Modified

CBCS SCHEME

USN ☐☐☐☐☐☐☐☐☐☐ **18ME54**

Fifth Semester B.E. Degree Examination, Feb./Mar.2022
Turbo Machines

Time: 3 hrs. Max. Marks: 100

Note: Answer any FIVE full questions, choosing ONE full question from each module.

Important Note : 1. On completing your answers, compulsorily draw diagonal cross lines on the remaining blank pages.
2. Any revealing of identification, appeal to evaluator and /or equations written eg, 42+8 = 50, will be treated as malpractice.

Module-1

1 a. Differentiate between turbo machine and positive displacement machine under the following aspects (i) Action (ii) Operation (iii) Mechanical features (iv) Efficiency of energy conversion (v) Volumetric efficiency **(10 Marks)**

b. A ¼ scale turbine model is tested under a head of 10 meters. The prototype is required to work under a head of 30 meters and to run at 425 rpm. Estimate the speed of the model if it develops 125 kW and uses 1.1 m^3/sec of water at this speed. Also calculate the power output, discharge of prototype and suggest the type of turbine. **(10 Marks)**

OR

2 a. Explain static and stagnation state for a fluid. **(04 Marks)**

b. Show that polytropic efficiency for compressor is given by $\eta_P = \left(\frac{r-1}{r}\right)\times\left(\frac{n}{n-1}\right)$. **(08 Marks)**

c. A turbine has four stages and each stage pressure ratio is 2. The inlet static temperature is 630°C. The mass flow rate is 30 kg/sec. The overall efficiency is 0.8. Calculate
(i) Polytropic efficiency (ii) The stage efficiency
(iii) The power developed (iv) Reheat factor. **(08 Marks)**

Module-2

3 a. Define degree of reaction and utilization factor. Derive relation between degree of reaction and utilization factor. **(10 Marks)**

b. In an axial flow machine (turbine), the discharge blade angles are 20° each for both stator and rotor. The steam speed at the exit of the fixed blade is 140 m/sec. The ratio $\frac{V_f}{U} = 0.7$ at the entry and 0.76 at the exit of the rotor blade. Find the inlet rotor angle, the power developed by the blade ring for a mass flow rate of 2.6 kg/sec and the degree of reaction. **(10 Marks)**

OR

4 a. A radial outward flow turbo machine has no inlet whirl. The blade speed at the exit is twice that at inlet. Radial velocity is constant throughout. Taking the inlet blade angle as 45°. Show that the degree of reaction is given by $R = \frac{2+\cot\beta_2}{4}$, where β_2 is the blade angle at exit with respect to tangential direction. **(10 Marks)**

b. An inward flow turbine has water inlet angle of 20°, the water leaves radially, speed of wheel = 350 rpm. Velocity of flow is 4 m/sec. The inner and outer diameter of the turbine are 30 cm and 60 cm respectively. Width of the wheel at inlet is 12 cm. Find the blade angle of power developed. Also what will be the value of R. **(10 Marks)**

Module-3

5 a. What is compounding? Explain (i) Velocity compounding and (ii) Pressure compounding with neat sketches. **(10 Marks)**

b. A single stage impulse turbine has a diameter of 1.5 m and running at 3000 rpm. The nozzle angle is 20°. Speed ratio is 0.45. The ratio of relative velocity at outlet to that at inlet is 0.9. The outlet angle of the blade is 3° less than inlet angle. Steam flow rate is 6 kg/sec. Draw the velocity diagram and find the following : (i) Velocity of whirl (ii) Axial thrust (iii) Blade angles (iv) Power developed. **(10 Marks)**

OR

6 a. Derive condition for maximum efficiency of reaction steam turbine and hence prove that $n_{b_{max}} = \frac{2\cos^2\alpha_1}{1+\cos^2\alpha_1}$. **(10 Marks)**

b. In a Parson's turbine the axial velocity of flow of steam is 0.5 times the mean blade speed. The outlet angle of blade is 20°, the diameter of the blade ring is 1.3 m and the rotational speed is 3000 rpm. Determine inlet blade angles, power developed for the steam flow of 65 kg/sec and the isentropic enthalpy drop, if the stage efficiency is 80%. **(10 Marks)**

Module-4

7 a. With a mathematical expression, define the following : (i) Hydraulic efficiency (ii) Mechanical efficiency (iii) Overall efficiency (iv) Volumetric efficiency. **(08 Marks)**

b. Show that the maximum efficiency of Pelton wheel is given by $\eta_{b.max} = \frac{1+C_b\cos\beta_2}{2}$, where C_b = Blade velocity coefficient, β_2 = Bucket angle at its outlet. **(12 Marks)**

OR

8 a. Explain the functioning of a Kaplan turbine, with help of a sectional arrangement diagram. Draw the velocity triangles of Kaplan turbine. **(08 Marks)**

b. The following data is given for a Francis turbine, net head = 70 m, Speed = 600 rpm, Shaft power = 370 kW, $\eta_0 = 0.80, \eta_h = 0.95$, flow ratio = 0.25, breadth ratio is equal to 0.1, outer diameter of runner is equal to two times inner diameter of the runner. The thickness of vanes occupy 10% circumferential area of the runner. Velocity of flow is constant and discharge is radial at outlet. Determine (i) Guide blade angle (ii) Runner angle at inlet and outlet (iii) Diameter of the runner at inlet and outlet (iv) Width of the wheel at inlet. **(12 Marks)**

Module-5

9 a. Define the following with respect to centrifugal pump, (i) Static head (ii) Cavitation (iii) Priming (iv) Multistage centrifugal pumps. **(08 Marks)**

b. Derive an expression for minimum starting speed for a centrifugal pump. **(06 Marks)**

c. A centrifugal pump discharges 0.15 m^3/s of water against a head of 12.5 m, speed of impeller is 600 rpm. The outer and inner diameter of impeller are 500 mm and 250 mm respectively and the vanes are bent back at 35° to the wheel tangent at exit. If the area of flow remains 0.07 m^2 from inlet to, outlet, find
(i) Manometric efficiency (ii) Vane angle at inlet **(06 Marks)**

OR

10 a. Explain the following with respect centrifugal compressor: (i) Pressure coefficient (ii) Slip factor (iii) Power factor (iv) Surging **(08 Marks)**

b. A centrifugal compressor runs at a speed of 15000 rpm and delivers air at 30 kg/sec. Exit radius is 0.35 m, relative velocity and vane angles at exit are 100 m/s and 75°. Assuming axial inlet, inlet stagnation temperature and pressure as 300 K and 1 bar. Calculate (i) The torque (ii) The power required to drive the compressor. (iii) The ideal head developed (iv) The work done (v) The exit total pressure. Take $C_{P_{air}} = 1.005$ kJ/kg. **(12 Marks)**

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Re: Sir, regarding Modification of Scheme and solution

"Dr M S Govinde Gowda" <msggowda1964@gmail.com> March 9, 2022 1:13 PM

To: boe@vtu.ac.in

Dear Sir,

PFA for the corrected and approved scheme and solution of 18ME54-Turbomachines, for your kind notice and for the further approval from your end.

With regards

......

