Roll No. | | | | | | | | | | | | |

PRESIDENCY UNIVERSITY
BENGALURU

SCHOOL OF ENGINEERING

TEST – 1

Sem AY: Odd Sem 2019-20
Course Code: MEC 303
Course Name: TURBOMACHINERY
Program & Sem: B.Tech (MEC) & V DE

Date: 27.09.2019
Time: 2.30PM to 3.30PM
Max Marks: 40
Weightage: 20%

Instructions:

(i) The question paper consists of 3 Parts.
(ii) All Questions are compulsory.

Part A [Memory Recall Questions]

Answer all the Questions. Each Question carries four marks. (3Qx4M=12M)

1. State Buckingham's π theorum and obtain dimension of dynamic viscosity. and power (C.O.NO.1) [Knowledge]

2. Explain any four difference between Turbomachine and positive displacement machine. (C.O.NO.1) [Knowledge]

3. Explain geometrical similarity, kinematic similarity and dynamic similarity

(C.O.NO.1) [Knowledge]

Part B [Thought Provoking Questions]

Answer both the Questions. Each Question carries six marks. (2Qx6M=12M)

4. Explain physical significance of dimensionless parameter in turbomachine. Mention four points

(C.O.NO.1) [Knowledge]

5. A Quarter scale turbine model is tested under a head of 10 m. The full scale turbine is required to work under head of 10m. The full scale turbine is required to work under head of 28.5 m and 415 rpm. (a) At what speed must the model be run if it develops 94 kW and uses 0.96 m^3/s at this speed (b) What power will be obtained from full scale turbine.

(C.O.NO.1)[Comprehension]

Part C [Problem Solving Questions]

Answer both the Question. Each Question carries ten marks. **(2Qx8M=16)**

6. A turbomachine has inner and outer radius of 8 cm and 15 cm. The fluid enters at inner radius and leaves at larger radius of wheel. The fluid enters the blade at an angle of 22° with velocity of 43 m/s. The absolute velocity of fluid at rotor exit is 16 m/s and direction of 36° from wheel tangent. The speed of rotor is 3000 rpm

(C.O.NO 2) [Comprehension]

a) Draw appropriate inlet and outlet velocity triangle with proper nomenclature.

b) Power output in kW if mass flow rate of fluid is 10 kg/s.

c) Velocity of flow for inlet and outlet

7. A pipe of diameter 2 m is required to transport an liquid of specific gravity 0.9 viscosity 3×10^{-2} poise at a rate of 4000 litre/s. Tests were conducted on 15 cm diameter pipe (model) using water at 20°C.Dynamic similarity can be assumed between model and prototype. Find the velocity and rate of flow in model.

Viscosity of water at 20°C= 0.01 poise (C.O.NO.2) [Comprehension]

SCHOOL OF ENGINEERING

Semester: V
Course Code: MEC 303
Course Name: Turbomachinery

Date: 27th sept. 2019
Time: 1 hr.
Max Marks: 40
Weightage: 20%

Date:
Time:
Max Marks:
Weightage:

Extract of question distribution [outcome wise & level wise]

Q.NO	C.O.NO	Unit/Module Number/Unit /Module Title	Memory recall type [Marks allotted] Bloom's Levels			Thought provoking type [Marks allotted] Bloom's Levels			Problem Solving type [Marks allotted]			Total Marks
			K			C			A			
1	1	MODULE 1		4								
2	1	MODULE 1		4								

3	1	MODULE 1		4								
4	1	MODULE 1					6					
5	2	MODULE 2					6					
6	2	MODULE 2								8		
7	2	MODULE 2								8		
	Total Marks	40										

K =Knowledge Level   C = Comprehension Level, A = Application Level

Note: While setting all types of questions the general guideline is that about 60%

Of the questions must be such that even a below average students must be able to attempt, About 20% of the questions must be such that only above average students must be able to attempt and finally 20% of the questions must be such that only the bright students must be able to attempt.

I here certify that All the questions are set as per the above lines Joel Hemant]

Annexure- II: Format of Answer Scheme

GAIN MORE KNOWLEDGE
REACH GREATER HEIGHTS

SCHOOL OF ENGINEERING

SOLUTION

Semester: V	**Date**: 27/09/2019	**Date**:
Course Code: MEC 303	**Time**: 2.30 P.M.-3.30 P.M.	**Time**:
Course Name:Turbomachinery	**Max Marks**: 40	**Max Marks**:
	Weightage: 20%	**Weightage**:

Part A (3Q x4 M = 12Marks)

Q No	Solution	Scheme of Marking	Max. Time requ for each Quest
1	If there are n variables in a problem and these variables contain m primary dimensions (for example M, L, T) the equation relating all the variables will have (n-m) dimensionless groups. Buckingham referred to these groups as π groups. The final equation obtained is in the form of :	2 marks for definition and 1-1 marks for each dimensional formula	5 min

<table>
<tr><td></td><td>$\pi_1 = f(\pi_2, \pi_3, \ldots \pi_{n-m})$
Power=watt=N-m/s= $kgms^{-2}ms^{-1}$
$=ML^2T^{-3}$
Dynamic viscosity(μ)=kg/m-s=$ML^{-1}T^{-1}$</td><td></td><td></td></tr>
<tr><td>2.</td><td>Comparison between positive displacement machines and Turbo machines
<table>
<tr><th>Turbo machines</th><th>Positive displacement machines</th></tr>
<tr><td>It creates Thermodynamic & Dynamic action b/w rotating element & flowing fluid, energy transfer takes place if pressure and momentum changes</td><td>It creates Thermodynamic & Mechanical action b/w moving member&static fluid, energy transfer takes place with displacement of fluid</td></tr>
<tr><td>It involves a steady flow of fluid & rotating motion of mechanical element</td><td>It involves a unsteady flow of fluid & reciprocating motion</td></tr>
<tr><td>They operate at high rotational speed</td><td>They operate at low speed</td></tr>
<tr><td>Change of phase during fluid flow causes serious problems in turbomachine</td><td>Change of phase during fluid flow causes less problems in Positive displacement machines</td></tr>
<tr><td>Efficiency is usually less</td><td>Efficiency is higher</td></tr>
</table></td><td>1 marks for each difference</td><td>5 min</td></tr>
<tr><td>3.</td><td>Geometric Similarity:
The ratio of all corresponding linear dimension in the model and prototype are equal.

Let L_m = length of model
b_m = width of model
d_m = diameter of model
A_m = area of model
V_m = volume of model

L_p, b_p, d_p, A_p, V_p are corresponding values of the prototype.

$$\frac{L_p}{L_m} = \frac{b_p}{b_m} = \frac{d_p}{d_m} = L_r$$
$$\frac{A_p}{A_m} = L_r^2, \quad \frac{V_p}{V_m} = L_r^3$$</td><td>1-1-1 marks for each definition and 1 marks for expression</td><td>5 min</td></tr>
</table>

	Kinematic Similarity: means the similarity of motion between model and prototype. Thus kinematic similarity is said to exist between the model and the prototype if the ratios of the velocity and acceleration at the corresponding points in the model and prototype are the same in magnitude; the directions also should be parallel. $$\frac{V_{p_1}}{V_{m_1}} = \frac{V_{p_2}}{V_{m_2}} = V_r \qquad \frac{a_{p_1}}{a_{m_1}} = \frac{a_{p_2}}{a_{m_2}} = a_r$$ **Dynamic Similarity**: means the similarity of forces between model and prototype. Thus dynamic similarity is said to exist between the model and the prototype if the ratios of the forces acting at the corresponding points in the model and prototype are the same in magnitude; the directions also should be parallel $$\frac{F_{p_1}}{F_{m_1}} = \frac{F_{p_2}}{F_{m_2}} = \frac{F_{p_3}}{F_{m_3}} = F_r$$		

