NAME:- --
NUMBER:- ---

DEPARTMENT OF MECHANICAL ENGINEERING
THERMO-FLUID GROUP\
FLUID MACHINERY-(TURBOMACHINERY)
SECOND MID TERM EXAMINATION
FIRST SEMSTER 1428-1429

Time: 2 hours

Question (1) (15 Marks)

(i) Draw enthalpy change diagram for a centrifugal compressor.
(ii) Draw h-s diagram for an axial flow turbine
(iii) Draw velocity diagram at the inlet of the rotor of a centrifugal compressor with out inlet pre-whirl showing the effect of increase in flow coefficient.
(iv) Draw velocity diagram at the exit of an impeller of a centrifugal compressor with radial tipped impeller showing the effect of slip.
(v) Draw the velocity diagram for an axial flow turbine with 50 percent reaction.

Question (2) (10 Marks)

Define and write simple expressions for the following terms

(i) Total to total efficiency for centrifugal compressor.
(ii) Total to static efficiency for an axial flow turbine.
(iii) Stage loading factor for an axial flow turbine stage.
(iv) Degree of reaction for an axial flow turbine stage.
(v) Slip factor of a rotor of a centrifugal compressor.

Question (3) (10 Marks)

Write True or False for the statements.

(i) For zero reaction axial flow turbine $h_2=h_3$.
(ii) For zero reaction axial flow turbine $\beta_2=\beta_3$.
(iii) For zero reaction axial flow turbine $W_2=W_3$.
(iv) For 50 percent reaction axial flow turbine $h_2=(h_1-h_3)/2$.
(v) For 50 percent reaction axial flow turbine $\alpha_1=\beta_2$.
(vi) For 50 percent reaction axial flow turbine $C_2=W_3$
(vii) For 100 percent reaction axial flow turbine $h_3=(h_1+h_2)/2$.
(viii) For 100 percent reaction axial flow turbine $C_1=C_2=C_3$.
(ix) For 100 percent reaction axial flow turbine $\alpha_1=\alpha_2=\alpha_3$.
(x) For normal stage of an axial flow turbine $C_1=C_2$.

Question (4) (20 Marks)

A centrifugal compressor impeller has 17 radial vanes with a tip diameter of 165 mm. It runs at 46000 rpm having a mass flow rate of 0.6 kg/s with no inlet whirl. If the mean diameter at the inlet of the impeller is 63.5 mm, eye hub to tip height of 25 mm and total to total efficiency of impeller is 90% then calculate (i) Theoretical power transferred to air. (ii) Blade angle at impeller eye mean diameter. (iii) Stagnation temperature at the exit of the impeller. (iv) Stagnation pressure at the exit of the impeller. Given P_{01}=101 kPa, T_{01}=288K.

Question (5) (20 Marks)

In a certain normal stage axial gas turbine the flow leaves and enters the stage in an axial direction. The gases leave the nozzle at 72^0 with a flow coefficient of 0.6. Assuming h/b = 3 and Re = 10^5 Cp = 1.148 kJ/kg-K and R = 0.287 kJ/k=K calculate.

(i) The stage loading factor. (ii) The relative flow angles at the inlet and exit of the rotor. (iv) The stage reaction R. (vi) The total to total and total to static efficiency

SOME USEFUL FORMULAE

$$\psi = \varphi(\tan\alpha_2 - \tan\alpha_3)$$

$$\psi = \varphi(\tan\beta_2 - \tan\beta_3)$$

$$\psi = 1 + \varphi(\tan\beta_2 - \tan\alpha_3)$$

$$\psi = -1 + \varphi(\tan\alpha_2 - \tan\beta_3)$$

$$\eta_{tt} = \left[1 + \frac{\xi_s C_2^2}{2\psi U^2} + \frac{\xi_r W_3^2}{2\psi U^2}\right]^{-1}$$