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On Mon, Mar 7, 2022 at 2:24 PM <boe@vtu.ac.in> wrote:

" APPROVED "

Reg — B E

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18ME54

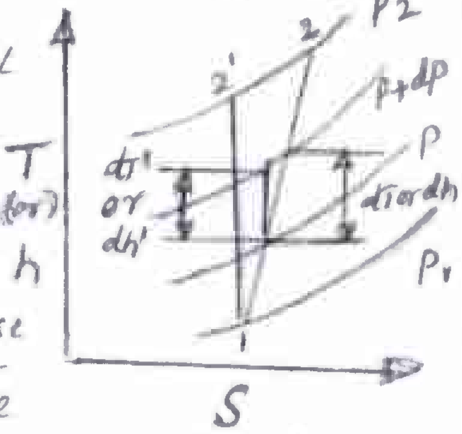
Scheme & Solutions

Signature of Scrutinizer

Subject Title : Turbo Machines **Subject Code :** 18ME54

Question Number	Solution		Marks Allocated
1a.	Positive displacement Machine	Turbo Machine	
	Action		
	1. Action between a nearly static fluid and a slowly moving surface	1. Dynamic action between a flowing fluid and a rotating element	②
	2. Involves volume change (or) displacement of fluid	2. Involves pressure and momentum change	
	Operation		
	1. Involves a reciprocating motion and unsteady flow	1. Involves a steady flow of fluid and pure rotary motion	②
	2. Fluid contianment is positive	2. There is no positive contianment of fluid	
	Mechanical Features		
	1. Low speed Machine	1. Works at high rotational speed	②
	2. Complex in design	2. Relatively simple in design	
	3. Heavier foundation needed	3. Lighter foundation	
	Efficiency of Energy Conversion		
	(i) High Efficiency because of static energy transfer	(i) Low Efficiency because of dynamic energy transfer	②
	(ii) Compression and expansion efficiencies are almost same	(ii) Efficiency of compression process is low	
	Volumetric Efficiency		
	(i) volumetric efficiency is lower	(i) volumetric efficiency is nearly 100%	②
	2. Low fluid handling capacity	2. High fluid handling capacity	

Question Number	Solution	Marks Allocated
1 b.	Data: $\frac{D_m}{D_p} = \frac{1}{4}$, $H_m = 10m$, $H_p = 30m$, $N_p = 425$ rpm, $N_m = ?$ $P_m = 125kW$, $Q_m = 1.1 m^3/sec$ $P_p = ?$, $Q_p = ?$, Type of turbine = ?	
	(i) Speed of Model $\frac{gH_m}{N_m^2 D_m^2} = \frac{gH_p}{N_p^2 D_p^2} \Rightarrow N_m^2 = N_p^2 \times \frac{H_m}{H_p} \times \left(\frac{D_p}{D_m}\right)^2$ $N_m^2 = 425^2 \times \frac{10}{30} \times 4^2 \Rightarrow N_m = \underline{981.49}$ rpm →	③
	(ii) Discharge of prototype $\frac{Q_m}{N_m D_m^3} = \frac{Q_p}{N_p D_p^3} \Rightarrow Q_p = Q_m \times \frac{N_p}{N_m} \times \left(\frac{D_p}{D_m}\right)^3$ $Q_p = 1.1 \times \frac{425}{981.49} \times 4^3 = \overset{\textbf{30.48}}{\cancel{27.71}}\ m^3/sec$ →	②
	(iii) Power of the prototype $\frac{P_m}{\rho N_m^3 D_m^5} = \frac{P_p}{\rho N_p^3 D_p^5} \Rightarrow P_p = \left(\frac{N_p}{N_m}\right)^3 \times \left(\frac{D_p}{D_m}\right)^5 \times P_m$ $= \left(\frac{425}{981.49}\right)^3 \times 4^5 \times 125 = \underline{10392.4 kW}$	(02)
	(iv) Type of the turbine $N_{sm} = N_{sp} = \frac{N_p\sqrt{N_p}}{H_p^{5/4}} = \frac{425\sqrt{10392.48}}{(30)^{5/4}}$ $= \underline{617.08}$ rpm Since N_s is in the range of 368 to 856, → it is a <u>kaplan turbine</u>	(03)

Question Number	**Solution**	**Marks Allocated**
2 a.	Static state: If properties of fluid are measured with instrument or device which are at rest relative to the fluid then they are called as static state properties.	②
	Stagnation state: is the Terminal state of a fictious isentropic and work free process during which K.E and p.E are reduced to zero in steady flow.	②
2 b.	Consider an infinitesimal stage b/n p and p+dp The polytropic Efficiency of small stage is $\eta_p = \frac{\text{Isentropic temp rise}}{\text{Actual temp rise}}$  fig 2(b)	
	$\frac{dT}{T} = \left(\frac{\gamma-1}{\gamma}\right)\frac{1}{\eta_p}\times\frac{dp}{p}$ —— ①	②
	$\frac{T_2}{T_1} = \left(\frac{P_2}{P_1}\right)^{\frac{\gamma-1}{\gamma\eta_p}}$ —— ②	②
	$\eta_p = \frac{\log_e\left(\frac{T_2}{T_1}\right)}{\left(\frac{\gamma-1}{\gamma}\right)\log_e\left(\frac{P_2}{P_1}\right)}$ —— ③	②
	$\frac{T_2}{T_1} = \left(\frac{P_2}{P_1}\right)^{\frac{n-1}{n}}$ —— ④	
	$\eta_p = \left(\frac{\gamma-1}{\gamma}\right)\left(\frac{n-1}{n}\right)$ ——→	②

Subject Title : TurboMachines **Subject Code :** 18ME54

Question Number	Solution	Marks Allocated
2 c.	Data: $K=4$, $P_r=2$, $T_1=630^\circ C$, $m=30 kg/s$, $\eta_t=0.8$	
	$\eta_p=?$ $P=?$ $R.F=?$	
	(i) Polytropic efficiency:	
	$\eta_t = \frac{T_1-T_{K+1}}{T_1-T'_{K+1}} = \frac{1-P_r^{-(\frac{\gamma-1}{\gamma})\eta_p k}}{1-P_r^{-(\frac{\gamma-1}{\gamma})k}} = \frac{1-2^{-(\frac{1.4-1}{1.4})\eta_p 4}}{1-2^{-(\frac{1.4-1}{1.4})4}}$	
	$= 0.8 \Rightarrow \eta_p = 0.5816 = 58.16\% \rightarrow$	02
	(ii) Stage efficiency:	
	$\eta_s = \frac{1-P_r^{-(\frac{\gamma-1}{\gamma})\eta_p}}{1-P_r^{-(\frac{\gamma-1}{\gamma})}} = \frac{1-2^{-(\frac{1.4-1}{1.4})\times 0.5816}}{1-2^{-(\frac{1.4-1}{1.4})}}$	
	$= 0.6056 = 60.56\% \rightarrow$	02
	(iii) Power output:	
	$\frac{P_1}{P_{K+1}} = P_r^K = 2^4 = 16$	
	$\frac{T_1}{T_{K+1}} = \left(\frac{P_1}{P_{K+1}}\right)^{(\frac{\gamma-1}{\gamma})\eta_p} = 16^{(\frac{14-1}{14})\times 0.5816}$	
	$\therefore P = m C_p \left[1-\frac{T_{K+1}}{T_1}\right] \times T_1$	
	$= 30 \times 1.005 \left[1-\left(\frac{1}{16}\right)^{0.286\times 0.5816}\right] \times (680+273)$	
	$P = 10.6 \times 10^3 kW \longrightarrow$	03
	(iv) Reheat factor $= \frac{\eta_t}{\eta_s} = \frac{0.8}{0.60506} = 1.321 \rightarrow$	01

