Exemple (1)

Exo Turbine a gaz

1) A Low pressure Turbine, Constrain of 5 repeating stage. $T_{01} = 1200\,K$ and $P_{01} = 213\,Kpa$.

$\dot{m} = 15\,Kg/s$ and generate 6,64 MW of mechanical power.

$\alpha_1 = 15°$ زاوية دخول stator

$\alpha_2 = 70°$ ~~زاوية دخول~~ زاوية الخروج من stator

مثلث

Triangle de vitesse

The turbine mean radius 0,48m and

$W = 5600\,rpm$

A- calcule loading coefficient of (ψ) stage and flow coeffici (ϕ)

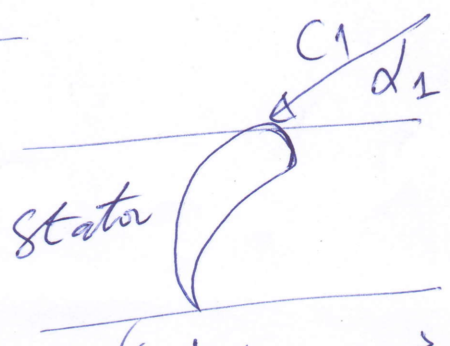
avec $R = 0,5$ and calculate

2) ~~axi~~ Small are and high of blad

* Take = $\gamma = 1,333$, $R = 287\,\frac{J}{Kg.K}$

$c_p = 1150\,J/Kg.K$

Solution



* أرسم مثلثات السرعة

(CE) تلخيص المرن =

data =

No of stage = 5

$T_{01} = 1200 K$

$P_{01} = 213 kPa$

$\dot{m} = 15 kg/s$

$P_{mech} = 6,64 MW$

$N = 5600 rpm$

$\alpha_1 = 15^\circ$

$\alpha_2 = 70^\circ$

Deg × Required = ψ, ϕ

Make sure that $R = 0.5$

Required A_x, H, HTR

For first stator stage.

$$U = \omega r = \frac{2\pi N}{60} \cdot \frac{D}{2} = \pi \cdot \frac{5600 \times 0{,}46 \times 2}{60} = 269{,}75 \, m/s$$

$$\cancel{\psi = \frac{\Delta W_{stage}}{2 \cdot U^2} = \frac{6{,}64 \cdot 10^6}{5}}$$

$$\psi = \frac{\Delta h_{stage}}{U^2} , \quad \boxed{\Delta h_{stage} = \frac{\Delta W_{stage}}{\dot m}}$$

$$\text{and } \Delta h_{stage} = \frac{\Delta h_T}{5}$$

عدد المراحل → 5

وبما أنه قال "Repeating stage" أي أن المراحل تعطي نفس كمية العمل

$$\psi = \frac{\Delta W_{stage}}{\dot m \cdot U^2} = \text{إذن}$$

الإنشطة ← ΔW_{stage}

ψ = Loading coefficient / coefficient de chargement

$$\psi = \frac{6{,}64 \cdot 10^6}{5 \cdot 15 \cdot (269{,}75)^2} = 1{,}216$$

$$\psi = \phi \left[\tan\alpha_2 + \tan\alpha_3 \right] = \text{من جهة أخرى عندنا}$$

Repeating stage = ومعناه

$$\boxed{\alpha_3 = \alpha_1} = \text{إذن}$$

Rotor زاوية الخروج من

stator زاوية الدخول إلى

$$\phi = \frac{\psi}{\tan\alpha_2 + \tan\alpha_3} = \frac{1,216}{\tan 70 + \tan 15} =$$

$$\phi = 0,40325$$

* التأكد من $R = 0,5$

$$R = 1 + \frac{\phi}{2}\left[\tan\alpha_3 - \tan\alpha_2\right]$$

$$= 1 + \frac{0,40325}{2}\left[\tan 15 - \tan 70\right] \approx 0,4999 \approx$$

$$\approx 0,5.$$

B) * $\dot{m} = \rho_{01} C_x A_{x_1}$, $\boxed{\phi = \frac{C_x}{U}}$ $\Rightarrow C_x = \phi \cdot U$

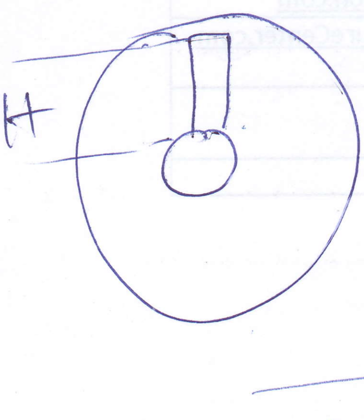
~~$\Rightarrow C_x = 0,40325$~~

$$\rho_{01} = \frac{P_{01}}{R T_{01}} = \frac{213\,10^3}{287 \cdot 1200} = 0,6184 \ kg/m^3$$

$$C_x = 0,40325 \cdot 269,75 = 108,77 \ m/s$$

$$A_{x_1} = \frac{\dot{m}}{\rho_{01} C_x} = 0,223 \ m^2$$

* H ?



$$, \ A_{x_1} = 2\pi r_m \cdot H$$

$$\Rightarrow H = \frac{A_{x_1}}{2\pi r_m} = 77,15 \ mm$$

Hub To Tib ratio : $HTR = \frac{D_H}{D_T} = \frac{r_H}{r_T}$

$$= \frac{r_m - H/2}{r_m + H/2} = \frac{0,46 - \frac{0,07715}{2}}{0,46 - \frac{0,07715}{2}} = 0,8452$$

EXO 2 = A single stage gas turbine, with (3)

absolute axial flow at entry exit from the stage.