$$\eta_{tt} = \left[1 + \frac{\varphi^2}{2\psi}\left\{\frac{\xi_s}{\cos^2\alpha_2} + \frac{\xi_r}{\cos^2\beta_3}\right\}\right]^{-1}$$

$$\eta_{ts} = \left[1 + \frac{\xi_s C_2^2}{2\psi U^2} + \frac{\xi_r W_3^2}{2\psi U^2} + \frac{C_1^2}{2\psi U^2}\right]^{-1}$$

$$\eta_{ts} = \left[1 + \frac{\varphi^2}{2\psi}\left\{\frac{\xi_s}{\cos^2\alpha_2} + \frac{\xi_r}{\cos^2\beta_3} + \frac{1}{\cos^2\alpha_1}\right\}\right]^{-1}$$

$$^0R = -\frac{\varphi}{2}(\tan\beta_2 + \tan\beta_3)$$

$$^0R = 1 - \frac{\phi}{2}(\tan\alpha_2 + \tan\alpha_3)$$

$$^0R = \frac{1}{2} - \frac{\phi}{2}(\tan\beta_2 + \tan\alpha_3)$$

$$^0R = \frac{1}{2} - \frac{\phi}{2}(\tan\alpha_2 + \tan\alpha_3)$$

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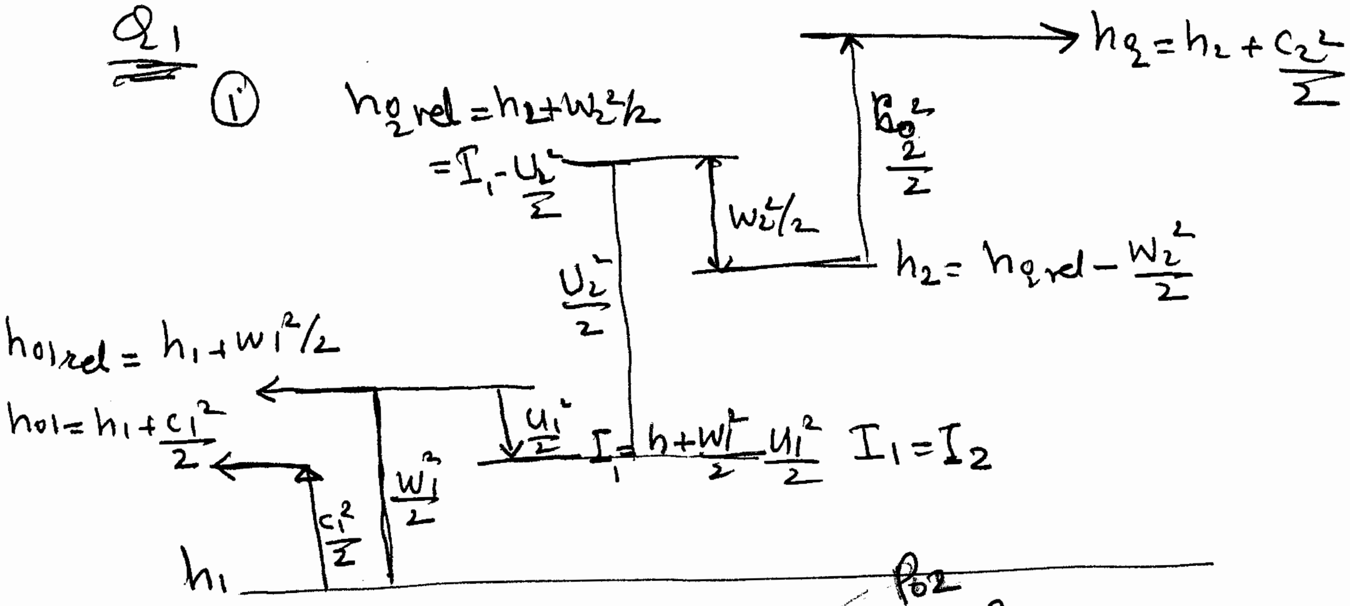
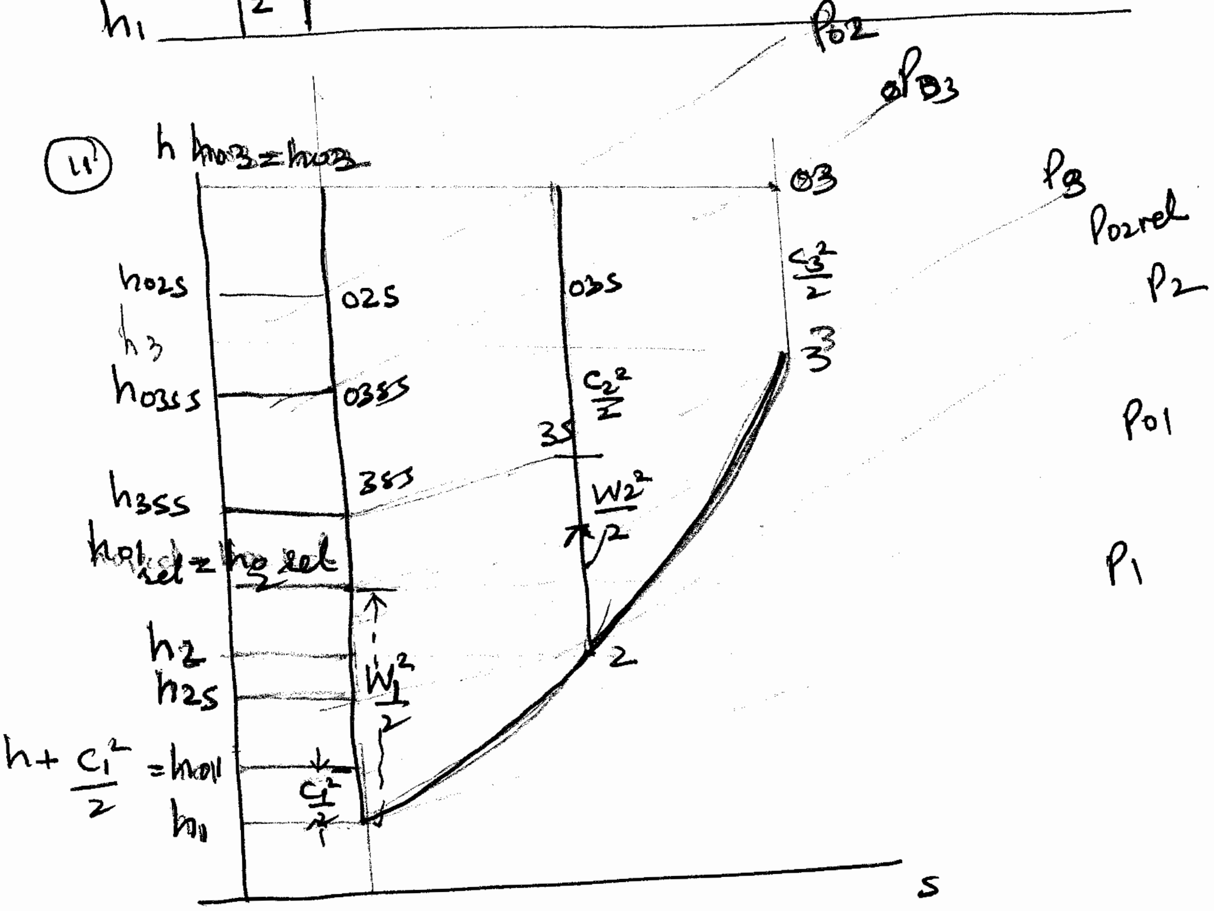
Q1

(i)



(ii)