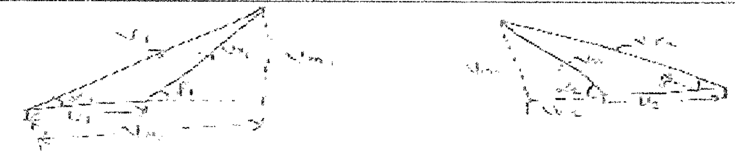
Part B (2Q x6M =12 Marks)

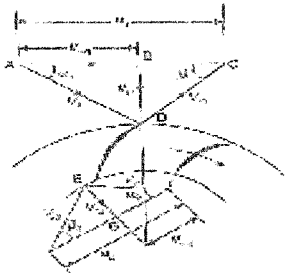
Q No	Solution	Scheme of Marking	Max. Time required for each Question
1.	The use of dimensionless numbers in engineering and physics allows the important task of data reduction of similar problems. This means that a lot of experimental runs are avoided if data is correlated using appropriate dimensionless parameters. Recall, for example, the transient 1D heat conduction in a slab with a convection boundary condition. In this case, the parameters involved are the slab thickness (L), conductivity (k), specific heat (cp), density (ρ), heat convection coefficient (h), temperature (T) and a space coordinate (x). Using dimensionless numbers the temperature dependence of six parameters reduces to a dependency of Biot, Fourier and x/L. Besides this fundamental application of the dimensionless numbers, they also serve as an important mechanism for understanding the physics of the phenomenon There are two widely used ways for obtaining the dimensionless numbers. The first one is the use of the well-known, π-theorem where it is, first, chosen the important variables of the physical process, including physical properties, geometry and flow variables, followed by the solution of a linear system for determining the exponents of the different variables which form the	1.5 marks for each points	10 min

	dimensionless numbers. This procedure requires foreknowledge, since if some important variable is forgotten, its influence in the dimensionless numbers is missed. And, missing an important parameter may result in the appearance of meaningless dimensionless numbers, which would correlate the physics of a non-existing phenomenon. The second approach for determining dimensionless numbers is through the use of the partial differential equations governing the physical phenomena. The key issue in this approach is the definition of the dimensionless dependent and independent variables. A good choice is required to end up in dimensionless numbers that properly correlate the physical data.		
2.	$\therefore \quad N_m = 4N_p\left[\frac{H_m}{H_p}\right]^{-1/2} = 4\times\left[\frac{10}{28.5}\right]^{1/2}\times 415 = 983.3$ rpm **(b) Power developed by the full scale turbine, i.e. prototype (P_p):** $[N_s]_m = \left[\frac{N\sqrt{P}}{H^{5/4}}\right]_m = \frac{983.3\times\sqrt{94}}{10^{5/4}} = 536.11$ rpm $\left[\frac{N\sqrt{P}}{H^{5/4}}\right]_p = \left[\frac{N\sqrt{P}}{H^{5/4}}\right]_m$ $\frac{415\sqrt{P}}{28.5^{5/4}} = 536.11; \therefore P_p = 7236.29$ kW *Solution:* (a) **Speed of the model (N_m):** Given that $\frac{L_m}{L_p} = \frac{1}{4}$ m – model, p – prototype (full-scale turbine) We have the speed relations as follows: $\frac{U_m}{U_p} = \left[\frac{H_m}{H_p}\right]^{1/2} = \frac{D_m N_m}{D_p N_p} = \frac{1}{4}\times\frac{N_m}{N_p}$	3-3 marks for a and b each	10 min

Part C (2Q x 8M =16 Marks)

Q No	Solution	Scheme of Marking	Max. Time required for each Question

1.	Inner radius, $R_1 = 0.08$ m ; $D_1 = 16$ cm $= 0.16$ m Outer radius, $R_2 = 15$ cm ; $D_2 = 30$ cm $= 0.3$ m Nozzle angle, $\alpha_1 = 22°$, at inlet $V_1 = 43$ m/s ; $V_2 = 16$ m/s fixed blade angle, $\alpha_2 = 36°$ at outlet	3 marks for velocity triangle	15 min
	 We know that, $u_1 = \frac{\pi D_1 N}{60} = \frac{\pi \times 0.16 \times [illegible]}{60} = [illegible]$ m/s $u_2 = \frac{\pi D_2 N}{60} = \frac{\pi \times 0.3 \times [illegible]}{60} = [illegible]$ m/s From velocity triangle at inlet, at outlet $\cos\alpha_1 = \frac{V_{w_1}}{V_1}$ $\cos\alpha_2 = \frac{V_{w_2}}{V_2}$ $\cos 22 = \frac{V_{w_1}}{43}$ $\cos 36 = \frac{V_{w_2}}{16}$ $V_{w_1} = [illegible]$ m/s $V_{w_2} = [illegible]$ m/s here, $V_{w_1} \rightarrow$ $V_{w_2} \leftarrow$ $E = V_{w_1} u_1 + V_{w_2} u_2 = ([illegible] \times [illegible]) + ([illegible] \times [illegible])$	3 marks for power 2 marks for velocity of flow	

	$\boxed{E = 1612\ J/kg}$ Power, $P = mE = 10 \times 1612$ $\boxed{P = 16.12\ kW}$ From velocity triangles, At inlet, $\sin \alpha_1 = \frac{V_{m_1}}{V_1} = \frac{V_{m_1}}{...}$ $\boxed{V_{m_1} = 16.203\ m/s}$ At outlet, $\sin \alpha_2 = \frac{V_{m_2}}{V_2}$ $\sin 36 = \frac{V_{m_2}}{16}$ $\boxed{V_{m_2} = 9.40\ m/s}$		
1.	V absolute velocity of fluid V_r relative velocity (relative to the rotor) V_f flow velocity. This is one component of absolute velocity V. It is either radial velocity in case of radial flow machines and axial velocity in case of axial flow machines. V_u = tangential velocity, i.e. tangential component of absolute velocity V.  Figure 2.3 Parts of rotor of generalised turbomachine with inlet and outlet velocity triangles. From inlet velocity triangle ABD (figure 2.3): $V_{f1}^2 = V_1^2 - V_{u1}^2$ (2.5) Now consider the triangle DCB: $V_{f1}^2 = V_{r1}^2 - (u_1 - V_{u1})^2$	2 marks for triangle and 6 marks for derivation	

or

$$V_{r1}^2 - V_{f1}^2 = u_1^2 - V_{w1}^2 + 2u_1V_{w1}$$

Equating Eqs. (2.3) and (2.4),

$$V_1^2 - V_{w1}^2 = V_{r1}^2 - u_1^2 - V_{w1}^2 + 2u_1V_{w1}$$

or

$$u_1V_{w1} = \frac{(V_1^2 + u_1^2 - V_{r1}^2)}{2}$$

Similarly,

$$u_2V_{w2} = \frac{(V_2^2 + u_2^2 - V_{r2}^2)}{2}$$

Substituting Eqs. (2.5) and (2.6) in (2.2),

$$\frac{\text{W.D.}}{\text{Unit mass flow rate}} = \frac{(V_1^2 + u_1^2 - V_{r1}^2)}{2g_c} - \frac{(V_2^2 + u_2^2 - V_{r2}^2)}{2g_c}$$

$$= \frac{(V_1^2 - V_2^2) + (u_1^2 - u_2^2) + (V_{r2}^2 - V_{r1}^2)}{2g_c}$$

2.	Given, $D_p = 2m$; $\mu_p = 3 \times 10^{-2}$ poise $Q_p = 4000$ litres/s $= 3 m^3/s$ $S_p = 0.9$; $\rho_p = 0.9 \times 1000 = 900 kg/m^3$ diameter of model. $D_m = 15cm = 0.15$ $\mu_{[20°C]} = 0.01$ poise $= 1 \times 10^{-2}$ poise $\rho_{water} = 1000 kg/m^3$ For dynamic similarity $\frac{\rho_m V_m D_m}{\mu_m} = \frac{\rho_p V_p D_p}{\mu_p}$ $\frac{V_m}{V_p} = \frac{\rho_p}{\rho_m} \times \frac{D_p}{D_m} \times \frac{\mu_m}{\mu_p}$ $\Rightarrow \frac{900}{1000} \times \frac{2}{0.15} \times \frac{1 \times 10^{-2}}{3 \times 10^{-2}}$ $\rightarrow \frac{9}{10} \times \frac{200}{15} \times \frac{1}{3}$ $\boxed{\frac{V_m}{V_p} = 4}$ $V_m = 4V_p$ $V_p = \frac{4}{\frac{\pi}{4} \times (2)^2} = 1.27 m/s$ $\boxed{V_p = 1.27 m/s}$ $\boxed{V_m = 5.09 m/s}$ $Q_m = \frac{\pi}{4} \times (0.15)^2 \times 5.09$ $\rightarrow 0.114525 m^3/s$	4-4 marks for velocity and discharge	10 min

Roll No.													