$(\alpha_2 = 70 , \alpha_1 = 0)$. $T_{01} = 1123 K$, $P_{01} = 311 kPa$

$P_3 = 100 kPa$

D' η_{TT} ... (a het)

Data

$C_1 = C_3 = C_x$

$\alpha_2 = 70°C$

$\alpha_1 = 0 C$

$C_p = 1.148 \, kJ/kg.K$

$P_{01} = 311 kPa$

$T_{01} = 1123 K$

$P_3 = 100 kPa$

$\eta_{TS} = 87\%$

$U = 500 m/s$

1) $\Delta W ? = \Delta h$

2) $M ?$

3) $C_x ?$

D) $\eta_{TT} ?$

E) $R ?$

$$\eta_{TS} = \frac{h_{01} - h_{03}}{h_{01} - h_{3s}} = \frac{\Delta W}{c_p T_{01}\left[1 - \left(\frac{P_3}{P_{01}}\right)^{\frac{\gamma-1}{\gamma}}\right]}$$

$$\Delta W = \Delta h = \eta_{TS} \, c_p T_{01}\left[1 - \left(\frac{P_3}{P_{01}}\right)^{\frac{\gamma-1}{\gamma}}\right]$$

$$= 0.87 \times 1.148 \times 1123 \left[1 - \left(\frac{100}{311}\right)^{\frac{1.33-1}{1.33}}\right]$$

$$= 0.87 \cdot 1148 \cdot 1123 \left[1 - \left(\frac{100}{311}\right)^{\frac{1.33-1}{1.33}}\right]$$

$$= 275.204 \, kJ/kg$$

2) Mach number leaving the Nozzle

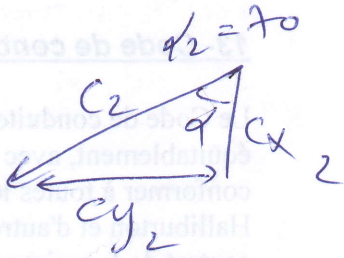
2

$$M_2 = \frac{C_2}{a_2} = \frac{C_2}{\sqrt{\gamma R T_2}}$$

$$\Delta W = U(C_{y_2} + C_{y_3}) \qquad C_3 = C_x$$

$$C_{y_3} = \text{zero}.$$

$$\Delta W = U C_{y_2} \Rightarrow C_{y_2} = 510{,}40 \ m/s$$



$$C_2 = \frac{C_{x_2}}{\cos \alpha_2} \ \checkmark$$

$$C_{x_2} = C_2 \cos \alpha_2 \rightarrow (1)$$

$$\sin \alpha_2 = \frac{C_{y_2}}{C_2} \Rightarrow C_2 = \frac{C_{y_2}}{\sin \alpha_2} = \frac{510{,}40}{\sin 70} =$$

$$543{,}17 \ m/s$$

across Rotor $h_{02} \neq h_{03}$

Stator $h_{01} = h_{02}$

so $\boxed{T_{01} = T_{02}}$

$$\left\{ \begin{array}{l} T_{01} = T_1 + \dfrac{C_1^2}{2c_p} \\ T_{02} = T_2 + \dfrac{C_2^2}{2c_p} \end{array} \right\} \Rightarrow T_2 = T_{02} - \frac{C_2^2}{2c_p} =$$

$$= 973{,}57 K$$

32

$$M_2 = \frac{C_2}{\sqrt{\gamma R T_2'}} = \frac{585,7}{\sqrt{1,33 \cdot 284 \cdot 973,17}} = 0,946$$

* for gas dynamics $\Rightarrow$ $\boxed{R = \frac{\gamma - 1}{\gamma} C_p}$

$$R = 284,84 \ \frac{J}{kg \cdot K}$$

C) axial velocity

$$C_x = C_2 \cos \alpha_2 = 585,7 \cos 70 = 200,324 \ m/s$$

D) η_{TT}?

$$\eta_{TT} = \frac{h_{01} - h_{03}}{h_{01} - h_{03ss}} = \frac{W}{h_{01} - h_{3s} - \frac{1}{2} C_3^2}$$

$$\frac{1}{\eta_{TT}} = \frac{h_{01} - h_{3s} - \frac{1}{2} C_3^2}{W} = \frac{1}{\eta_{TS}} - \frac{\frac{1}{2} C_3^2}{W}$$

$$\frac{1}{\eta_{TT}} = \frac{1}{0,87} - \frac{\frac{1}{2} (200,324)^2}{275,2 \cdot 10^3} \Rightarrow$$

$$\Rightarrow \eta_{TT} = 92,87 \%$$

(E) R of stage [stage ratio] = (34)