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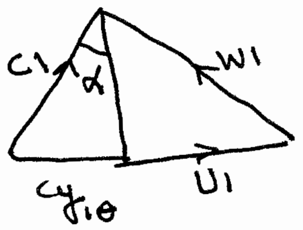
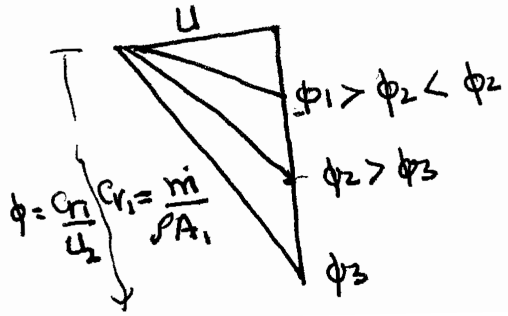
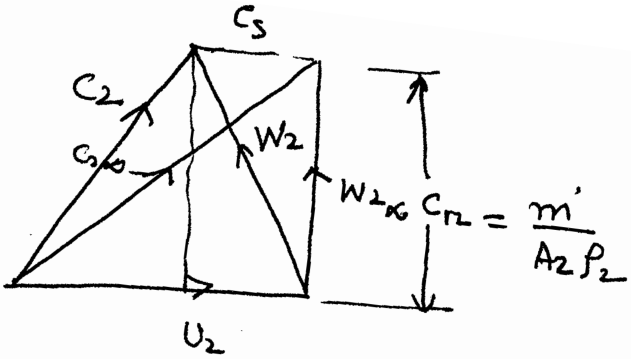


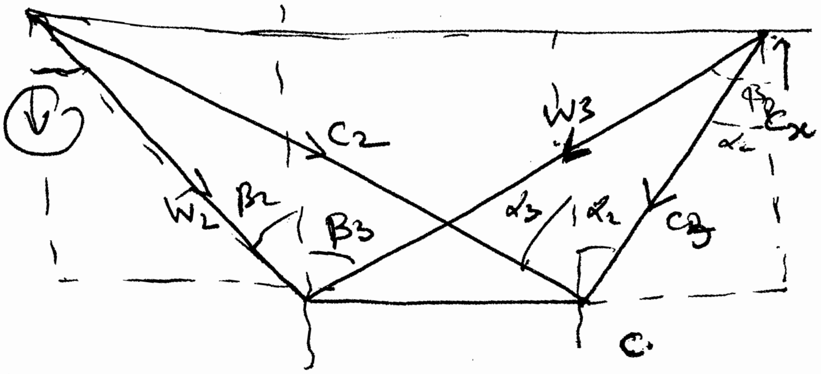


(iv)



$$C_{r2} = \frac{m'}{A_2 \rho_2}$$

(v)



Q ②

① It is ratio between ideal enthalpy rise to actual rise in enthalpy.

$$\eta_c = \frac{h_{03ss} - h_{01}}{h_{03} - h_{01}} \qquad \eta_c = \frac{W_{is}}{W_{ia}}$$

(ii) It is ratio of actual enthalpy decrease or work output to that of ideal case when exit velocity is wasted

$$\eta_{ts} = \frac{h_{01} - h_{03}}{h_{01} - h_{3ss}}$$

(iii) Stage loading factor is ratio of specific work to the kinetic energy of blade.

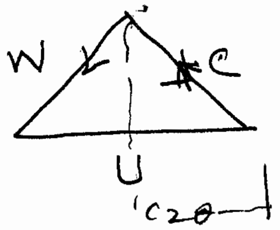
$$\psi = \frac{\Delta W}{U^2}$$

(iv) Degree of reaction of axial compressor is ratio to pressure rise in rotor to that in a stage

$$R = \frac{P_2 - P_1}{P_3 - P_1} \approx \frac{h_2 - h_1}{h_3 - h_1}$$

ⓥ Slip factor of a centrifugal compressor is defined as actual whirl component of exit velocity to that of ideal case

$$\sigma = \frac{C_{\theta 2}}{C_{\theta 2\infty}}$$



Q3 (i) True (ii) True (iii) true (iv) true (v) true
(vi) true (vii) false (viii) true ix true (x) true