GAIN MORE KNOWLEDGE
REACH GREATER HEIGHTS

PRESIDENCY UNIVERSITY
BENGALURU

SCHOOL OF ENGINEERING

TEST – 2

Sem & AY : Odd Sem 2019-20
Course Code: MEC 303
Course Name: TURBOMACHINERY
Program & Sem: B.Tech (MEC) & V

Date: 16.11.2019
Time: 2:30 PM to 3:30 PM
Max Marks: 40
Weightage: 20%

Instructions:

(i) Use of Un-programmable calculators is permitted.

Part A [Memory Recall Questions]

Answer all the Question. Each Question carries four marks. (4Qx4M=16M)

1. Derive the velocity relation for 50% reaction turbine assuming U_1=U_2.
   Take V_{r1}= Relative velocity at inlet, V_{r2}= Relative velocity at exit
   V_1=Absolute velocity at inlet, V_2= Absolute velocity at exit.

   (C.O.NO.1) [Knowledge]

2. Define different types of head related to hydraulic turbine with appropriate diagram. Also give classification of Hydraulic turbine for four different condition

   (C.O.NO.1) [Knowledge]

3. Define degree of reaction. Write expression for Degree of Reaction in term of different velocity (U_1,U_2,V_1,V_2, V_{r1}, V_{r2})

   (C.O.NO.1) [Knowledge]

4. Define Hydraulic efficiency, Mechanical efficiency and overall efficiency of turbine. Also write expression for hydraulic efficiency in term of Blade speed (U), Whirl velocity(V_{w1},V_{w2}) and absolute velocity(V_1)

   (C.O.NO.1) [Knowledge]

Part B [Thought Provoking Questions]

Answer both the Questions. Each Question carries seven marks. (2Qx7M=14M)

5. Increasing the velocity of jet for Pelton wheel having blade speed U will increase its hydraulic efficiency. If yes than obtain the relation between jet velocity V and blade velocity U which will give maximum hydraulic efficiency

(C.O.NO.2) [Comprehension]

6. How can you identify that turbomachine is a power absorbing and power producing based on degree of reaction. Explain with help of different velocities involved in Turbomachine. (C.O.NO.2) [Comprehension]

Part C [Problem Solving Questions]

Answer the Question. The Question carry ten marks. (1Qx10M=10M)

7. A Pelton wheel is to be designed for following specification.
   Shaft Power=11772 kW
   Net head=380m
   Speed 750 rpm
   Overall efficiency=86%
   Jet diameter is not to exceed (1/6) of wheel diameter
   Determine-a) Wheel diameter (in m)
   b) No. of jet required
   c) Diameter of jet (in m)

Assume speed ratio, $U/V_1=0.45$

And coefficient of velocity (C_v) as 0.985.

GAIN MORE KNOWLEDGE
REACH GREATER HEIGHTS

SCHOOL OF ENGINEERING

Semester: 5

Course Code: MEC 303

Course Name: Turbomachinery

Date: 16 /11/2019

Time: 1 hr

Max Marks: 40

Weightage: 20%

Extract of question distribution [outcome wise & level wise]

Q.NO.	C.O.NO	Unit/Module Number/Unit /Module Title	Memory recall type [Marks allotted] Bloom's Levels			Thought provoking type [Marks allotted] Bloom's Levels			Problem Solving type [Marks allotted]			Total Marks
			K			C			A			
1	1	1		K	4							4
2	1	1		K	4							4
3	1	1		K	4							4
4	1	1		K	4							4
5	2	2		K	4							7
6	1	1					C	2				7
7	1	1							C	2		10
	Total Marks											40

K =Knowledge Level C = Comprehension Level, A = Application Level

Note: While setting all types of questions the general guideline is that about 60%

Of the questions must be such that even a below average students must be able to attempt, About 20% of the questions must be such that only above average students must be able to attempt and finally 20% of the questions must be such that only the bright students must be able to attempt.

Annexure- II: Format of Answer Scheme

SCHOOL OF ENGINEERING

SOLUTION

Semester: 5

Course Code: MEC 303

Course Name: BASIC THERMODYNAMICS

Date:

Time: 1 hr

Max Marks: 40

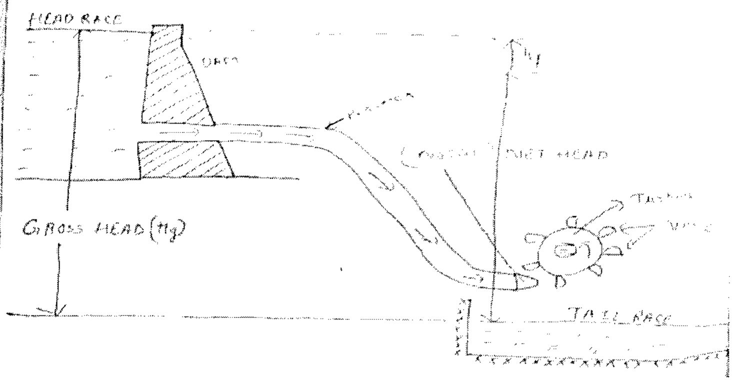
Weightage: 20%

Part A (4Q x 4M =16 Marks)

Q No	Solution	Scheme of Marking	Max. Ti required each Questi
1	50 % Reaction turbomachine i.e. $R = 0.5 = \frac{1}{2}$ $R = \frac{S}{S+D} \Rightarrow \frac{1}{2} = \frac{S}{S+D}$ $\Rightarrow \frac{S}{2} + \frac{D}{2} = S \Rightarrow \frac{S}{2} = \frac{D}{2} \Rightarrow \boxed{S = D}$ $\Rightarrow V_1^2 - V_2^2 = (u_1^2 - u_2^2) + (V_{r_2}^2 - V_{r_1}^2)$ If $u_1 = u_2$ $\Rightarrow V_1^2 - V_2^2 = V_{r_2}^2 - V_{r_1}^2$ $\boxed{V_1 = V_{r_2}}$ $\boxed{V_2 = V_{r_1}}$ i.e. Absolute velocity of fluid at inlet (V_1) is equal to relative velocity at outlet (V_{r_2}) and absolute velocity of fluid at outlet (V_2) is equal to relative velocity at inlet (V_{r_1}).	2-2 marks for each velocity relation	7 min

<table>
<tr>
<td>2.</td>
<td></td>
<td>Hydro-electric Power

* Different Heads and Efficiency of turbines



Gross Head (Hg)
→ The head from ground level to the level of water at the top of water surface in dam.