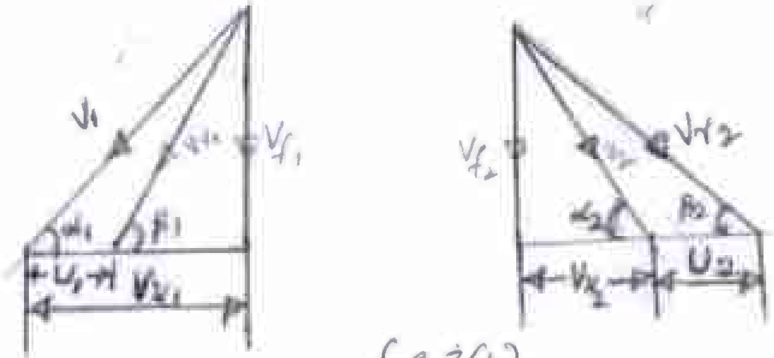
Question Number	Solution	Marks Allocated
3 a.	Degree of Reaction (R) = $\frac{\text{Static head}}{\text{Total head}}$	
	The ratio of Static Energy transfer due to the static pressure change to the total Energy transfer due to the total pressure change in rotor is called the degree of reaction denoted by R.	(02)
	Utilization factor (ϵ): ~~It is~~ The ratio of Ideal Work to the Energy supplied is called utilization factor, denoted by ϵ.	(02)
	Relation between R and ϵ: $R = \frac{\frac{1}{2}[(U_1^2-U_2^2)+(V_{r_2}^2-V_{r_1}^2)]}{\frac{1}{2}[(V_1^2-V_2^2)+(U_1^2-U_2^2)+(V_{r_2}^2-V_{r_1}^2)]}$ $(U_1^2-U_2^2)+(V_{r_2}^2-V_{r_1}^2) = \frac{R}{1-R}(V_1^2-V_2^2) \longrightarrow$	(3)
	$\epsilon = \frac{\frac{1}{2}[(V_1^2-V_2^2)+(U_1^2-U_2^2)+(V_{r_2}^2-V_{r_1}^2)]}{\frac{1}{2}[V_1^2+(U_1^2-U_2^2)+(V_{r_2}^2-V_{r_1}^2)]}$ $\epsilon = \frac{V_1^2-V_2^2}{V_1^2-RV_2^2} \longrightarrow$	(3)
3 b.	Data: $\alpha_1 = 20°$, $\beta_2 = 20°$, $V_1 = 140$ m/sec, $\frac{V_{f_1}}{U_1} = 0.7$ $\frac{V_{f_2}}{U_2} = 076$, $\beta_1 = ?$ $P = ?$, $\dot{m} = 2.6$ kg/sec $R = ?$ For axial flow turbine $U_1 = U_2$ $V_{u_1} = V_1 \cos\alpha_1 = 140 \times \cos 20 = 131.56$ m/sec	

$V_{f_1} = V_1 \sin\alpha_1 = 140 \times \sin 20 = 4788\, m/se$

$U_1 = \frac{V_{f_1}}{0.7} = \frac{4788}{0.7} = 68.4\, m/sec$

$\therefore V_{x_1} > U_1$

velocity Δ^{le} at Inlet | velocity Δ^{le} at outlet



→ (2)

fig 3(b)

From inlet velocity Δ^{le}.

$\tan\beta_1 = \frac{V_{f_1}}{V_{x_1} - u_1} = \frac{47.88}{131\,53 - 68.4} \Rightarrow \underline{\underline{\beta_1 = 37.2}}$ → (2)

$V_{r_1}^2 = V_{f_1}^2 + (V_{x_1} - U_1)^2 = 47.88^2 + (131.53 - 68\,4)^2$

$V_{r_1} = 79\,24\, m/sec$

$U_1 = U_2 = 68.4\, m/sec, \quad \frac{V_{f_2}}{U_2} = 0\,76 \Rightarrow V_{f_2} = 51.98\, m/sec$

from outlet velocity Δ^{le}.

$\tan\beta_2 = \frac{51\,98}{V_{x_2} + 68.4} \Rightarrow V_{x_2} = 74.42\, m/sec$

$V_{r_2}^2 = V_{f_2}^2 + (V_{x_2} + U_2)^2 = 51.98^2 + (74.42 + 68\,4)^2$

$V_{r_2} = 151.96\, m/sec$ & V_2=90.8m/s, E=U(Vu1+Vu2)/gc=14.1 kJ/kg

Power develped, $P = \dot{m} U [V_{x_1} + V_{x_2}]$

$= 2.6 \times 684 [131.52 + 744\,2]$

Power developed = 36.63 kW → ③

Degree of Reaction (R) $= \dfrac{\frac{1}{2}[V_{r2}^2 - V_{r1}^2]}{E}$

$= \dfrac{\frac{1}{2} m [V_{r2}^2 - V_{r1}^2]}{P}$

$= \dfrac{\frac{1}{2} \times 2.6 [151.96^2 - 79.24^2]}{36.63 \times 10^3}$

$R = 0.5967 = 59.67\%$ → ③

Alternate Method for R:

$$R = \frac{E - \frac{V_1^2 - V_2^2}{2}}{E}$$

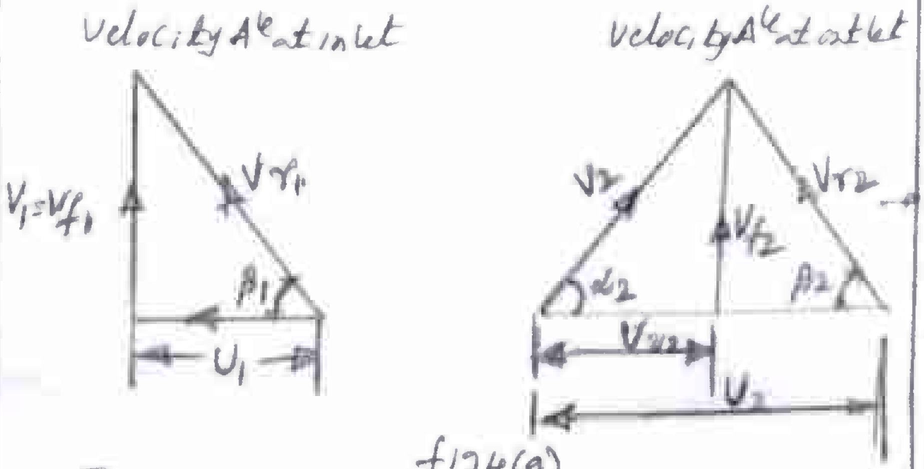
$$R = \frac{14.1 - \frac{140^2 - 90.8^2}{2000}}{14.1}$$

= 0.597 or 59.7%

4 ⓐ

Given $V_{x_1} = 0$, $V_1 = V_{f_1}$, $U_2 = 2U_1$, $V_f = V_{f_1} = V_{f_2}$

$\beta_1 = 45^\circ$


Velocity Δle at inlet

Velocity Δle at outlet

→ ⓪②

fig 4(a)

$E = U_2 V_{x_2}$ J/kg

From outlet velocity Δle $V_{x_2} = U_2 - V_f \cot\beta_2$

$E = 4V_f^2 - 2V_f^2 \cot\beta_2$

$= 2V_f^2(2 - \cot\beta_2)$ → ① ⓪②

Subject Title : Turbo Machines **Subject Code :** 18ME54

Question Number	Solution	Marks Allocated

Alternate method:

From Velocity Triangles,

$V_2^2 - V_1^2 = V_2^2 - V_{f2}^2 = V_{u2}^2$

Now,

$$R = \frac{E - \frac{V_2^2 - V_1^2}{2}}{E}$$

$$= 1 - \frac{V_2^2 - V_1^2}{2E} = 1 - \frac{V_{u2}^2}{2U_2 V_{u2}}$$

$$= 1 - \frac{V_{u2}}{2U_2} = 1 - \frac{(U_2 - V_{f2} Cot\beta_2)}{2U_2}$$

As $U_2 = 2U_1 = 2V_{f2}$

$$R = \frac{2 + Cot\beta_2}{4}$$

$$R = \frac{E - \frac{1}{2}(V_2^2 - V_1^2)}{E}$$ (power absorbing M/C) → ② (01)

$V_1 = V_{f_1} = V_f \longrightarrow$ ③

$V_2^2 = V_{f_2}^2 (5 + Cot^2\beta_2 - 4 Cot\beta_2) \longrightarrow$

$$\frac{V_2^2 - V_1^2}{2} = \frac{V_f^2 \times (4 + Cot^2\beta_2 - 4 Cot\beta_2)}{2} \rightarrow ④ \rightarrow$$ (3)

Sub ①, ③ + ④ in eq ②

$$R = \frac{2 + Cot\beta_2}{4} \longrightarrow$$ (2)

4(b)

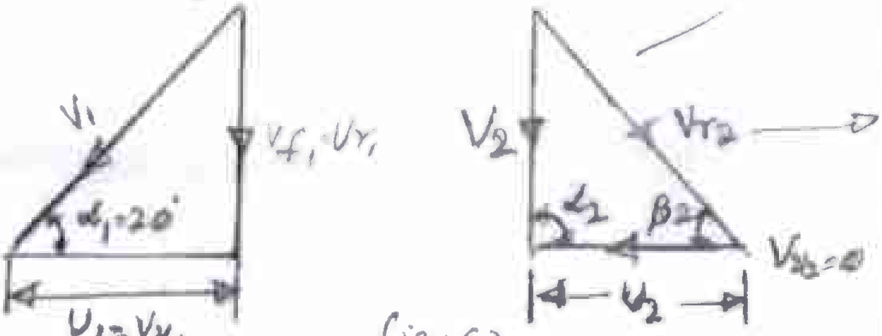
Data: $N = 350$ rpm, $D_1 = 0.6$ m, $V_2 = V_{f_2}$, $\alpha_2 = 90°$

$D_2 = 0.3$ m, $B_1 = 0.12$ m

$\alpha_1 = 20°$, $B_1 = 0.12$ m, $V_f = V_{f_1} = V_{f_2} = 4$ m/sec

$V_{f_2} = V_2 = 4$ m/sec, $\beta_2 = ?$, $P = ?$, $R = ?$

Velocity Δle at inlet   Velocity Δle at outlet



→ (2)

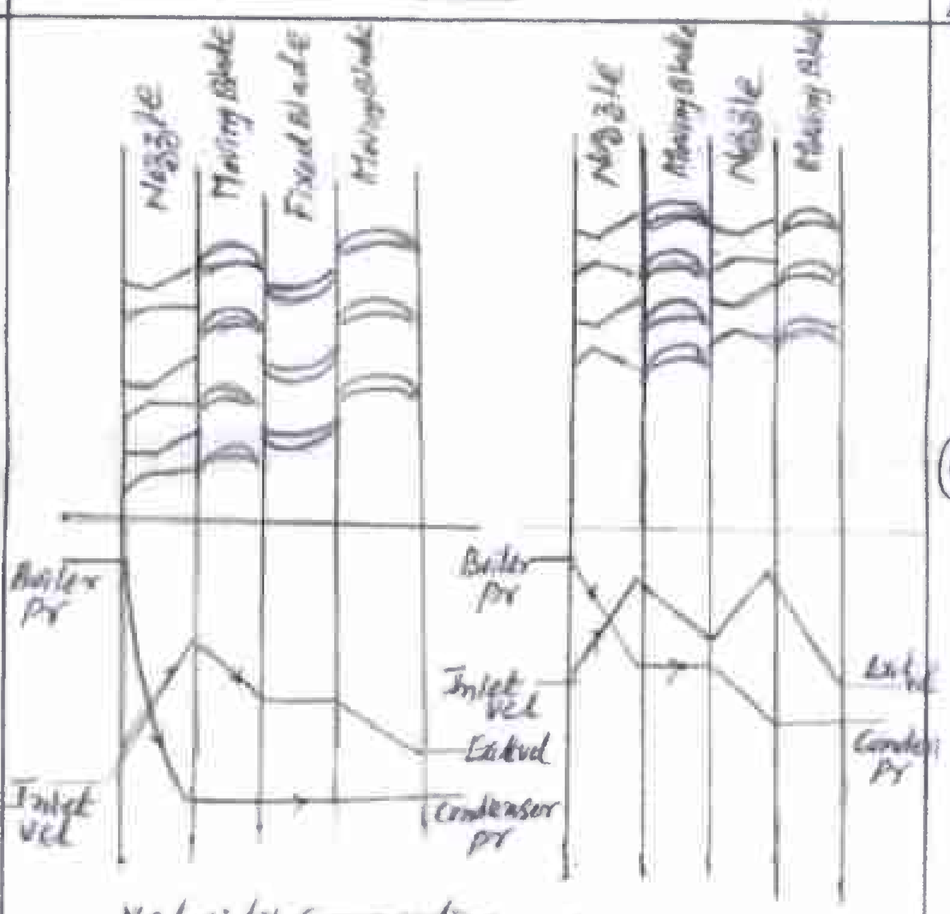
fig 4(b)

$$U_1 = \frac{\pi D_1 N}{60} = \frac{\pi \times 0.6 \times 350}{60} = 10.996 \text{ m/sec}$$

$$U_2 = \frac{\pi D_2 N}{60} = \frac{\pi \times 0.3 \times 350}{60} = 5.498 \text{ m/sec}$$

Subject Title : Turbo Machines **Subject Code :** 18ME54

Question Number	Solution	Marks Allocated
	$V_{f_1} = V_f = V_1 \sin\alpha_1 \Rightarrow V_1 = \frac{4}{\sin 20} = 11695 \, m/sec$	
	$V_{x_1} = V_1 \cos 20^\circ = 11.695 \times \cos 20 = 1099 \, m/sec$	
	$V_{r_2} = \sqrt{V_{f_2}^2 + U_2^2} = \sqrt{4^2 + 5.498^2} = 6.799 \, m/sec$	
	$\tan\beta_2 = \frac{V_{f_2}}{U_2} = \frac{4}{5.498} \Rightarrow \beta_2 = \underline{\underline{36.04}}$ $\rightarrow$	②
	Power developed $= \dot{m}\left[U_1 V_{x_1} - U_2 V_{x_2}\right]$ $= \rho Q \left[U_1 V_{x_1} - U_2 V_{x_2}\right]$ $= \rho \times \pi D_1 B_1 V_{f} \left[U_1 V_{x_1} - U_2 V_{x_2}\right]$ $= 1000 \times \pi \times (0.6 \times 0.12) \times 4 (10.96 \times 10.996)$ $\longrightarrow$ $= \underline{109.338 kW}$	③
	$R = \frac{\frac{1}{2}\left[(U_1 - U_2^2) + (V_{r_2}^2 - V_{r_1}^2)\right]}{\frac{1}{2}\left[(U_1^2 - U_2^2) + (V_{r_2}^2 - V_{r_1}^2) + (V_1^2 - V_2^2)\right]}$ $= \frac{(10.996^2 - 5.498^2) + (6.799^2 - 4^2)}{(11.695^2 - 4^2) + (10.996^2 - 5.498^2) + (6.797^2 - 4^2)}$ $R = \underline{0.5} \ (or) \ 50\%$ $\longrightarrow$	③
	Alternative Method: **Here $U_1 = V_{u1}$ and Hence $E = V^2_{u1}/g_c$** $R = \frac{E - \frac{V_1^2 - V_2^2}{2}}{E}$ $= \frac{U_1 V_{u1} - \frac{V_1^2 - V_{f1}^2}{2}}{U_1 V_{u1}}$ $= 1 - \frac{V_1^2 - V_{f1}^2}{2 U_1 V_{u1}} = 1 - \frac{V_{u1}^2}{2 U_1 V_{u1}}$ $= 1 - \frac{1}{2} = \frac{1}{2}$ **= 0.5 or 50%**	
5 ⓐ	Definition for Compounding: Method of obtaining reasonable tangential speed of rotor for a given overall pressure drop by using more than one stages is defined as compounding	②