(Q4) $Z = 17$ $D_2 = 165\,mm$ $N = 46000\,rpm$

$\dot{m} = 0.6\,kg/s$ No inlet prewhirl $C_{\theta 1} = 0$, $D_{m1} = 63.5\,mm$

$r_s - r_h = b_1 = 25\,mm$. $\eta_{tt} = 0.9$ $W_{c} = ?$ $\beta_{1s} ?$

$T_{02} ?$, $P_{02} = ?$. $P_{01} = 101\,kPa$ $T_{01} = 288K$ $\beta_{2B} = 0$

$$\Delta W = U_2 C_{\theta 2} - U_1 \cancel{C_{\theta 1}} = U_2 C_{\theta 2}$$

$$C_{\theta 2} = \sigma C_{\theta 2\infty} = \sigma (U_2 + C_{r2} \overset{0}{\cancel{\tan \beta_{B2}}})$$

$$\therefore \Delta W_c = \sigma U_2^2 \qquad \sigma = 1 - \frac{2}{Z} = 1 - \frac{2}{17} = 0.88$$

$$U_2 = \frac{\pi D_2 N}{60} = 397.2$$

$$\Delta W_c = 0.88\,(397.2)^2$$

$$= 138.84\,kJ/kg$$

$$W_c = \dot{m}\,\Delta W_c = 0.6 \times 138.84 = 83.3\,\frac{kJ}{s}$$

$$\boxed{W_c = 83.3\,kW}$$

$$A_1 = \pi D_{m_1} b_1 = \pi \times \frac{63.5}{1000} \times \frac{25}{1000} = \underline{0.005\,m^2}$$

$$\rho_1 = \rho_0 = \frac{P_0}{RT_0} = \frac{101}{0.287 \times 288} = \underline{1.22\ kg/m^3}$$

$$C_{x1} = C_1 = \frac{\dot{m}}{\rho_1 A_1} = \underline{98.5\ m/s}$$

$$U_{m_1} = \frac{\pi D_{m_1} N}{60} = \pi \times \frac{63.5}{1000} \times \frac{46000}{60} = \underline{152.87\ m/s}$$

$$\beta_{1s} = \tan^{-1} \frac{U_{m1}}{C_{x1}} = \underline{57.2^\circ}$$

$$\eta_{tt} = \frac{C_p(T_{02s} - T_{01})}{C_p(T_{02} - T_{01})} = \frac{\left(\frac{T_{02s}}{T_{01}} - 1\right) C_p}{\Delta W_c}$$

$$0.9 = \frac{\left[\left(\frac{P_{02}}{P_{01}}\right)^{\frac{k-1}{k}} - 1\right] C_p T_{01}}{\Delta W_c} = \frac{\left[\left(\frac{P_{02}}{P_{01}}\right)^{\frac{1.4-1}{1.4}} - 1\right] \times 1.005 \times 288}{138.84}$$

$$\left(\frac{P_{02}}{P_{01}}\right)^{0.286} - 1 = \frac{0.9 \times 138.4}{1.005 \times 288}$$

$$\left(\frac{P_{02}}{P_{01}}\right)^{0.286} = 1 + \frac{0.9 \times 138.4}{1.005 \times 288}$$

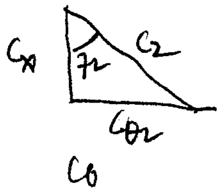
$$\frac{P_{02}}{P_{01}} = 3.5 \qquad \boxed{P_{02} = 353.5\ kPa}$$