Net head (H)
→ The head at which turbine works. It is equal to gross head minus head loss due to friction

$H = Hg - h_f$

where $h_f = \frac{fLV^2}{2gD}$

where f = friction factor ; L = length of pipe
V = velocity of water in pipe, D = diameter of pipe

CLASSIFICATION

A/C to type of energy at inlet
→ Impulse turbine
→ React^n turbine

A/C to direc^n of flow through Runner
→ tangential flow
→ Radial flow
→ Axial flow
→ mixed flow

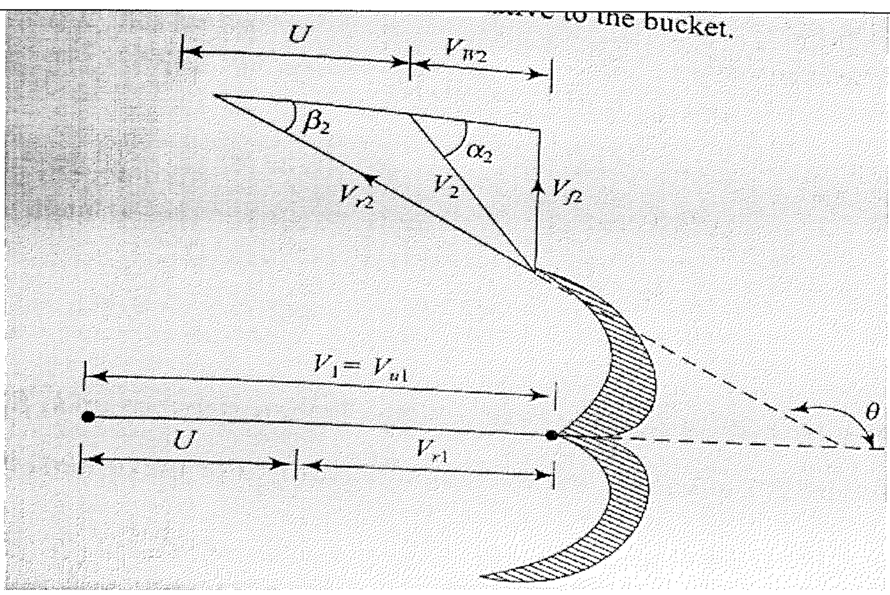
A/C to head at inlet
→ high head
→ low head
→ medium head

A/C to specific speed
→ low
→ medium
→ high</td>
<td>1 marks for diagram 1.5 marks for heads and 1.5 marks for classification</td>
<td>7 min</td>
</tr>
<tr>
<td>3</td>
<td></td>
<td>* Degree of React^n → (R)
→ Ratio of change in static pressure in rotor to total energy transfer in rotor

$$R = \frac{\Delta h_s}{\Delta h_o}$$
$$R = \frac{\frac{1}{2g_c}\left[(U_1^2 - U_2^2) + (V_{r_2}^2 - V_{r_1}^2)\right]}{\frac{1}{2g_c}\left[(V_1^2 - V_2^2) + (U_1^2 - U_2^2) + (V_{r_2}^2 - V_{r_1}^2)\right]}$$
$$R = \frac{(U_1^2 - U_2^2) + (V_{r_2}^2 - V_{r_1}^2)}{(V_1^2 - V_2^2) + (U_1^2 - U_2^2) + (V_{r_2}^2 - V_{r_1}^2)}$$</td>
<td>1 marks for definition and 3 marks for expression</td>
<td>4 min</td>
</tr>
</table>

4	Hydraulic efficiency= $\frac{\text{Power delivered by water to runner}}{\text{Power supplied by water at inlet of turbine}}$ Mechanial efficiency= $\frac{\text{power at shaft of turbine}}{\text{Power delivered by water to runner}}$ Overall efficiency = $\frac{\text{shaft power}}{\text{water power}}$ $=\frac{SP}{WP}\times\frac{RP}{RP}=\frac{SP}{RP}\times\frac{RP}{WP}$=Mechanical efficiency×hydraulic efficiency Hydraulic efficiency= $\frac{2\times(Vw1+Vw2)U}{V_1^2}$	1-1-1 marks for each efficiency and 1 marks for expression of hydraulic efficiency	4 mi

Part B (2Q x 7M = 14 Marks)

Q No	Solution	Scheme of Marking	Max. Time required for each Question
5		2 marks for diagram and 5 marks for derivation	15 min

	$W = P = FU = \rho Q(V_{w1} - V_{w2})U$ $= \rho Q[(V_{r1} + U) - (U - V_{r2}\cos\beta_2)]U$ [∵ $V_{w1} = V_{r1} + U$ and $V_{w2} = U - V_{r2}\cos\beta_2$] $= \rho Q(V_{r1} + V_{r2}\cos\beta_2)U$ $= \rho Q V_{r1}[1 + k\cos\beta_2]U$ [∵ $V_{r2} = kV_{r1}$] or $W = \rho Q(V_1 - U)[1 + k\cos\beta_2]U$ The power input to the wheel is $\rho Q\frac{V_1^2}{2}$ The hydraulic efficiency can be expressed as $\eta_h = \frac{\rho Q(V_1 - U)[1 + k\cos\beta_2]U}{\rho Q\frac{V_1^2}{2}}$ or $\eta_h = \frac{2[1 + k\cos\beta_2](V_1 - U)U}{V_1^2}$ or $\eta_h = 2[1 + k\cos\beta_2]\left(1 - \frac{U}{V_1}\right)\frac{U}{V_1}$ It is clear from Eq. (19.17) that the hydraulic efficiency of a Pelton turbine depends on k, β_2 … For a given bucket (constant k and β_2), efficiency is a function of $\frac{U}{V_1}$ only. For maximum effi… $\frac{d\eta_h}{d\left(\frac{U}{V_1}\right)} = 0$ or $2[1 + k\cos\beta_2]\left(1 - 2\frac{U}{V_1}\right) = 0$ or $\frac{U}{V_1} = \frac{1}{2}$		
6	When degree of reaction is more than 1 R>1 $R = \frac{S}{S+D} > 1$ $S > S + D$ D<0 $V_1^2 - V_2^2 < 0$ $V_1 < V_2$ Power absorbing machine when R is positive When degree of reaction is less than 1 R<1 $R = \frac{S}{S+D} < 1$ $S < S + D$ D>0 $V_1^2 - V_2^2 > 0$ $V_1 > V_2$ Power output machine when R is negative.	3.5-3.5 marks for each degree of reaction	10 min

Part C (1Q x 10M =10 Marks)

Q No	**Solution**	**Scheme of Marking**	**Max. Time required for each Question**

7	$\eta_o = 0.86$, $\frac{d}{D} = \frac{1}{6}$ $V_1 = C_{v_1}\sqrt{2gH} = 0.985\sqrt{2\times 9.81\times 380} = 85.05$ ~~[illegible]~~ $0.45 = \frac{U}{85.05}$ $U = 38.27\ m/s$ $U = \frac{\pi D N}{60}$ $D = \frac{U\times 60}{\pi N} = \frac{38.27\times 60}{\pi \times 750}$ $D = 0.975\ m$ $\frac{d}{D} = \frac{1}{6}$ $d = \frac{1}{6}\times D = \frac{1}{6}\times 0.975 = 0.1625$ $d = 0.1625 \approx 0.163\ m$ discharge through one jet, q q = Area of jet × Velocity of jet $\Rightarrow \frac{\pi}{4}d^2 \times V_1 = \frac{\pi}{4}\times(0.163)^2\times 85.05$ $q = 1.77\ m^3/s$ $0.86 = \eta_o = \frac{S.P}{W.P} = \frac{11772}{\frac{9.81 Q H}{1000}} = \frac{11772\times 1000}{1000\times 9.81\times Q\times 380}$ $Q = 3.672\ m^3/s$ ∴ No. of jets $= \frac{\text{Total discharge}}{\text{Discharge through jet}} = \frac{Q}{q} = \frac{3.672}{1.77} \approx 2$ Ans	1 marks for given data 3-3-3 marks for each a,b,c part	13 min