Velocity Compounding PrCompounding
fig 5(a)

(4)

Explination to Compoundings →

(4)

5. (b)

Data: D = 1.5m, m = 6kg/sec, N = 3000rpm

$\alpha_1 = 20°$, $\phi = \frac{U}{V_1} = 0.45$, $C_b = \frac{V_{r2}}{V_{r1}} = 0.9$, $\beta_2 = \beta_1 - 3$

Construction Velocity dia:
Scale 1:50

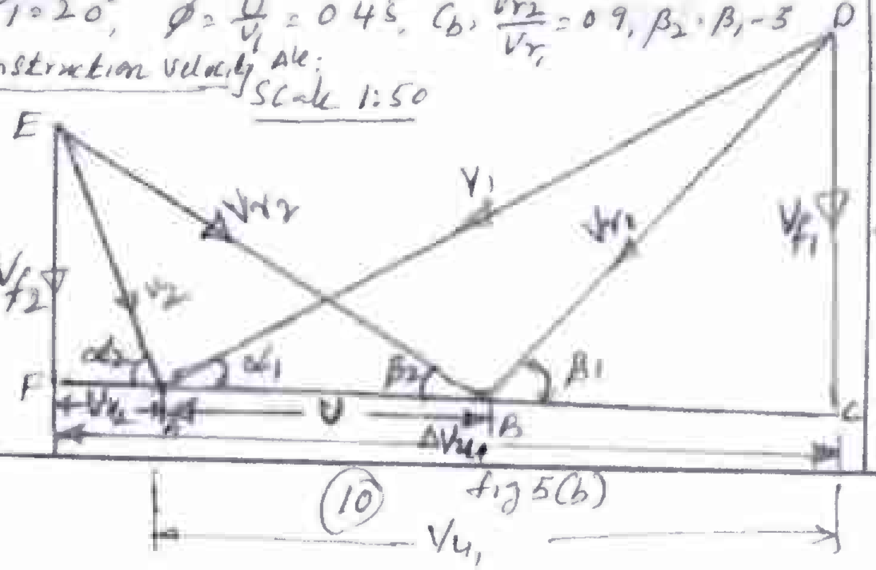
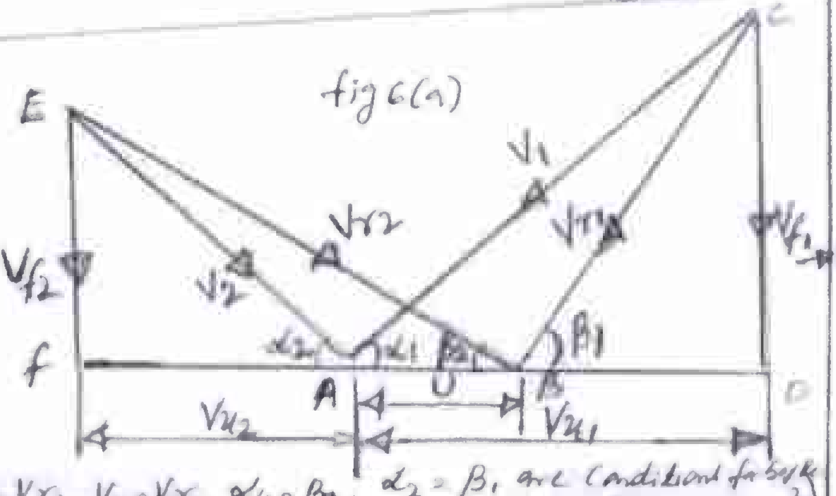


fig 5(b)

(04)

(10)

Subject Title: Turbo Machines **Subject Code:** 18ME54

Question Number	Solution	Marks Allocated
	$U = \frac{\pi D N}{60} \Rightarrow U = 235.6$ m/sec, $V_1 = 523.6$ m/sec From Graph ($V_1 = \frac{\phi}{U}$)	
	$\beta_1 = 35°$, $V_{r_1} = 312.5$ m/sec, $V_{r_2} = 0.9 \times 312.5 = 281.3$ m/sec	
	$\beta_2 = 35° - 3° = 32°$ **ΔV_u=495 m/s, ΔV_f= 30 m/s**	
	(i) velocity of whirl $\Delta V_x = 495$ m/sec $\rightarrow$	01
	(ii) Axial thrust $= \dot{m} \times \Delta V_f = 180$ N $\rightarrow$	02
	(iii) Blade angles $\beta_1 = 35°$; $\beta_2 = 32° \rightarrow$	01
	(iv) power developed $= \dot{m} U \Delta V_x = 6 \times 235.6 \times 495 = 700$ kW $\rightarrow$	02
6a		1
	$V_1 = V_{r_2}$, $V_2 = V_{r_1}$, $\alpha_1 = \beta_2$, $\alpha_2 = \beta_1$ are Conditions for Sym	
	Work done per kg of Steam (W) $= (2UV_1\cos\alpha_1 - U^2)$	
	Work done per kg of steam $W = V_1^2[2\phi\cos\alpha_1 - \phi^2] \rightarrow$	2
	Total Energy Supplied $= \frac{1}{2}[V_1^2 + V_{r_2}^2 - V_{r_1}^2]$	
	$= \frac{V_1^2}{2}[1 + \phi\cos\alpha_1 - \phi^2] \rightarrow$	2
	Blade Efficiency $\eta_b = \frac{\text{Work done per kg of steam}}{\text{Total Energy Supplied}}$	

$$\eta_b = \frac{2(2\phi\cos\alpha_1 - \phi^2)}{(1+2\phi\cos\alpha_1 - \phi^2)} \longrightarrow$$ ②

for Max blade efficiency $\frac{\partial\eta_b}{\partial\phi} = 0 \Rightarrow \phi = \frac{U}{V_1}\cos\alpha_1 \rightarrow$ ②