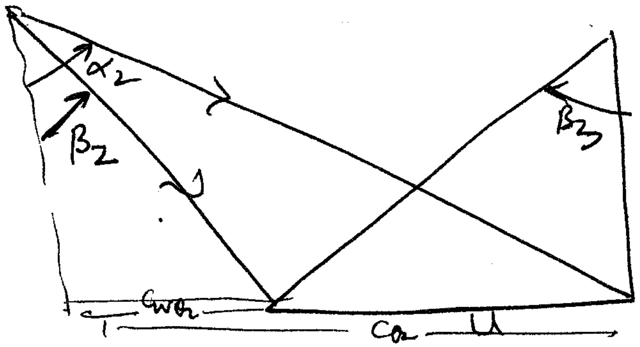
$$\Delta W_c = h_{02} - h_{01} = C_p(T_{02} - T_{01})$$

$$T_{02} = T_{01} + \frac{\Delta W_c}{C_p} = 288 + \frac{138.84}{1.005}$$

$$\boxed{T_{02} = 425.72\ K}$$

Q5





$\alpha_3 = \alpha_1 = 0$

$C_1 = C_3 = C_{x_1}$

$\alpha_2 = 72^\circ$ $\quad \phi_2 = 0.6$

$\frac{h}{b} = 3$ $\quad Re = 10^5$ $\quad C_p = 1.148 \frac{kJ}{kg\text{-}K}$ $\quad R = 0.287 \frac{kJ}{kg\text{-}K}$

$$\Delta W_t = (C_{\theta 2} + \cancel{C_{\theta 3}}^{\,0})U = U C_{\theta 2}$$

$$\text{stage loading} = \psi = \frac{\Delta W}{U^2} = \frac{U C_{\theta 2}}{U^2} = \frac{C_{\theta 2}}{U}$$

$$\frac{C_{\theta 2}}{C_x} = \tan 72 \qquad C_{\theta 2} = C_x \tan 72$$

$$\psi = \frac{C_x}{U} \tan 72 = \phi \tan 72 = 0.6 \tan 72 = 1.85$$

$$\boxed{\psi = 1.85}$$

$$\tan\beta_3 = \tan\alpha_3 - \frac{1}{\phi}$$

$$\tan\beta_3 = -\frac{U}{C_{x1}} = \frac{1}{0.6} \cancel{7}\ 59.04^\circ \qquad \underline{\beta_3 = -59.04^\circ}$$

$$\tan\beta_2 = \frac{W_{\theta 2}}{C_{\cancel{x}}} = \frac{C_{\theta 2} - U}{C_x} = \frac{C_{\theta 2}}{C_x} - \frac{U}{C_x}$$

$$\tan\beta_2 = \tan\alpha_2 - \frac{1}{\phi} = 1.411$$

$$\underline{\beta_2 = 54.67^\circ}$$

$$R = \frac{\phi}{2}(\tan\beta_3 + \tan\beta_2) = 0.08$$

$$\eta_{tt} = \left[1 + \frac{\phi^2}{2\psi}\left(\xi_s \sec^2\alpha_2 + \xi_R \sec^2\beta_2\right)\right]^{-1}$$

$$= \left[1 + \frac{0.6^2}{2 \times 1.85}\left(\frac{0.071}{\cos^2 72} + \frac{0.118}{\cos(39.04)}\right)\right]^{-1}$$

~~[illegible]~~

$$= 83.8\%$$

$$\xi_R = 0.04 + 0.06\left(\frac{\epsilon_R}{t\omega}\right)^2 \qquad \epsilon_R = (\beta_2 - \beta_3) \quad \xi_R = 0.118$$

$$\xi_s = 0.04 + 0.06\left(\frac{\epsilon_s}{t\omega}\right)^2 \quad \epsilon_s = \alpha_2 - \alpha_1 \qquad \xi_s = 0.071$$

$$\eta_{ts} = \left[1 + \frac{\phi^2}{2\psi}\left(\xi_s \sec^2\alpha_2 + \xi_R \sec^2\beta_3 + \sec^2\alpha_1\right)\right]^{-1}$$

$$= 82.4\%$$