$\alpha_1 = \alpha_3 = \text{zero}, \alpha_2 = 70$

$$R = 1 + \frac{\phi}{2}[\tan \alpha_3 + \tan \alpha_2]$$

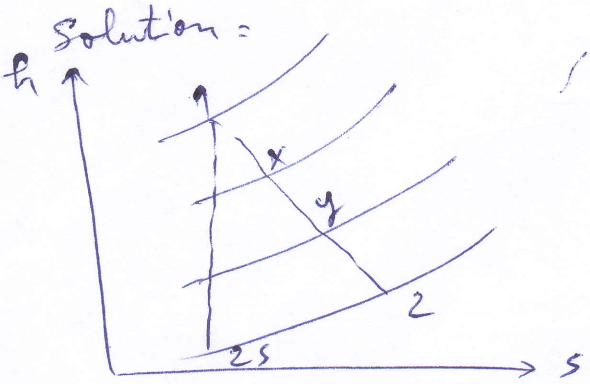
zero

$$R = 1 + \frac{C_x}{2U}[\tan \alpha_3 - \tan \alpha_2]$$

$$R = 1 + \frac{200.32}{2 \cdot 500}[-\tan 70] = 0,4494$$

Ex01 . A gas turbine expands the exhaust gases from a pressure of 7 bars and Temperature of 300 °C to a pressure of 1,5 bars. the turbine has 3 stages and each stage develops equal work. The Turbine has actual enthalpy drop of 200 kJ/kg. for first stage calculate its efficiency and compare it with turbine efficiency. Take $\begin{cases} K = 1,34 \\ C_p = 1180\ J/kg.K \end{cases}$

Solution:



$$\Delta h_T = C_p \Delta T_T = C_p (T_1 - T_2)$$

$$T_2 = T_1 - \frac{\Delta h_T}{C_p} = 130,5\ °C$$

$$T_2 = 300 - \frac{200}{1,8} = 130,5\ °C$$

$$W = C_p T_1 \left[1 - (P_r)^{\frac{\gamma-1}{\gamma}\eta_p}\right]$$

$$\ln\left[P_r^{\frac{1-\gamma}{\gamma}\eta_p}\right] = \ln\left[1 - \frac{W}{C_p T_1}\right]$$

$$\frac{T_2}{T_1} = \left(\frac{P_2}{P_1}\right)^{\frac{\gamma-1}{\gamma}\eta_p} = \left(\frac{P_1}{P_2}\right)^{\frac{\gamma-1}{\gamma}}$$

$$\eta_p \ln\left(P_r^{\frac{\gamma-1}{\gamma}}\right) = \ln\left[1 - \frac{W}{C_p T_1}\right]$$

$$\Rightarrow \eta_p = \frac{\ln\left[1 - \frac{W}{C_p T_1}\right]}{\ln\left[P_r^{\frac{\gamma-1}{\gamma}}\right]} = \frac{\ln\left[1 - \frac{200}{1,18\cdot[300+273]}\right]}{\ln\left[\left(\frac{1,5}{7}\right)^{\frac{0,34}{1,34}}\right]}$$

$$\eta_p = \frac{-0,3509}{-0,390} = 89,93\,\% \rightarrow K$$

for first stage:

$$\left(\frac{T_1}{T_x}\right) = \left(\frac{P_1}{P_x}\right)^{\frac{\gamma-1}{\gamma}\eta_p} = (P_{rst})^{\frac{\gamma-1}{\gamma}\eta_p}$$

$$\Delta h_T = C_p \Delta T_T \Rightarrow \Delta T_T = \frac{\Delta h_T}{C_p} = \frac{200}{1,8} = 169,49\ °C$$

$$\Delta T_i = \frac{\Delta T_T}{K} = \frac{169,49}{3} = 56,49\ °C \Rightarrow T_x = T_1 - \Delta T_i = 300 - 56,49 = 243,50\ °C$$

$$\Rightarrow Pr_{st} = \left[\frac{T_1}{T_x}\right]^{\frac{1}{\left[\frac{(\gamma-1)}{\gamma}\eta_p\right]}} = \left[\frac{T_1}{T_x}\right]^{\frac{\gamma}{\eta_p[\gamma-1]}}$$ ②

?

$$\boxed{Pr_{st} = 1{,}58 = P_1/P_2}$$

?

$$\eta_{st_1} = \frac{T_1 - T_x}{T_1 - T_{xs}} = \frac{T_1 - T_x}{T_1\left(1 - (Pr_{st})^{\frac{1-\gamma}{\gamma}}\right)} =$$

? $\frac{T_x}{T_1}$

$$= \frac{300 - 243.5}{573\left(1 - (1{,}58)^{\frac{-0{,}34}{1{,}34}}\right)} = 89{,}9\%$$

$$\eta_T = \frac{T_1 - T_2}{T_1\left(1 - (Pr_T)^{\frac{1-\gamma}{\gamma}}\right)} = \frac{300 - 130{,}5}{573\left(1 - \left(\frac{7}{1{,}5}\right)^{\frac{-0{,}4}{1{,}34}}\right)} = 91{,}43\%$$

Note $\boxed{\eta_T > \eta_{sT} > \eta_p}$

"reheat factor"

Exo 2:

single stage axial flow air compressor operates at a pressure ratio 5. the axial velocity constant throughout the compressor the total efficiency of the compressor is 85%. Calculate the stage efficiency if equal pressure ratio per stage is assumed.