Roll No												

PRESIDENCY UNIVERSITY
BENGALURU

SCHOOL OF ENGINEERING

END TERM FINAL EXAMINATION

Semester: Odd Semester: 2019 - 20	**Date**: 23 December 2019
Course Code: MEC 303	**Time**: 9:30 AM to 12:30 PM
Course Name: TURBOMACHINERY	**Max Marks**: 80
Program & Sem: B.Tech (MEC) & V (DE-II)	**Weightage**: 40%

Instructions:

(i) Read the all questions carefully and answer accordingly.
(ii) Question paper consists of 3 parts
(iii) Scientific and Non-programmable calculators are permitted

Part A [Memory Recall Questions]

Answer all the Questions. Each Question carries 4 marks. (4Qx5M=20M)

1. State Buckingham's pi theorem with expression. Find the dimension of kinematic viscosity, specific speed of turbine and torque. (C.O.No.1) [Knowledge]

2. With neat and clean diagram explain velocity compounding and pressure compounding in steam turbine (C.O.No.2) [Knowledge]

3. With help of neat diagram explain the working of Francis turbine along with its parts. (C.O.No.3) [Knowledge]

4. With help of neat diagram explain the working of centrifugal pump along with its parts (C.O.No.4) [Knowledge]

Part B [Thought Provoking Questions]

Answer both the Questions. Each Question carries 10 marks. (2Qx10M=20M)

5. A design engineer designs a centrifugal pump which delivers water against a head of 16 m. The external and internal diameter of the impeller are 400 mm and 200 mm respectively. Will this pump start at any speed? What is the minimum speed in rpm given to the pump so that it will start delivering water (Minimum starting speed of pump) (C.O.No.2) [Comprehension]

6. Construct velocity triangle for maximum utilization factor and with the help of triangle find the expression for maximum utilization factor. At which condition utilization factor can be maximum or unity. (C.O.No.2) [Comprehension]

Part C [Problem Solving Questions]

Answer all the Questions. Each Question carries 10 marks. **(4Qx10M=40M)**

7. A Centrifugal Pump is to discharge 0.118 m^3/s at a speed of 1450 rpm against a head of 25 meter. The impeller diameter is 250 mm and its width at outlet is 50 mm and manometric efficiency is 75%. Draw velocity triangle at inlet and outlet and vane angle at outlet.
(C.O.No.3) [Comprehension]

8. The penstock supplies water from a reservoir to a pelton wheel with a gross head of 500 m. one third of gross head is lost in friction in penstock. The rate of flow of water through the nozzle fitted at the end of penstock is 2 m^3/s. The angle of deflection of jet is 165°.Speed ratio (U/V_1) is equal to 0.45. Construct velocity triangle and find power given by water to runner and Hydraulic efficiency. (C.O.No.4) [Application]

9. In a francis turbine the runner outer diameter is 75 cm and inner diameter is 50 cm. The runner speed is 400 rpm. Liquid water enters the wheel at speed of 15 m/s at an angle of 15° at point of entry. The discharge at outlet is radial and absolute velocity is 5 m/s. Construct velocity triangle and find a) Power output for m= 1 kg/s b) Degree of Reaction(R) (c) Utilization factor.
(C.O.No.4) [Application]

10. The outer diameter of an impeller of a centrifugal pump is 400 mm and outlet width is 50 mm. The pump is running at 800 rpm and is working against head of 15 m. The vane angle at outlet is 40° and manometric efficiency is 75%. Draw velocity triangle and determine;

    a) Velocity of flow at outlet and velocity of water leaving the vane (V_2)

    b) Angle made by absolute velocity at outlet.

    c) Discharge (in Litre/sec)

(C.O.No.4) [Application]

I hereby certify that all the questions are set as per the above guidelines.

Faculty Signature:

Reviewer Commend:

Format of Answer Scheme

SCHOOL OF ENGINEERING

GAIN MORE KNOWLEDGE
REACH GREATER HEIGHTS

SOLUTION

Semester: Odd Sem. 2019-20
Course Code: MEC 303
Course Name: Turbomachinery
Program & Sem: B.Tech & V (DE-II)

Date: 23.12.2019
Time: 9:30 AM to 12:30 PM
Max Marks: 80
Weightage: 40%

Part A (4Q x 5M =20Marks)

Q No	Solution	Scheme of Marking	Max. Time required for each Question
1	If there are n variables in a problem and these variables contain m primary dimensions (for example M, L, T) the equation relating all the variables will have (n-m) dimensionless groups. Buckingham referred to these groups as π groups. The final equation obtained is in the form of : $\pi l = f(\pi 2, \pi 3, \ldots \pi n\text{-}m)$ Kinematic viscosity- L^2/T^2 Specific speed of turbine= $M^{0.5}L^{-0.25}T^{-2.5}$ Torque =ML^2T^{-2}	2 marks for theorem and 1 -1-1 marks for dimensions	10 min
2	Velocity compounding- This turbine is also termed as Curtis Turbine. Velocity drop is arranged in many small drops through many moving blades instead of single row of moving blades .High pressure steam is expandaning nozzle which is then transferred to first set of moving blades where steam losses part of its kinetic energy. Fixed blade are guide blades that guide the steam to succeeding row of fixed blade which further reduces its velocity. In this pressure drop from chest pressure to the condenser pressure is split up into smaller pressure drop across several stages of impulse turbine. It consists of alternate rings of nozzles and turbine blades.The nozzles are fitted to the casing and the blades are keyed to the turbine shaft. In this type of compounding the steam is expanded in a number of stages, instead of just	2.5 marks for velocity compounding and 2.5 marks for pressure compounding	15 min

SCHOOL OF ENGINEERING

GAIN MORE KNOWLEDGE
REACH GREATER HEIGHTS

END TERM FINAL EXAMINATION

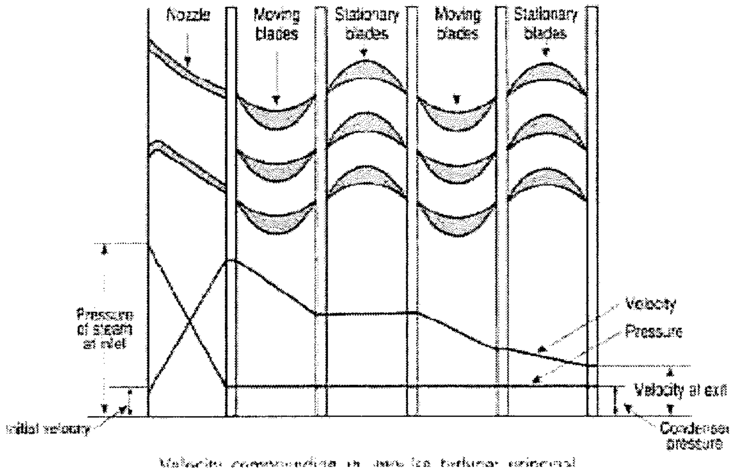
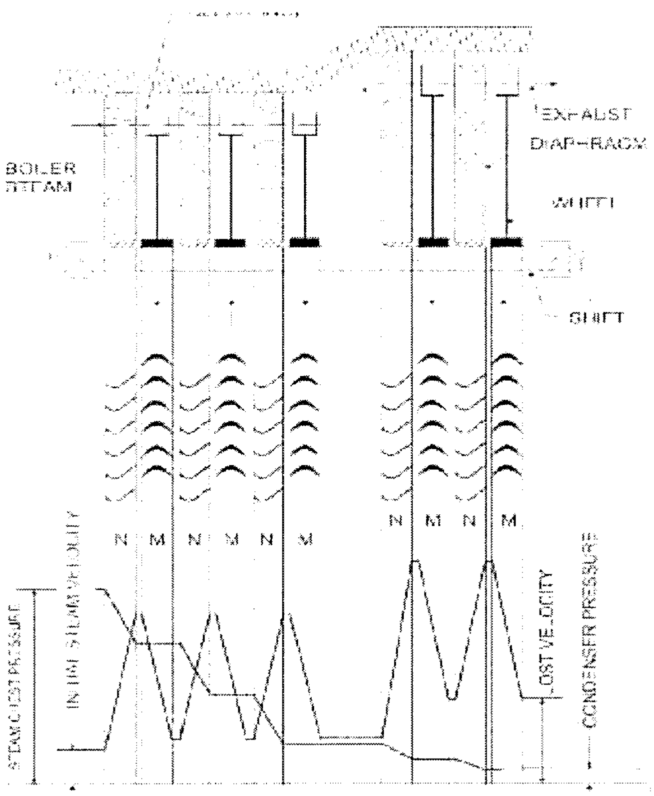
Extract of question distribution [outcome wise & level wise]