$$\eta_{b\,max} = \frac{2\cos^2\alpha_1}{1+\cos^2\alpha_1} \longrightarrow$$ ①

6 b. $V_f = 0.5U$, $\alpha_1 = \beta_2 = 20^\circ$, $D = 1.3m$, $N = 3000rpm$

$\alpha_2 = ?$ $\beta_1 = ?$ Power devloped = ? $\dot{m} = 65 kg/sec$

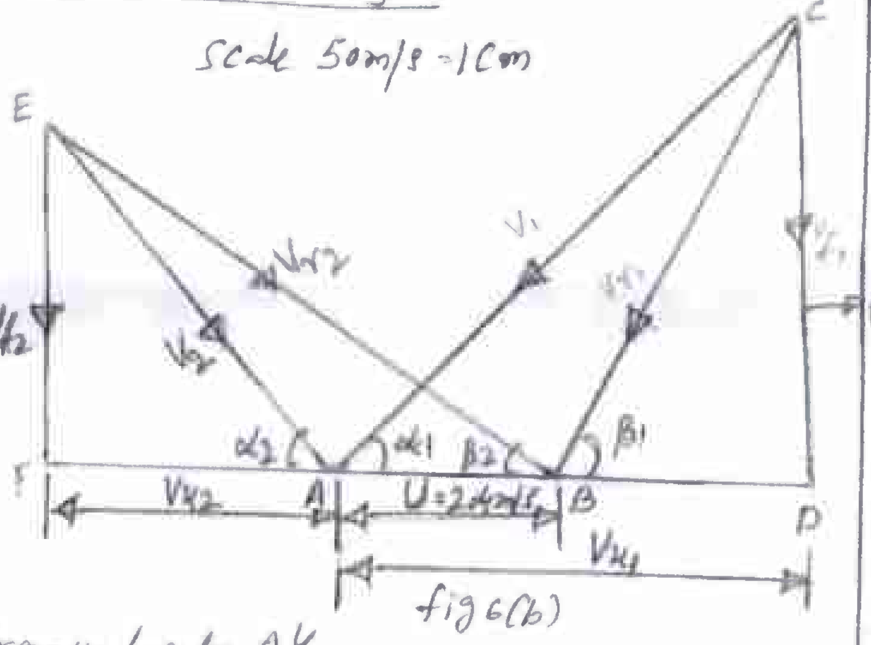
$\Delta H = ?$, $\eta_s = 0.8$

Blade speed $U = \frac{\pi DN}{60} = \frac{\pi \times 1.3 \times 3000}{60} = 204 m/sec$

$V_f = 0.5 \times U = 0.5 \times 204 = 102 m/sec \rightarrow$ ①

Construction of velocity Δle

Scale 50m/s = 1Cm



→ ④

fig 6(b)

From velocity Δle

V_{x_1} = ~~2.95~~ 280.5 m/sec, V_{x_2} = ~~60~~ 76.3 m/sec

⑫ $\Delta V_u = 356.8 m/s$

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Question Number	Solution	Marks Allocated
	(I) Inlet blade angle $\beta_1 = \overset{53.2^0}{\cancel{60}} = \alpha_2 \longrightarrow$	①
	(II) Power developed $= \frac{\dot{m}(\overset{\Delta V_u}{\cancel{V_{x1}+V_{x2}}})U}{1000}$ $= \frac{65(\overset{356.8}{\cancel{295+60}})\times 204}{1000}$ $= \overset{4735.8}{\cancel{4707.3}}$ kW $\longrightarrow$	②
	(iii) Isentropic Enthalpy drop $\eta_s = \frac{\text{Power developed}}{\text{Isentropic Enthalpy drop}} = \frac{P}{\dot{m}\Delta H}$ $0.8 = \frac{\overset{4735.8}{\cancel{4707.3}}}{65 \times \Delta H} \Rightarrow \Delta H = \overset{91.1}{\cancel{90.5}}$ kJ/kg $\longrightarrow$	②
7 a.	(i) Hydraulic Efficiency: It is the ratio of work done/s by the runner to the Energy posses by Water at inlet $\eta_h = \frac{2U[V_{x1} \pm V_{x2}]}{\rho g Q H}$	②
	(ii) Mechanical Efficiency: It is the ratio of power available at the shaft of turbine to the power delivered to the runner $\eta_{mech} = \frac{S.P}{\rho Q[V_{x1} \pm V_{x2}]U}$	②
	(iii) overall efficiency: It is the ratio of power available at shaft of turbine to the power posses by Water at inlet $\eta_{overall} = \frac{S.P}{\rho g Q H}$	②

⑬

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Question Number	Solution	Marks Allocated

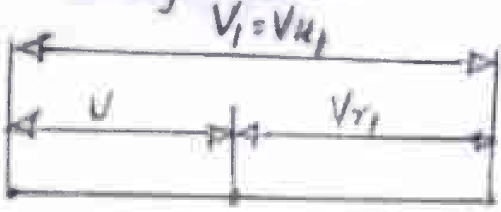
(iv) Volumetric Efficiency: It is the ratio of volume of water actually striking the runner to the volume of water supplied to the turbine. ②

$$\eta_V = \frac{Q - dQ}{Q}$$

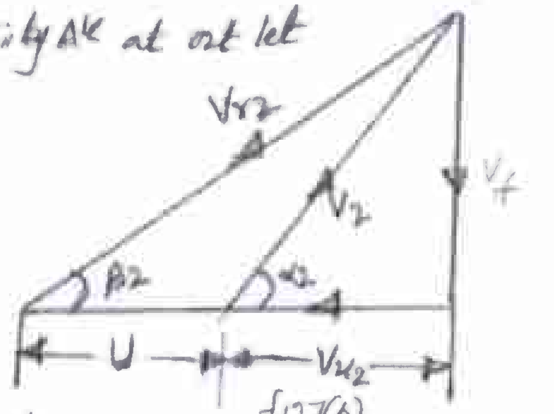
dQ - amount of water leaving without striking

7b: Maximum Efficiency of pelton wheel:

Velocity Δle at inlet



Velocity Δle at outlet



→ ②

fig 7(b)

Work done per kg of water by the runner } = $W = U[V_{w_1} + V_{w_2}]$

$$W = U[(V_1 - U)(1 + \cos\beta_2)$$

If bucket velocity coefficient C_b is considered

$$W = U[(V_1 - U)(1 + C_b \cos\beta_2)] \rightarrow ③$$

The Energy supplied to wheel $= \frac{V_1^2}{2}$ → ①

Hydraulic Efficiency $\eta_H = \frac{\text{Work done per kg of water}}{\text{KE supplied}}$

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$$\eta_H = \frac{2U[(V_1-U)(1+C_b\cdot\cos\beta_2)]}{V_1^2} \longrightarrow$$ ②

For maximum blade efficiency $\frac{d\eta_H}{dU} = 0$

Condition is $U = \frac{1}{2}V_1 \longrightarrow$ ③

$$\eta_{Hmax} = \frac{2U[(2U-U)(1+C_b\cos\beta_2)]}{(2U)^2}$$

$$\eta_{Hmax} = \frac{1+C_b\cos\beta_2}{2} \longrightarrow$$ ①

8 a.