$Pr_{st} = \text{cost}$, $Pr_{ST} = 5$.

$\gamma = 1{,}3$,

$\eta_{T.T\,av} = 85\%$; $K = 1$

$$\eta_c = \frac{(Pr_{st})^{\frac{\gamma-1}{\gamma}K} - 1}{(Pr_{st})^{\frac{\gamma-1}{\gamma}\cdot\frac{K}{\eta_p}} - 1}$$

$$(P_{rst})^{\frac{\gamma-1}{\gamma}\cdot\frac{k}{\eta_p}} = \frac{(P_{rst})^{\frac{\gamma-1}{\gamma}\cdot k} - 1}{\eta_c} + 1$$

$$\frac{1}{\eta_p}\ln\left[(P_{rst})^{\frac{(\gamma-1)k}{\gamma}}\right] = \ln\left[\frac{(P_{rst})^{\frac{(\gamma-1)}{\gamma}\cdot k} - 1}{\eta_c} + 1\right]$$

$$\eta_p = \frac{\ln\left[(P_{rst})^{(\frac{\gamma-1}{\gamma})k}\right]}{\ln\left[\frac{(P_{rst})^{(\frac{\gamma-1}{\gamma})\cdot k} - 1}{\eta_c} + 1\right]} = \frac{\ln\left[(5)^{\frac{0,3}{1,3}\cdot 1}\right]}{\ln\left[\frac{5^{\frac{0,3}{1,3}} - 1}{0,85} + 1\right]}$$

$$= \frac{0,371}{0,425} = 0,87$$

$$\eta_{st} = \frac{(P_{rst})^{\frac{\gamma-1}{\gamma}} - 1}{(P_{rst})^{\frac{\gamma-1}{\gamma}\cdot\frac{1}{\eta_p}} - 1} = 85\%$$

منطقي ان تكون كفاءة المرحلة = كفاءة الضاغط لان الضاغط مرحلة واحدة

وهكذا اذا كانت أكثر من مرحلة $\eta_p > \eta_{st} > \eta_c$

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(3) - for the adiabatic expansion of a perfect gas through a turbine show that the overall efficiency η_t and small efficiency η_p are related by : $\eta_T = \frac{1 - \varepsilon^{\eta_p}}{1 - \varepsilon}$ avec $\varepsilon = \left(\frac{P_1}{P_2}\right)^{\frac{1-\gamma}{\gamma}}$

* An axial flow turbine has a small stage efficiency of 86% an overall pressure ratio of 4,5 to 1 and a mean value of γ equal to 1,33. calculate the overall turbine efficiency.

$\eta_p = 88\%$

$Pr = 4.5$

$\gamma = 1.33$

$$\eta_T = \frac{1 - (4.5)^{\frac{-0.33}{1.33} \cdot 0.86}}{1 - (4.5)^{\frac{-0.33}{1.33}}} = 88\%$$

Note $\eta_T > \eta_p$

بعد الشرح في الجزء الخاص بالشرح

⑤ Air is expanded in a multi-stage axial flow turbine. The pressure drop across each stage being very small. Assuming that air behaviour as a perfect gas with ratio of specific heats γ derive pressure – temperature relationship for the flowing processes:

a) Reversible adiabatic expansion.

b) Irreversible adiabatic expansion, with small stage efficiency η_p.

c) ~~Irreversible~~ Reversible expansion in which the heat loss in each stage is a constant fraction k of the enthalpy drop in that stage ($dq = k\,dh$ = ٤ لين)

d) Reversible expansion in which the heat loss is proportional to the absolute temperature T ($\delta q = T \cdot ds$ ٤ لين)

e) Sketch the first three processes on a T-S diagram. The entry Temperature is 1200 K. and the pressure ratio across the turbine is 6.

1) Calculate the exhaust temperature in each of these cases. Assume that γ is 1.333, that $\eta_p = 0.87$ and that $k = 0.1$.

ملاحظة مهمة جدا !!

تطبيق القانون الأول الترموديناميك لنظام مفتوح

$$dQ + dW = \underbrace{dQ + d(PV)}_{} + d\cancel{E_c} + d\cancel{E_p}$$

$dE_c = 0$, $dE_p = 0$: Turbine or Compressor

$$\Rightarrow \boxed{dQ + dW = dh}$$

$$dW = \int^{2} v\,dP = \text{شغل نظام مفتوح}$$

$dW = v\,dP$

مثال

Reversible + adiabatique $\Rightarrow$ isentropique :

$$\cancel{dQ} + dW = dh \Rightarrow dW = dh$$

$dQ = 0$

$$\Rightarrow \boxed{dh = v\,dP}$$

$$\begin{cases} PV = RT \Rightarrow V = \dfrac{RT}{P} \\ dh = c_p\,dT = \dfrac{\gamma R}{\gamma - 1}\,dT \end{cases}$$

$$\frac{\gamma \cancel{R}}{\gamma - 1}\,dT = \cancel{R}T\,\frac{dP}{P} \Rightarrow \boxed{\frac{dT}{T} = \frac{\gamma - 1}{\gamma}\,\frac{dP}{P}}$$