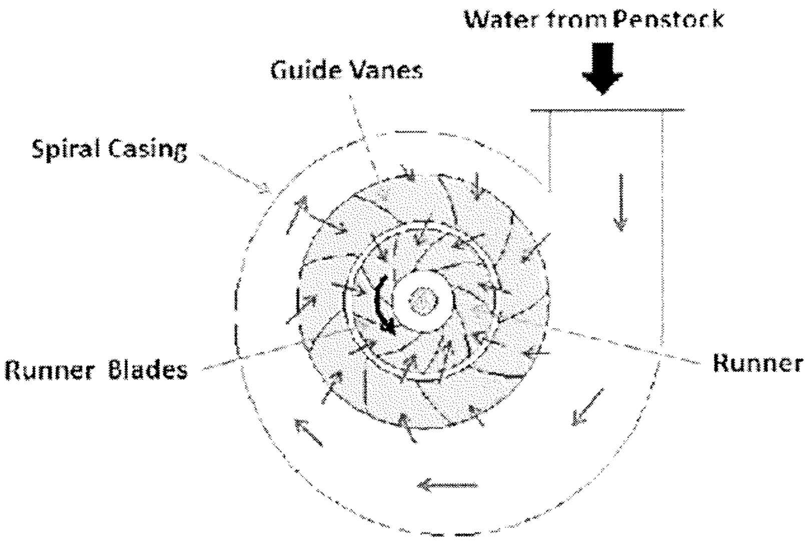
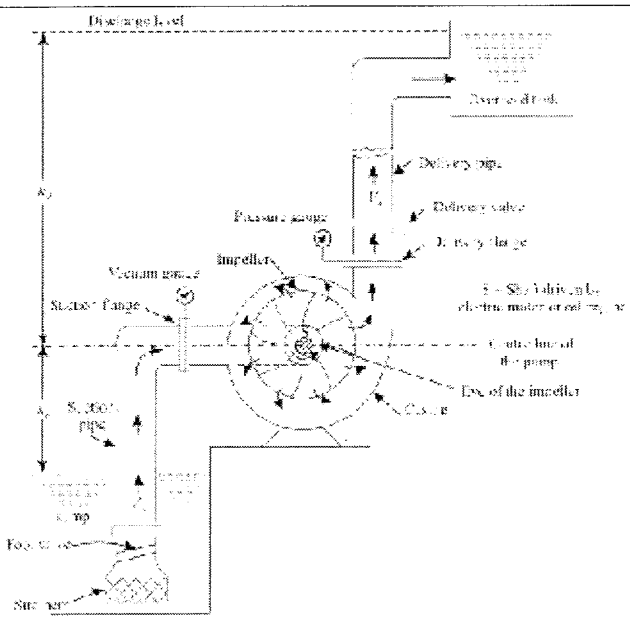
Q.NO.	C.O.NO (% age of CO)	Unit/Module Number/Unit /Module Title	Memory recall type [Marks allotted] Bloom's Levels	Thought provoking type [Marks allotted] Bloom's Levels	Problem Solving type [Marks allotted]	Total Marks
			K	C	A	
1	CO1	MODULE 1	5			5
2	CO1	MODULE 3		5		5
3	CO1	MODULE 4	5			5
4	CO1	MODULE 4			5	5
5	CO2	MODULE 4		10		10
6	CO2	MODULE 2		10		10
7	CO3	MODULE 4		10		10
8	CO4	MODULE 3			10	10
9	CO4	MODULE 3			10	10
10	CO4	MODULE 4			10	10
	Total Marks		20	30	30	80

K =Knowledge Level C = Comprehension Level, A = Application Level

Note: While setting all types of questions the general guideline is that about 60%

Of the questions must be such that even a below average students must be able to attempt, About 20% of the questions must be such that only above average students must be able to attempt and finally 20% of the questions must be such that only the bright students must be able to attempt.

	one (nozzle) velocity compounding.   		
3	Main components of Francis turbine **Spiral casing**- Spiral casing is the inlet medium of water to the turbine. The water flowing from the reservoir or dam is made to pass through this pipe with high pressure. The blades of the turbines are circularly placed, which mean the water striking the turbines blades should flow in the circular axis for efficient striking. So the spiral casing is used, but due to circular movement of the water, it looses its pressure. **Stay Vanes**- Stay vanes and guide vanes guides the water to the runner blades. Stay vanes remain stationary at their position and reduces the swirling of water due to radial flow, as it enters the runner blades. Thus making turbine more efficient.	1 marks for figure and 4 marks for description	15 min

	Guide vanes- Guide vanes are not stationary, they change their angle as per the requirement to control the angle of striking of water to turbine blades to increase the efficiency. They also regulate the flow rate of water into the runner blades thus controlling the power output of a turbine according to the load on the turbine. **Runner** - The performance and efficiency of the turbine is dependent on the design of the runner blades. In a Francis turbine, runner blades are divided into 2 parts. The lower half is made in the shape of small bucket so that it uses the impulse action of water to rotate the turbine **Draft tube**- The pressure at the exit of the runner of Reaction Turbine is generally less than atmospheric pressure. The water at exit cannot be directly discharged to the tail race. A tube or pipe of gradually increasing area is used for discharging water from the exit of turbine to the tail race.  		
4	 **Impeller**- It is a wheel or rotor which is provided with a series of backward curved blades or vanes. It is mounded on the shaft which	1 marks for figure and 4 marks for description	15 min

	is coupled to an external source of energy which imparts the liquid energy to the impeller there by making it to rotate. **Casing-** It is a pipe which is connected at the upper end to the inlet of the pump to the centre of impeller which is commonly known as eye. The double end reaction pump consists of two suction pipe connected to the eye from both sides. The lower end dips into liquid in to lift. The lower end is fitted in to foot valve and strainer. **Delivery pipe-** It is a pipe which is connected at its lower end to the out let of the pump and it delivers the liquid to the required height. Near the outlet of the pump on the delivery pipe, a valve is provided which controls the flow from the pump into delivery pipe. **Suction Pipe with Foot Valve and Strainer** suction pipe is connected with the inlet of the impeller and the other end is dipped into the sump of water. At the water end, it consists of foot value and strainer. The foot valve is a one way valve that opens in the upward direction. The strainer is used to filter the unwanted particle present in the water to prevent the centrifugal pump from blockage.		

Part B (0Q x 0M = 0 Marks)

Q No	Solution	Scheme of Marking	Max. Time require for eac Questic
5	To get the ***minimum starting speed of a centrifugal pump***, it is notice that if the pressure rise in the Impeller is more than or equal to manometric head (Hm) then the centrifugal pump will start to deliver water. Otherwise the pump will not discharge any water, the impeller is rotating. If the impeller is rotating, the water in contact with the Impeller is also rotating. This is called forced vortex. In this case, the centrifugal head or head due to pressure rise in the impeller. $\frac{U_2^2}{2g} - \frac{U_1^2}{2g} > H_m$	3 marks for description and 7 marks for speed	20 mir

Head $H = 16$ m

External diameter of impeller $D_2 = 400$ mm $= 0.4$ m

Internal diameter of impeller $D_1 = 200$ mm $= 0.2$ m

Let the minimum starting speed be N rpm.