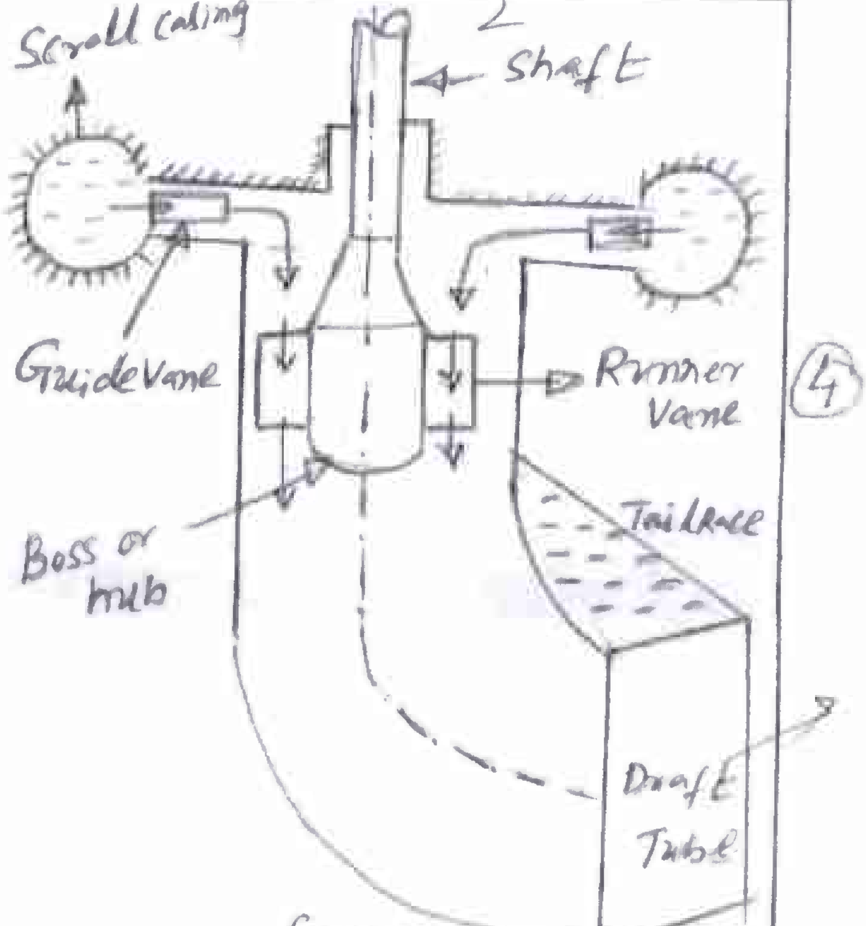
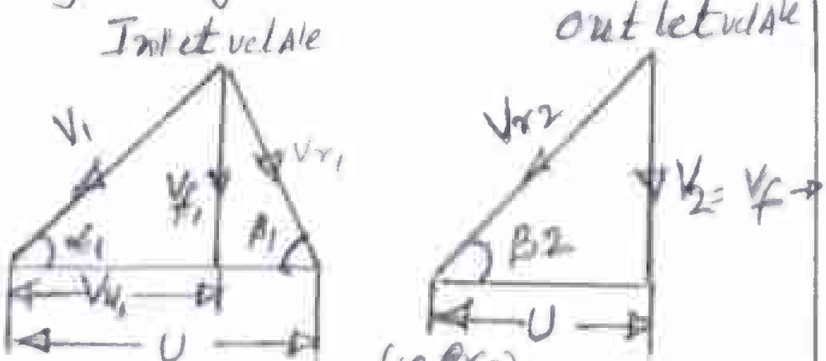


fig8(a) ④

Question Number	Solution	Marks Allocated

<u>Function of Kaplan Turbine</u>: Water from head race enters the Scroll casing and then moves to the Guide vanes. From the guidevanes water turn through 90° and flows axialy through the runner → ②

Velocity triangles of Kaplan turbine:



→ ②

fig 8(a)

8 b. Data: $H = 70m$, $P = 370kW$, flow ratio $= 0.25$. $N = 600rpm$, $\eta_h = 0.95$, $\frac{B_1}{D_1} = 0.1$, $\eta_0 = 0.8$, $D_1/D_2 = 2$, flow area $= 0.9 \times \pi D_1 B_1$, $V_{f_1} = V_{f_2} = V_f$, $\alpha_2 = 90°$, $\alpha_1 = ?$, $\beta_1 = ?$, $\beta_2 = ?$, $D_1 = ?$, $D_2 = ?$, $B_1 = ?$

$$\text{Flow ratio} = 0.25 = \frac{V_{f_1}}{\sqrt{2gH}} = \frac{V_{f_1}}{\sqrt{2 \times 9.81 \times 70}}$$

$$V_{f_1} = 9.26\ m/sec \longrightarrow ①$$

$$\eta_0 = \frac{P}{wQH/1000}$$

$$0.8 = \frac{370}{9.81 \times Q \times 70/1000}$$

$$Q = 0.674\ m^3/sec \longrightarrow ①$$

Diameter of Runner at inlet and outlet:

$Q = 0.9 \pi D_1 B_1 V_{f1}$

$0.674 = 0.9 \times \pi D_1 \times 0.1 D_1 \times 9.26 \longrightarrow$

$D_1 = \underline{0.507 m}, \; D_2 = \frac{1}{2} D_1 = \underline{0.254 m} \longrightarrow$ ②

Width of wheel at inlet

$B_1 = 0.1 D_1 = 0.1 \times 0.507 = \underline{0.0507 m} \longrightarrow$ ①

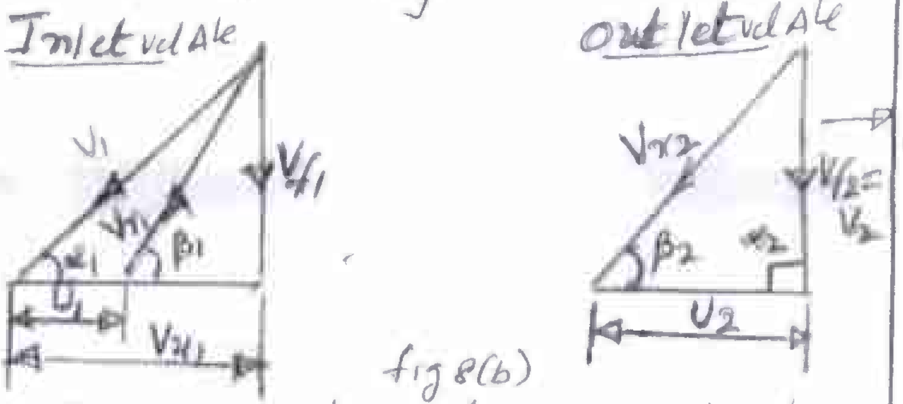
$U_1 = \frac{\pi D_1 N}{60} = \frac{\pi \times 0.507 \times 600}{60} = 15.94 m/sec$

$U_2 = \frac{\pi D_2 N}{60} = \frac{\pi \times 0.254 \times 600}{60} = 7.98 m/sec$ $\longrightarrow$ ①

$\eta_h = \frac{V_{x1} \times U_1}{gH} \Rightarrow 0.95 = \frac{V_{x1} \times 15.94}{9.81 \times 70}$

$V_{x1} = 40.92 m/sec \longrightarrow$ ①

∴ $U_1 < V_{x1}$ velocity Δles are constructed as



$\longrightarrow$ ②

fig 8(b)

From Inlet triangle Guide Blade angle:

$\tan \alpha_1 = \frac{V_{f1}}{V_{x1}} = \frac{9.26}{4.26} \Rightarrow \underline{\alpha_1 = 12.75°} \longrightarrow$ ①