$$\frac{T_2}{T_1} = \left(\frac{P_2}{P_1}\right)^{\frac{\gamma - 1}{\gamma}}$$

Solution :

a - Reversible - adiabatic Expansion :

$$\boxed{PV = RT}$$

$$T.\cancel{ds}_{\to 0} = dh - vdP \Rightarrow dh = vdP$$

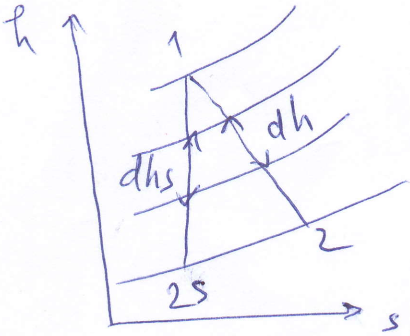
$$CpdT = \frac{dP}{\cancel{\beta}} \Rightarrow \frac{\gamma R}{\gamma - 1} dT = \frac{RT}{P} dP$$

$$\int_1^2 \frac{dT}{T} = \frac{\gamma - 1}{\gamma} \int_1^2 \frac{dP}{P}$$

$$\ln \frac{T_2}{T_1} = \frac{\gamma - 1}{\gamma} \ln \frac{P_2}{P_1} \Rightarrow \frac{T_2}{T_1} = \left(\frac{P_2}{P_1}\right)^{\frac{\gamma - 1}{\gamma}}$$

(غير رجعي)

b - irreversible adiabatic with "Small stage efficiency" η_p



$$\eta_p = \frac{dh}{dh_s}$$

$$dh = CpdT = \frac{\gamma R}{\gamma - 1} dT$$

$$dh_s = vdP = \frac{RT}{P} dP$$

$$\eta_p \frac{RT}{P} dP = \frac{\gamma R}{\gamma - 1} dT$$

$$\eta_p \frac{\gamma - 1}{\gamma} \int_1^2 \frac{dP}{P} = \int_1^2 \frac{dT}{T}$$

$$\frac{\gamma - 1}{\gamma} \eta_p \ln \frac{P_2}{P_1} = \ln \frac{T_2}{T_1}$$

$$\Rightarrow \frac{T_2}{T_1} = \left(\frac{P_2}{P_1}\right)^{\frac{\gamma - 1}{\gamma} \eta_p}$$

$$\boxed{dS = \frac{dQ}{T}}$$

$$S_2 - S_1 = \int_1^2 \frac{dQ}{T} + S_{gen}$$

c - Reversible expansion with heat loss $= K.dh$

from 1st law of thermodynamic :

~~$\delta Q = \delta W + dU$~~

~~$K.dh = Pdv$~~

$$\left\{\begin{array}{l} dU = dQ + dW \\ dQ = Kdh \\ dW = -PdV \end{array}\right.$$

$$\left.\begin{array}{l} K.dh = P.dV + dU \\ dh = PdV + VdP + dU \end{array}\right\} \begin{array}{l} dh = Kdh + VdP \\ (1-K)\underbrace{dh}_{CpdT} = VdP \end{array}$$

$$\frac{RT}{P}dP = \frac{\gamma R}{\gamma-1}(1-k)\,dT \Rightarrow \int_1^2 \frac{dT}{T} = \frac{\gamma-1}{\gamma}\left(\frac{1}{1-k}\right)\int_1^2 \frac{dP}{P}$$

$$\ln\left(\frac{T_2}{T_1}\right) = \frac{\gamma-1}{\gamma}\frac{1}{1-k}\ln\left(\frac{P_2}{P_1}\right) \Rightarrow \frac{T_2}{T_1} = \left(\frac{P_2}{P_1}\right)^{\frac{\gamma-1}{\gamma}\left(\frac{1}{1-k}\right)}$$

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d) Reversible expansion in wich the heat loss is proportional to absolute Temperature T. $\Rightarrow$ $\delta Q \propto T \longrightarrow \delta Q = T\cdot dS$.

$$\delta Q = \delta W + dU$$

$$T\cdot dS = PdV + dU$$

$$dS = \frac{PdV}{T} + \frac{dU}{T} \quad \text{ona } dU = c_v\,dT$$

$$\int_1^2 dS = R\int_1^2 \frac{dV}{V} + c_v\int_1^2 \frac{dT}{T}$$

$$S_2 - S_1 = R\ln\frac{V_2}{V_1} + c_v\ln\frac{T_2}{T_1}$$

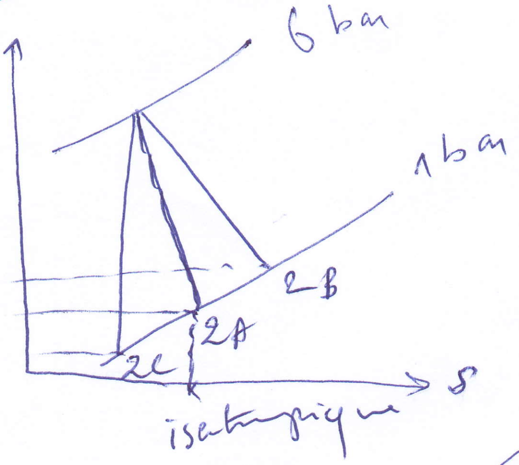
ona $\dfrac{P_2V_2}{P_1V_1} = \dfrac{T_2}{T_1}$

