,}2857}\right) = 715 \text{ kJ/kg}$$

$$P_{rT} = \dot{m}_a \, l_{rT} = \frac{10000}{3600} \cdot 715 = 1988 \text{ kW}$$

$$P_r^{RR} = 0{,}1721 \cdot 1988 + 1988 = 2330 \text{ kW}.$$

$$P_r^{RR} = \dot{m}_e \, l_{rt}^{RR} \Rightarrow l_{rt}^{RR} = \frac{2330}{2{,}78} = 838 \text{ kJ/kg}.$$

$$\begin{cases} l_r^{RR} = l_{rt1} + l_{rt2} = 838 \\ \frac{l_{rt1}}{l_{rt2}} = 1{,}951 \end{cases} \Rightarrow \begin{cases} (1{,}951 + 1)\, l_{rt2} = 838 \text{ kJ/kg}. \\ l_{rt1} = 1{,}951 \cdot l_{rt2} \end{cases}$$

$$\begin{cases} l_{rt2} = 284 \text{ kJ/kg} \\ l_{rt1} = 554 \text{ kJ/kg} \end{cases}$$

$$l_{rt1} = h_3 - h_4 = \frac{k}{k-1} R \, T_3 \left(1 - \left(\frac{1}{\beta_1}\right)^{\lambda \cdot \eta_{pt1}}\right) \qquad (2)$$

$\eta_{pt1} = \eta_{pt2} = \eta_{pt} = ?$

$$\eta_{at} = \frac{1 - (1/\beta)^{\lambda \cdot \eta_{pt}}}{1 - \left(\frac{1}{\beta}\right)^{\lambda}} \Rightarrow \eta_{pt} = \frac{\ln\left(1 - \eta_{at}\left(1 - \left(\frac{1}{\beta}\right)^{\lambda}\right)\right)}{\lambda \ln(1/\beta)}$$

$$\eta_{pt} = \frac{\ln\left(1 - 0{,}8726\left(1 - \left(\frac{1}{36}\right)^{0{,}2857}\right)\right)}{0{,}2857 \cdot \ln\left(\frac{1}{36}\right)} = \frac{-0{,}819}{-1{,}024} = 0{,}799$$

Dalle (2) ricavo β_1:

$$\left(\frac{1}{\beta_1}\right)^{\lambda \eta_{pt}} = 1 - l_{2t1} \frac{k-1}{k\, RT_3}$$

$$\frac{1}{\beta_1} = \left(1 - l_{2t1} \cdot \frac{k-1}{k} \cdot \frac{1}{RT_3}\right)^{1/\lambda \cdot \eta_{pt}} = \left(1 - 554 \cdot \frac{0{,}2857}{0{,}287 \cdot 1273}\right)^{\frac{1}{0{,}799 \cdot 0{,}2857}}$$

$$\frac{1}{\beta_1} = 0{,}08313 \Rightarrow \beta_1 = 12 \Rightarrow \beta_2 = \frac{\bar{\beta}}{\beta_1} = 3$$

$$\eta_{at_1} = \frac{1 - \left(\frac{1}{\beta_1}\right)^{\lambda \cdot \eta_{pt}}}{1 - \left(\frac{1}{\beta_1}\right)^{\lambda}} = \frac{1 - \left(\frac{1}{12}\right)^{0{,}2857 \cdot 0{,}799}}{1 - \left(\frac{1}{12}\right)^{0{,}2857}} = 0{,}8516$$

$$\eta_{at_2} = \frac{1 - \left(\frac{1}{\beta_2}\right)^{\lambda \cdot \eta_{pt}}}{1 - \left(\frac{1}{\beta_2}\right)^{\lambda}} = \frac{1 - \left(\frac{1}{3}\right)^{0{,}2857 \cdot 0{,}799}}{1 - \left(\frac{1}{3}\right)^{0{,}2857}} = 0{,}823$$

$$\eta_{at}^{RR} = \frac{\beta_1 \eta_{at_1} + \beta_2 \eta_{at_2}}{\beta_1 + \beta_2} = \frac{12 \cdot 0{,}8516 + 3 \cdot 0{,}823}{15} = 0{,}846$$

(5) Turbina a gas con interrefrigerazione

DATI:

$T_1 = 15°C$	$\lambda = 59{,}7$
$\beta_c = 30 = \beta_t$	$\dot{m}_a = 100$ kg/s
$\eta_{pc} = 0{,}8$	$H_i = 42500$ kJ/kg
$\eta_{pt} = 0{,}9$	$\Delta q_a = 68{,}5$ kJ/kg
$\eta_b = 0{,}98$	Calcolare $\frac{\Delta\eta}{\eta}$ e Δl_u ? (NON quello MAX)