Question Number	Solution	Marks Allocated
	Runner Blade angle at inlet and outlet $\tan\beta_1 = \frac{V_{f1}}{V_{w1}-u_1} = \frac{9.26}{40.92-\overset{15.94}{\cancel{9.26}}} \Rightarrow \beta_1 = \overset{20.34^0}{\cancel{16.3}}$	①
	$\tan\beta_2 = \frac{V_{f2}}{U_2} = \frac{9.26}{7.98} \Rightarrow \beta_2 = 49.25$	①
9 a.	**Static Head:** It is vertical distance between top surface of water in sump and top surface of water in delivery tank	②
	Cavitation: formation of bubbles and collapse on surface of blades, physically similar to corossion and pitting, forming cavities on blades phenomenon is known as cavitation	②
	Priming: Process of removing air present in suction pipe, in casing and in delivery pipe up to delivery valve called priming	②
	Multistage pump: Providing more than one impeller is called Multistage pump Types of arrangements i. series ii. parallel	②
9 b.	Minimum Starting Speed: $\frac{U_2^2}{2g} - \frac{U_1^2}{2g} \geq Hm$ For minimum speed $\frac{U_2^2}{2g} - \frac{U_1^2}{2g} = Hm \longrightarrow$	②

$$\eta_{mano} = \frac{Hm}{U_2 V_{x2}/g}$$

$$Hm = \eta_{mano} \times \frac{V_{x_2} \times U_2}{g}$$

$$\frac{U_2^2}{2g} - \frac{U_1^2}{2g} = \eta_{mano} \times \frac{V_{x_2} U_2}{g} \longrightarrow ②$$

$$\frac{\pi N}{120}\left[D_2^2 - D_1^2\right] = \eta_{mano} V_{x_2} D_2$$

$$N_{min} = \frac{120 \times \eta_{mano} V_{x_2} D_2}{\pi\left[D_2^2 - D_1^2\right]} \longrightarrow ②$$

9 c.

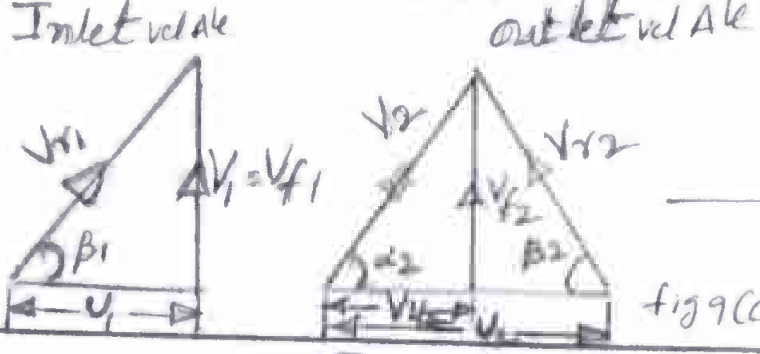
Data: $Q_1 = 0.15 m^3/sec$, $Hm = 12.5 m$, $N = 600 rpm$

$D_2 = 0.5 m$, $D_1 = 0.25 m$, $\beta_2 = 35°$, $A = 0.07 m^2$

$\eta_{man} = ?$ $\beta_1 = ?$

$$\left.\begin{aligned} U_1 &= \frac{\pi D_1 N}{60} = \frac{\pi \times 0.25 \times 600}{60} = 7.85 m/s \\ U_2 &= \frac{\pi D_2 N}{60} = \frac{\pi \times 0.5 \times 600}{60} = 15.7 m/sec \end{aligned}\right\} \rightarrow (02)$$

$$V_{f_1} = V_{f_2} = \frac{Q}{A} = \frac{0.15}{0.07} = 2.14 m/se$$



$\longrightarrow$ ①

fig 9(c)

Subject Title : TurboMachines **Subject Code :** 18ME54

Question Number	Solution	Marks Allocated
	(i) Manometric Efficiency: $\tan\beta_2 = \frac{V_{f_2}}{u_2 - V_{u_2}} \Rightarrow \tan 35 = \frac{2.14}{15.7 - V_{u_2}}$ $V_{u_2} = 12.64$ m/sec $\eta_{man} = \frac{H_m}{V_{u_2} u_2 / g} = \frac{12.5}{\frac{12.64 \times 15.7}{9.81}} = 0.6181$ $= \underline{61.81\%}$	②
	(ii) Vane angle at inlet: $\tan\beta_1 = \frac{V_{f_1}}{u_1} = \frac{2.14}{7.85} \Rightarrow \beta_1 = \underline{15.21}$	①
(10) a.	Pressure coefficient It is defined as the ratio of isentropic work to Eulers work	②
	Slip factor: It is defined as the ratio of actual whirl component to the ideal work component	②
	Power input factor: It is defined as the ratio of actual work supplied to theoratical work supplied power infactor	②
	Surging: Surging is the phenomenon resulting in unstable periodic and reversal of flow due to momentary increase in delivery pressure	②
10 b.	Data: $N = 15000$ rpm, $\dot{m} = 30$ kg/sec, $D_2 = 0.35 \times 2 = 0.7$m $V_{r2} = 100$ m/sec, $\beta_2 = 75°$, $T_{01} = 300$K, $P_{01} = 1$bar	

(20)

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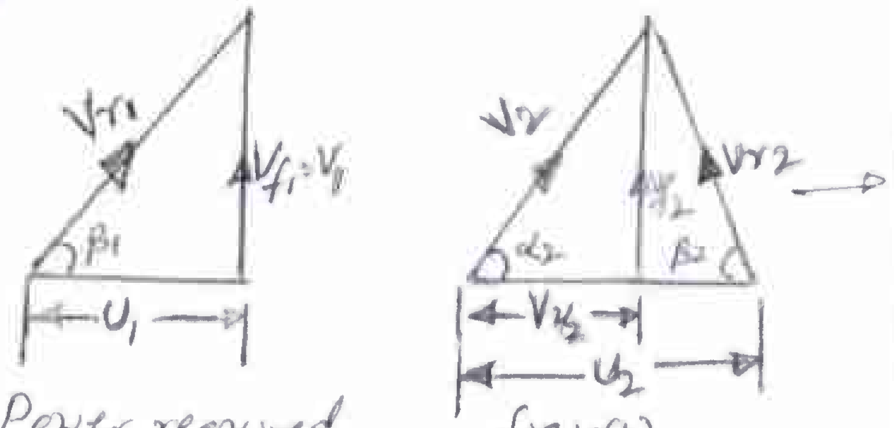
Question Number	Solution	Marks Allocated
	T = ?, P = ? H = ? N = ? P_{02} = ?	
	$U_2 = \frac{\pi D_2 N}{60} = \frac{\pi \times 0.7 \times 15000}{60} = 5498$ m/sec	①
	$\cos\beta_2 = \frac{U_2 - V_{x2}}{V_{r2}} \Rightarrow \cos 75 = \frac{5498 - V_{x2}}{1000}$	
	$V_{x2} = 523.9$ m/sec →	①
	 fig 10(b) →	②
	Power required $P = \frac{\dot m V_{x2} U_2}{1000} = \frac{30 \times 523.9 \times 5498}{1000}$ = 8641.5 kW →	②
	Torque $P = \frac{2\pi N T}{60} \Rightarrow 8641.5 = \frac{2\pi \times 15000 \times T}{60 \times 1000}$ T = 5501.3 Nm →	②
	Ideal Head $gH = V_{x2} U_2$	

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Question Number	Solution	Marks Allocated
	$H_2 = \frac{V_{x_2} \times U_2}{g} = \frac{523.9 \times 549.8}{9.81}$ $= \underline{\underline{29361.8\ m}}$	①
	Work done: $W = \frac{V_{x_2} u_2}{1000} = \frac{523.9 \times 549.8}{1000}$ $= \underline{\underline{288}}\ kJ/kg$	①
	Exit Total pressure: $W = C_p T_{01}\left[\left(\frac{P_{02}}{P_{01}}\right)^{\frac{\gamma-1}{\gamma}} - 1\right]$ $288 = 1.005 \times 800\left[\left(\frac{P_{02}}{1}\right)^{\frac{1.4-1}{1.4}} - 1\right]$ $P_{02} = \underline{10.44\ bar}$	②

Approved by

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