$$S_2 - S_1 = R\ln\frac{T_2}{T_1} + R\ln\frac{P_1}{P_2} + c_v\ln\frac{T_2}{T_1}$$

$$= (R + c_v)\ln\frac{T_2}{T_1} + R\ln\frac{P_1}{P_2} = c_p\ln\frac{T_2}{T_1} - R\ln\frac{P_2}{P_1}$$

$$S_2 - S_1 = \ln\left(\frac{T_2}{T_1}\right)^{c_p} - \ln\left(\frac{P_2}{P_1}\right)^{R} = \ln\left[\frac{\left(\frac{T_2}{T_1}\right)^{c_p}}{\left(\frac{P_2}{P_1}\right)^{R}}\right]$$

$$e^{(S_2-S_1)} = \frac{\left(\frac{T_2}{T_1}\right)^{c_p}}{\left(\frac{P_2}{P_1}\right)^{R}} \Rightarrow \left(\frac{T_2}{T_1}\right) = \left[\left(\frac{P_2}{P_1}\right)^{R}\cdot e^{\Delta S}\right]^{\frac{1}{c_p}}$$

e) 

Ⓐ $\frac{T_2}{T_1} = \left(\frac{P_2}{P_1}\right)^{\frac{\gamma-1}{\gamma}} \Rightarrow T_{2A} = 767K.$ ($\frac{1}{Pr}$)

B) $\frac{T_1}{T_2} = (Pr)^{\frac{\gamma-1}{\gamma}\eta_p} \Rightarrow T_{2B} = 813\,K$ (Reversib

C) $\frac{T_1}{T_2} = (Pr)^{\frac{\gamma-1}{\gamma}\cdot\frac{1}{1-K}} \Rightarrow T_{2C} = 729{,}7\,K$

$$T_{2B} > T_{2A} > T_{2C}.$$

Exo 6: A multi stage high pressure steam turbine is applied with steam at a stagnation pressure of 7 Mpa absolute and a stagnation temperature of 500°C. the corresponding specific enthalpy is 3420 kJ/kg the steam exhaust from the turbine at stagnation pressure of 0,7 MPa absolute, the steam having been a superheated condition throughout the expansion. it can be assumed that the steam behaves like a perfect gas over the range of the expansion and the $\gamma = 1{,}3$.
Given that the turbine flow process has a small-stage efficiency of 0,82, and $\eta_{st} = 0{,}82$.

determine :

1) the temperature and specific volume at the end of the expansion

2) the reheat factor

* the specific volume of superheated steam is represented by $pv = 0{,}24(h - 1945)$, where p is in kpa, v is in m^3/kg and h is in kJ/kg.

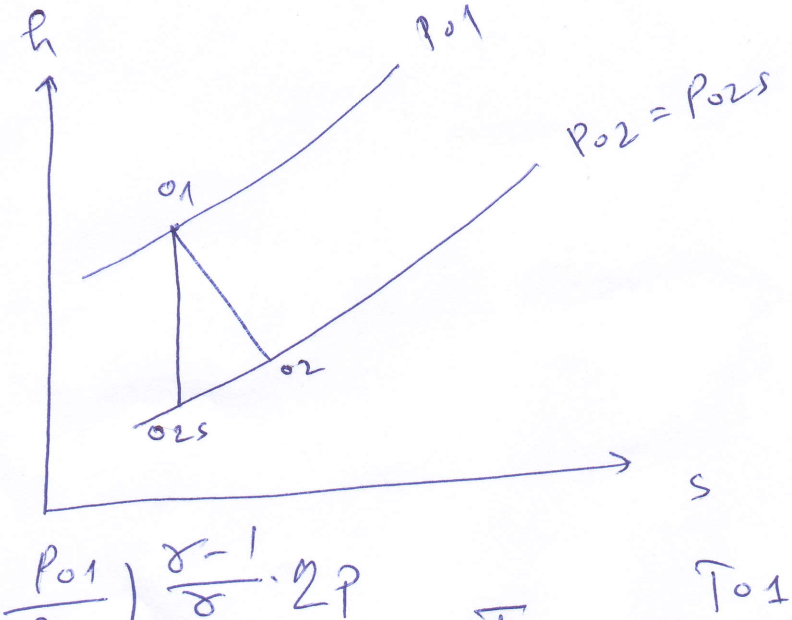
solution =

$$\begin{cases} P_{01} = 7\ MPa \\ T_{01} = 500\ °C \\ h_{01} = 3420\ kJ/kg \end{cases}$$

$\gamma = 1{,}3$

$\eta_p = 82\%$

$$\begin{cases} P_{02} = ? \\ T_{02} = ? \\ R.F. ? \end{cases}$$



1) $\frac{T_{01}}{T_{02}} = \left(\frac{P_{01}}{P_{02}}\right)^{\frac{\gamma-1}{\gamma}\cdot \eta_p} \Rightarrow T_{02} = \frac{T_{01}}{\left(\frac{P_{01}}{P_{02}}\right)^{\frac{\gamma-1}{\gamma}\eta_p}}$