Tangential velocity of impeller at inlet is given by

$$U_1 = \frac{\pi D_1 N}{60} = \frac{\pi \times 0.2 \times N}{60} = 0.0105\, N \text{ m/s}$$

Tangential velocity of impeller at outlet is given by

$$U_2 = \frac{\pi D_2 N}{60} = \frac{\pi \times 0.4 \times N}{60} = 0.0209\, N \text{ m/s}$$

Using Eq. (20.24), we have

$$\frac{U_2^2}{2g} - \frac{U_1^2}{2g} = H$$

or $$U_2^2 - U_1^2 = 2gH$$

or $$(0.0209N)^2 - (0.0105N)^2 = 2 \times 9.81 \times 16$$

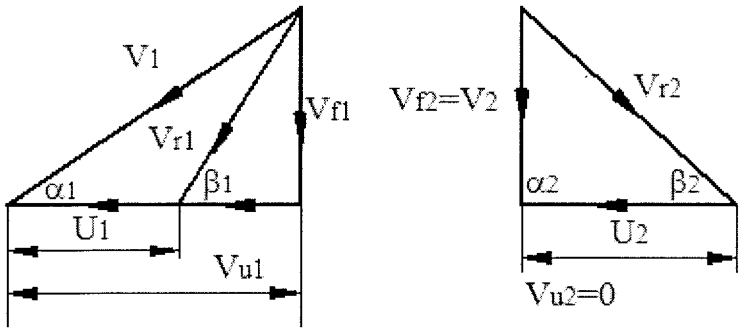
or $$N^2 = \frac{2 \times 9.81 \times 16}{(0.0209)^2 - (0.0105)^2} = 961293.48$$

or $$N = \sqrt{961293.48} = 980.45 \text{ rpm}$$

6

3 marks for triangle and 7 marks for expression

20 mir



For maximum utilization $V_{u2}=0$,

$$\frac{1}{2}[(V_1^2 - V_2^2) + (U_1^2 - U_2^2) - (V_{r1}^2 - V_{r2}^2)] = U_1 V_{u1}$$

$$(U_1^2 - U_2^2) - (V_{r1}^2 - V_{r2}^2) = \frac{R}{(1-R)}(V_1^2 - V_2^2)$$

Then,

$$\frac{1}{2}\left[(V_1^2 - V_2^2) + \frac{R}{(1-R)}(V_1^2 - V_2^2)\right] = U_1 V_{u1}$$

For maximum utilization $V_2 = V_{f2}$ and from inlet velocity diagram $V_{u1} = V_1 \cos\alpha_1$,

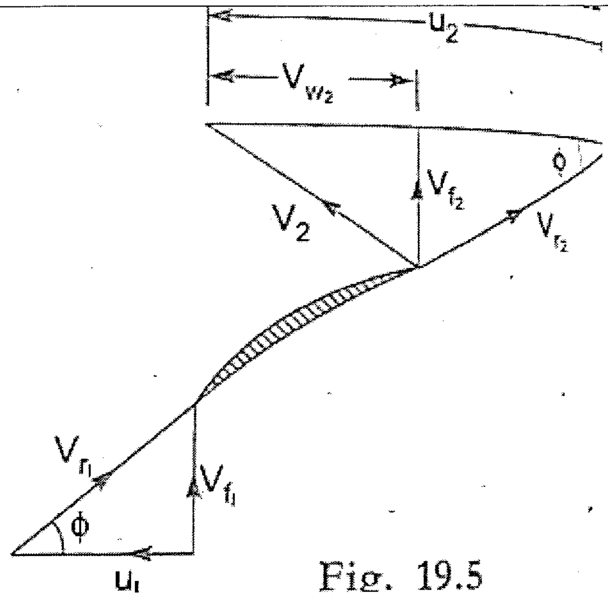
$$\frac{1}{2}\left[(V_1^2 - V_{f2}^2) + \frac{R}{(1-R)}(V_1^2 - V_{f2}^2)\right] = U_1 V_1 cos\alpha_1$$

$$\frac{(V_1^2 - V_{f2}^2)}{2(1-R)} = U_1 V_1 cos\alpha_1$$

	$$\frac{\left(1-\frac{V_{f2}^2}{V_1^2}\right)}{2(1-R)}=\frac{U_1}{V_1}cos\alpha_1$$ But blade speed ratio $\varphi=\frac{U}{V_1}$ $$\left(1-\frac{V_{f2}^2}{V_1^2}\right)=2(1-R)\varphi\ cos\alpha_1$$ Or, $$\frac{V_{f2}^2}{V_1^2}=1-2(1-R)\varphi\ cos\alpha_1$$ Utilization factor is given by: $$\epsilon=\frac{V_1^2-V_2^2}{V_1^2-RV_2^2}$$ For maximum utilization $V_2=V_{f2}$, $$\epsilon_{max}=\frac{V_1^2-V_{f2}^2}{V_1^2-RV_{f2}^2}$$ $$\epsilon_{max}=\frac{1-\frac{V_{f2}^2}{V_1^2}}{1-R\frac{V_{f2}^2}{V_1^2}}$$ From equation (2.11a) $$\epsilon_{max}=\frac{1-[1-2(1-R)\varphi\ cos\alpha_1]}{1-R[1-2(1-R)\varphi\ cos\alpha_1]}$$ $$\epsilon_{max}=\frac{2(1-R)\varphi\ cos\alpha_1}{(1-R)+2\varphi R(1-R)cos\alpha_1}$$ $$\boldsymbol{\epsilon_{max}=\frac{2\varphi\ cos\alpha_1}{1+2\varphi Rcos\alpha_1}}$$		

Part C (4Q x 10M = 40Marks)

Q No	Solution	Scheme of Marking	Max. Time required for each Question

7	 Fig. 19.5 Discharge, $Q = 0.118\ m^3/s$ Speed, $N = 1450$ r.p.m. Head, $H_m = 25$ m Diameter at outlet, $D_2 = 250$ mm $= 0.25$ m Width at outlet, $B_2 = 50$ mm $= 0.05$ m Manometric efficiency, $\eta_{man} = 75\% = 0.75$. Let vane angle at outlet $= \phi$ Tangential velocity of impeller at outlet, $u_2 = \frac{\pi D_2 N}{60} = \frac{\pi \times 0.25 \times 1450}{60} = 18.98$ m/s Discharge is given by $Q = \pi D_2 B_2 \times V_{f_2}$ $\therefore$ $V_{f_2} = \frac{Q}{\pi D_2 B_2} = \frac{0.118}{\pi \times 0.25 \times .05} = 3.0$ m/s. Using equation (19.8), $\eta_{man} = \frac{gH_m}{V_{w_2} u_2} = \frac{9.81 \times 25}{V_{w_2} \times 18.98}$ $\therefore$ $V_{w_2} = \frac{9.81 \times 25}{\eta_{man} \times 18.98} = \frac{9.81 \times 25}{0.75 \times 18.98} = 17.23$. From outlet velocity triangle, we have $\tan\phi = \frac{V_{f_2}}{(u_2 - V_{w_2})} = \frac{3.0}{(18.98 - 17.23)} = 1.7143$ $\phi = \tan^{-1} 1.7143 = 59.74°$ or $59° 44'$. **Ans.**	3 marks for triangle and 7 marks for angle	20 min