A.N. $T_{02} = \frac{273 + 500}{\left(\frac{7}{0{,}7}\right)^{\frac{0{,}3}{1{,}3}} \cdot 0{,}82} = 500\,K$

2) $PV = 0{,}24(h - 1945)$

$P_1 V_1 = 0{,}24(h_1 - 1945) \Rightarrow V_1 = \frac{0{,}24(h_1 - 1945)}{P_1}$

A.N $\Rightarrow$ $V_1 = \frac{0{,}24(3420 - 1945)}{7\,10^3} = 0{,}05\,\frac{m^3}{kg}$

(9)

$$PV = RT \Rightarrow \begin{cases} P_{01} V_{01} = RT_{01} \\ P_{02} V_{02} = RT_{02} \end{cases} \Rightarrow \frac{P_{01} V_{01}}{P_{02} V_{02}} = \frac{T_{01}}{T_{02}}$$

$$\Rightarrow V_{02} = \frac{P_{01} V_{01} \cdot T_{02}}{P_{02} T_{01}}$$

A.N.:

$$V_{02} = \frac{7 \cdot 0{,}05 \cdot 773}{0{,}7 \cdot 500} = 0{,}323 \ m^3/kg$$

2) Reheat factor:

$$\boxed{\eta_T = RH \cdot \eta_{st}}$$

$$\boxed{\eta_p = \eta_{st} \text{ if } Pr \sim 1}$$

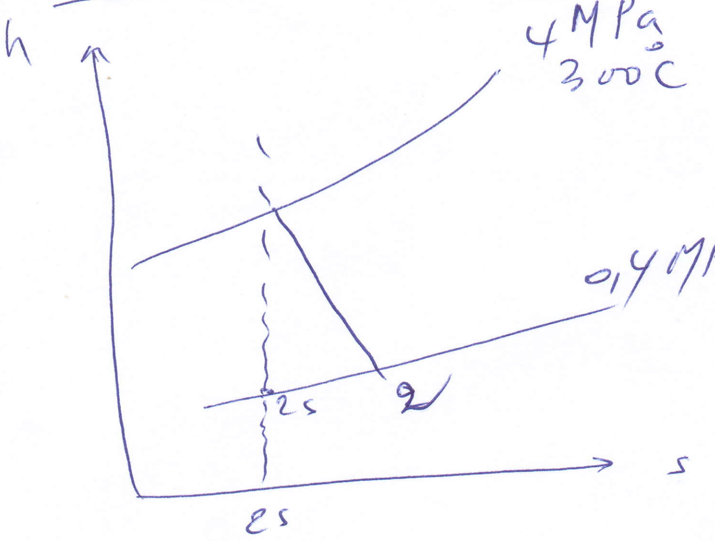
$$\eta_T = \frac{1 - P_r^{\frac{1-\gamma}{\gamma}\eta_p}}{1 - P_r^{\frac{1-\gamma}{\gamma}}} = \frac{1 - (10)^{\frac{-0{,}3}{1{,}3} \cdot 0{,}82}}{1 - (10)^{\frac{-0{,}3}{1{,}3}}} =$$

$$\eta_T = 85{,}5\%$$

$$RH = \frac{\eta_T}{\eta_p} = \frac{0{,}855}{0{,}82} = 1{,}0424$$

Exo 7: A 20 MW backpressure turbine recieves steam at 4 Mpa and 300 °C exhausting from the last stage at 0,4 MPa. the stage efficiency is 0,86, the reheat factor 1,05 and the external losses 2% of the ~~isentropic~~ enthalpy drop. Determine the rate of steam flow. At the exit from the first stage nozzle the steam is 245 m/s, specific volume 70 dm³/Kg, mean diameter 765 mm and steam exit angle 77 degree. Measured from the axial direction. Determine the nozzle exist height of this stage (No)

Solution



$$\begin{cases} \eta_{st} = 86\ \% \\ RH = 1{,}05 \\ 2\%\ \text{Loss} \\ V_1 = 245\ m/s \\ v_1 = 70\ \frac{dm^3}{kg} = 70 \cdot 10^{-3}\ \frac{m^3}{kg} \end{cases}$$

$(dm = 10^{-1}\,m \Rightarrow dm^3 = 10^{-3}\,m^3)$

$D_m = 765\ mm$

$\alpha_1 = 77°$

From Steam Table:

$h_1 = 2960\ kJ/kg$, $h_{2s} = 2500\ kJ/kg$

$$\eta_T = RH \cdot \eta_{st} = 1{,}05 \cdot 0{,}86 = 0{,}903$$

$$\eta_T = \frac{h_{01} - h_{02}}{h_{01} - h_{02s}} \Rightarrow h_{02} = h_{01} - \eta_T (h_1 - h_{2s})$$