8	See below	3 marks for triangle and 3.5-3.5 marks for power and efficiency	20 min

∴ Net head, $H = H_g - h_f = 500 - 166.7 = 333.30$ m

Discharge, $Q = 2.0\ m^3/s$

Angle of deflection $= 165°$

∴ Angle, $\phi = 180 - 165 = 15°$

Speed ratio $= 0.45$

Co-efficient of velocity, $C_v = 1.0$

Velocity of jet, $V_1 = C_v\sqrt{2gH} = 1.0 \times \sqrt{2 \times 9.81 \times 333.3} = 80.86$ m/s

Velocity of wheel, $u = \text{Speed ratio} \times \sqrt{2gH}$

or $u = u_1 = u_2 = 0.45 \times \sqrt{2 \times 9.81 \times 333.3} = 36.387$ m/s

∴ $V_{r_1} = V_1 - u_1 = 80.86 - 36.387$

$= 44.473$ m/s

Also $V_{w_1} = V_1 = 80.86$ m/s

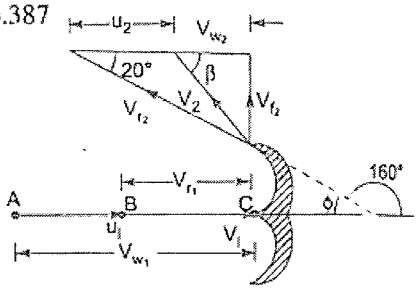


Fig. 18.7

From outlet velocity triangle, we have

$$V_{r_2} = V_{r_1} = 44.473$$

$$V_{r_2} \cos\phi = u_2 + V_{w_2}$$

or $44.473 \cos 15 = 36.387 + V_{w_2}$

or $V_{w_2} = 44.473 \cos 15 - 36.387 = 6.57$ m/s.

Work done by the jet on the runner per second is given by equation (18.9) as

$$\rho a V_1 [V_{w_1} + V_{w_2}] \times u = \rho Q [V_{w_1} + V_{w_2}] \times u \quad (\because\ aV_1 =$$

$$= 1000 \times 2.0 \times [80.86 + 6.57] \times 36.387 = 6362630 \text{ Nm/s}$$

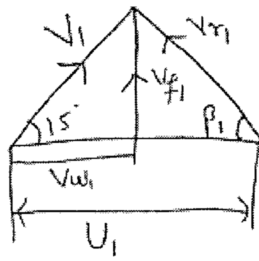
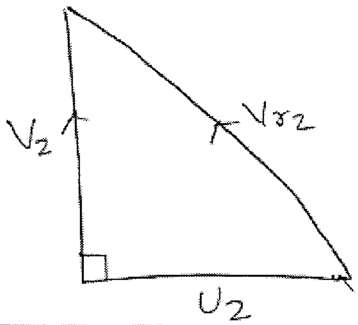
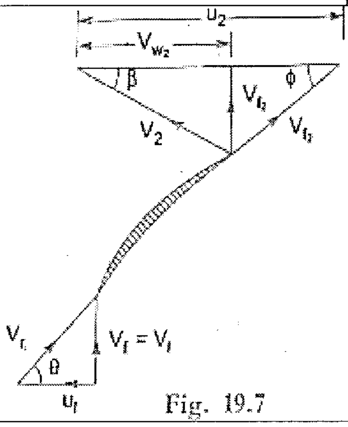
∴ Power given by the water to the runner in kW

$$= \frac{\text{Work done per second}}{1000} = \frac{6362630}{1000} = \mathbf{6362.63\ kW.\ Ans.}$$

Hydraulic efficiency of the turbine is given by equation (18.12) as

$$\eta_h = \frac{2[V_{w_1} + V_{w_2}] \times u}{V_1^2} = \frac{2[80.86 + 6.57] \times 36.387}{80.86 \times 80.86}$$

$$= 0.9731 \text{ or } \mathbf{97.31\%.\ Ans.}$$

9	$D_1 = 0.75m ; D_2 = 0.5m ; N = 400 \, r.p.m ; V_1 = 15 m/s$ $\alpha_1 = 15°, \; V_2 = 5 m/s$ $U_1 = \frac{\pi D_1 N}{60} = \frac{\pi \times 0.75 \times 400}{60} = 15.708 m/s$  $U_2 = \frac{\pi \times 0.5 \times 60}{60} = 10.472 m/s$ $V_{w1} = V_1 \cos 15° = 14.48 m/s$ $\cos 15° = \frac{V_{w1}}{V_1} \Rightarrow V_{w1} = 14.489 m/s$  Power, $P = \dot{m} \, V_{w1} U_1$ $P = 1 \times 15.708 \times 14.489$ $P = 227.593 W$ $\sin\alpha_1 = \frac{V_{f1}}{V_1} ; V_{f1} = 15 \sin 15° ; V_{f1} = 3.882 m/s$ $\tan\beta_1 = \frac{V_{f1}}{U_1 - V_{w1}} = \frac{3.882}{15.708 - 14.489}$ $\beta_1 = 72.57°$ $E = V_{w1} U_1 = 227.893 \, J/kg$ $\epsilon = \frac{227.893}{227.893 + 5^2/2} = 0.948$ $\epsilon = 0.948$ $\epsilon = \frac{V_1^2 - V_2^2}{V_1^2 - R V_2^2} \Rightarrow 0.948 = \frac{15^2 - 5^2}{15^2 - R \times 5^2}$ $R = 0.561$	2 marks for triangle 2 marks for power 3 marks for degree of reaction and 3 marks for utilization factor	20 min
10	*(iv) discharge.* **Solution.** Given : Outer diameter, $D_2 = 400$ mm $= 0.4$ m Width at outlet, $B_2 = 50$ mm $= 0.05$ m Speed, $N = 800$ r.p.m. Head, $H_m = 15$ m Vane angle at outlet, $\phi = 40°$ Manometric efficiency, $\eta_{man} = 75\% = 0.75$ Tangential velocity of impeller at outlet, $u_2 = \frac{\pi D_2 N}{60} = \frac{\pi \times 0.4 \times 800}{60} = 16.75$ m/s.  Fig. 19.7	2 marks for triangle 2 marks for a and 3-3 marks for b and c.	20 min

Using equation (19.8), $\eta_{man} = \dfrac{gH_m}{V_{w_2}\ u_2}$

$$0.75 = \frac{9.81 \times 15}{V_{w_2} \times 16.75}$$

$$\therefore \quad V_{w_2} = \frac{9.81 \times 15}{0.75 \times 16.75} = 11.71 \text{ m/s.}$$

From the outlet velocity triangle, we have

$$\tan \phi = \frac{V_{f_2}}{u_2 - V_{w_2}} = \frac{V_{f_2}}{(16.75 - 11.71)} = \frac{V_{f_2}}{5.04}$$

(*i*) $\therefore \quad V_{f_2} = 5.04 \tan \phi = 5.04 \times \tan 40° = \mathbf{4.23\ m/s.}$ **Ans.**

(*ii*) **Velocity of water leaving the vane** (V_2).

$$V_2 = \sqrt{V_{f_2}^2 + V_{w_2}^2} = \sqrt{4.23^2 + 11.71^2}$$

$$= \sqrt{17.89 + 137.12} = \mathbf{12.45\ m/s.} \quad \textbf{Ans.}$$

(*iii*) **Angle made by absolute velocity at outlet** (β),

$$\tan \beta = \frac{V_{f_2}}{V_{w_2}} = \frac{4.23}{11.71} = 0.36$$

$$\therefore \quad \beta = \tan^{-1} 0.36 = 19.80° \text{ or } \mathbf{19° \ 48'}. \quad \textbf{Ans.}$$

(*iv*) **Discharge through pump is given by,**

$$Q = \pi D_2 B_2 \times V_{f_2} = \pi \times 0.4 \times 0.05 \times 4.23 = \mathbf{0.265\ m^3/s.}$$