$$h_2 = 2544{,}62\ kJ/kg$$

$$P = \eta_{Mex} (h_{01} - h_{02}) \cdot \dot{M}_{st}$$

(external Losses) $= 2\% \Leftrightarrow \boxed{\eta_{ex} = 98\%}$

$$\Rightarrow \dot{M}_{st} = \frac{P}{\eta_{Mex}(h_1 - h_2)}$$

$$\Rightarrow \dot{M}_{st} = \frac{20 \cdot 10^3}{98\,(2960 - 2544{,}6}$$

$$\boxed{\dot{M}_{st} = 49{,}13\ kg/s}$$

$$\eta = \frac{h_{01} - h_{02}}{h_{01} - h_{02ss}}$$

$\boxed{P = \dot{m}\,\Delta h\,\eta_{ext}}$

$\Delta h \cdot \dot{m}_{st}$ $\dot{m}_{st}$

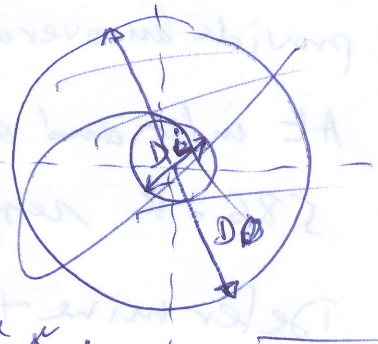
b) $\dot{M}_{st} = \rho_1 V_{x1} A_1 = \frac{V_x}{\nu_1} \cdot A_1$

$A = \frac{\pi}{4}(D_o^2 - D_i)^2$

$A = \frac{\pi}{4}(D_o - D_i)(D_o + D_i)$

$A = \pi * \frac{D_o - D_i}{2} \cdot \frac{D_o + D_i}{2}$

$A = \pi \cdot b \cdot D_m$

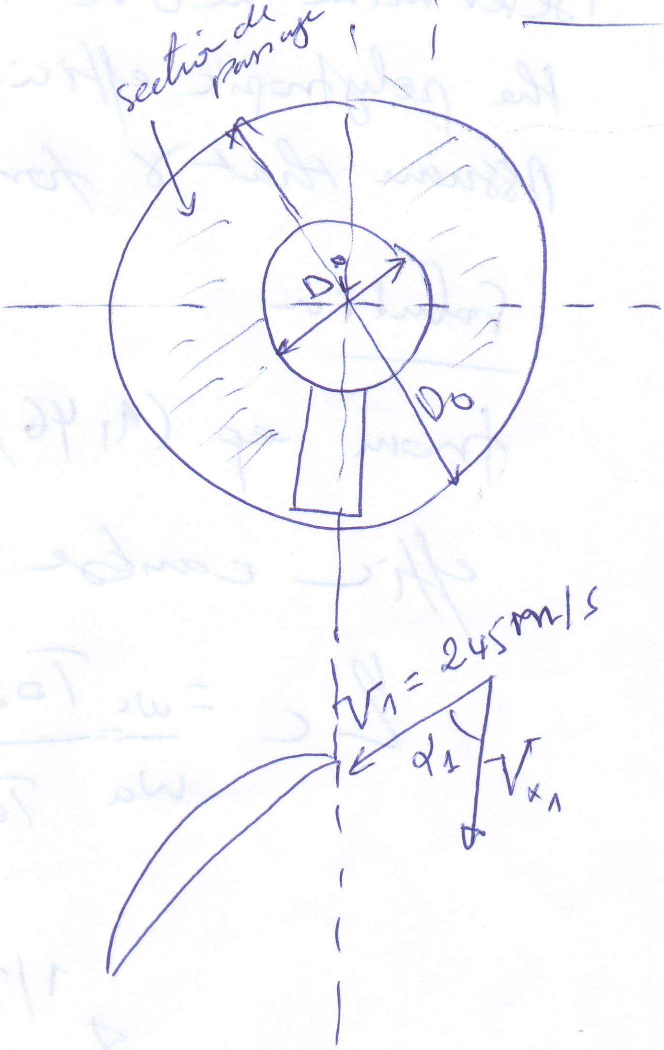


b = hauteur du Pale (height).

$V_{x1} = V_1 \cos\alpha_1$

$\dot{M}_{st} = \frac{V_1 \cos\alpha_1}{\nu_1} \cdot \pi \cdot b \cdot D_m$

$b = \frac{\nu_1 \dot{M}_{st}}{V_1 \cos\alpha_1 \cdot \pi D_m} = 25{,}96$ mm



Ex-(4) An axial flow air compressor is designed to provide an overall total-to total pressure ratio of 8-to-1. At inlet and outlet the stagnation temperature are 300 K and 586.K respectively.

Determine the overall total-to-total efficiency and the polytropic efficiency for the compressor.

Assume that γ for air is 1.4

Solution

from eq (1,46) substituting $h = C_p T$, the effic can be write as:

$$\eta_c = \frac{w_s}{w_a} = \frac{T_{02s} - T_{01}}{T_{02} - T_{01}} = \frac{\left(\frac{P_{02}}{P_{01}}\right)^{\frac{\gamma-1}{\gamma}} - 1}{\frac{T_{02}}{T_{01}} - 1} =$$

$$= \frac{8^{1/3,5} - 1}{(586 \times 4/300) - 1} \qquad 20,85$$

from eq (1,50)

$$\eta_p = \left(\frac{\gamma - 1}{\gamma}\right) \frac{\ln(P_{02}/P_{01})}{\ln(T_{02}/T_{01})} =$$

$$= \frac{1}{3,5} \cdot \frac{\ln 8}{\ldots} = 0,8866.$$