USN | | | | | | | | | | |

CMR INSTITUTE OF TECHNOLOGY, BENGALURU.

Internal Assessment Test 2 – Dec 2021

Sub:	TURBO MACHINES					Sub Code:	18ME54	Branch:	MECHANICAL
Date:	16/12/2021	Duration:	90 min's	Max Marks:	50	Sem/Sec:	5th Sem A &B		OBE

Answer all questions

		MARKS	CO	RBT
1.	Derive the condition for maximum hydraulic efficiency of pelton wheel and write the expression for maximum hydraulic efficiency.	[10]	CO4	L
2.	A three jet PELTON WHEEL is required to generate 10000 kW under a head of 400m. The blade angle at outlet is 15° and the reduction in the relative velocity while passing over the blade is 5%. If the overall efficiency is 80%, CV = 0.98, ϕ = 0.46, then find: (i) Diameter of jet (ii) Total flow (iii) Force excerted by jets on blades	[10]	CO4	L3
3.	A double jet PELTON WHEEL is required to generate 7500 kW when the available head at the base of the nozzle is 400m. The jet is deflected through 165° and the relative velocity of the jet is reduced by 15% in passing over the buckets. Determine (i) Diameter of jet (ii) Total flow (iii) Force excerted by jets on blades. Assume Generator efficiency of 95%, Overall efficiency as 80%, blade speed ratio as 0.47, nozzle velocity c-efficient as 0.98.	[10]	CO4	L3
4.	The following data refers to a hydraulic power plant. Tail race level to reservoir level = 175m. Head loss in penstock = 17.5m. Flow rate = 2.5 $\frac{m^3}{s}$, Head utilized by the turbine =135m, Leakage losses = 100 $\frac{litre}{s}$, Power loss due to mechanical friction= 75 kW. Find (i) Hydraulic Efficiency, (ii) Volumetric efficiency (iii) Overall Efficiency (iv) Mechanical efficiency (v) Brake power	[10]	CO4	L3
5.	Steam flows through a nozzle with a velocity of 450 m/s at a direction which is inclined at 16° to the wheel tangent. Steam comes out of the nozzle with a velocity of 100 m/s in the direction of 110° with the direction of blade motion. The blades are equiangular and the steam flow rate is 10 kg/s. Find (i) Power developed (ii) Axial thrust (iii) Blade efficiency	[10]	CO5	L3

[CI] [CCI] [HOD]

USN | | | | | | | | | | |

CMRIT — CMR INSTITUTE OF TECHNOLOGY, BENGALURU. ACCREDITED WITH A+ GRADE BY NAAC

Internal Assessment Test 2 – Dec 2021

Sub:	TURBO MACHINES					Sub Code:	18ME54	Branch:	MECHANICAL
Date:	16/12/2021	Duration:	90 min's	Max Marks:	50	Sem/Sec:	5th Sem A &B		OBE

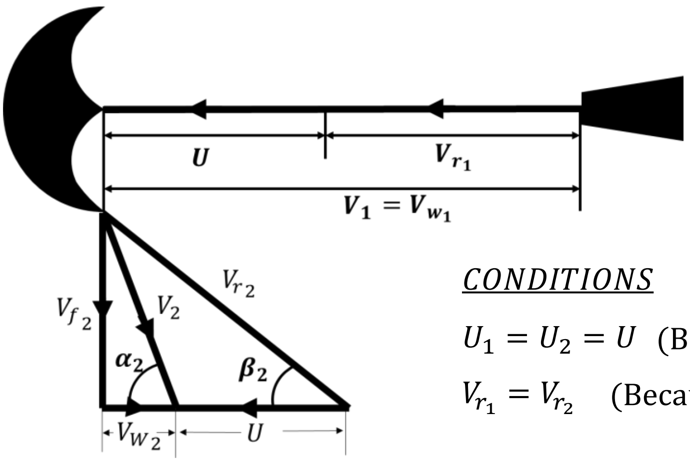
		MARKS	CO	RBT
	Answer all questions			
1.	Derive the condition for maximum hydraulic efficiency and write the expression for maximum hydraulic efficiency. **Diagram- 3 Marks** **Derivation- 7 Marks**	[10]	CO4	L
2.	A three jet PELTON WHEEL is required to generate 10000 kW under a head of 400m. The blade angle at outlet is 15° and the reduction in the relative velocity while passing over the blade is 5%. If the overall efficiency is 80%, CV = 0.98, ϕ = 0.46, then find: (i) Diameter of jet (ii) Total flow (iii) Force excerted by jets on blades **Velocity Triangle- 2 Marks** **Diameter- 2 Marks** **Flow- 2 Marks** **Force- 2 Marks**	[10]	CO4	L3
3.	A double jet PELTON WHEEL is required to generate 7500 kW when the available head at the base of the nozzle is 400m. The jet is deflected through 165° and the relative velocity of the jet is reduced by 15% in passing over the buckets. Determine (i) Diameter of jet (ii) Total flow (iii) Force excerted by jets on blades. Assume Generator efficiency of 95%, Overall efficiency as 80%, blade speed ratio as 0.47, nozzle velocity c-efficient as 0.98. **Velocity Triangle- 2 Marks** **Diameter- 2 Marks** **Flow- 2 Marks** **Force- 2 Marks**	[10]	CO4	L3
4.	The following data refers to a hydraulic power plant. Tail race level to reservoir level = 175m. Head loss in penstock = 17.5m. Flow rate = 2.5 $\frac{m^3}{s}$, Head utilized by the turbine =135m, Leakage losses = 100 $\frac{litre}{s}$, Power loss due to mechanical friction= 75 kW. Find (i) Hydraulic Efficiency, (ii) Volumetric efficiency (iii) Overall Efficiency (iv) Mechanical efficiency (v) Brake power **Hydraulic Efficiency- 2 Marks** **Volumetric efficiency- 2 Marks** **Overall Efficiency- 2 Marks** **Mechanical efficiency- 2 Marks** **Brake power- 2 Marks**	[10]	CO4	L3
5.	Steam flows through a nozzle with a velocity of 450 m/s at a direction which is inclined at 16° to the wheel tangent. Steam comes out of the nozzle with a velocity of 100 m/s in the direction of 110° with the direction of blade motion. The blades are equiangular and the steam flow rate is 10 kg/s. Find (i) Power developed (ii) Axial thrust (iii) Blade efficiency **Velocity Triangle Construction- 7 Marks** **Power- 1 Mark** **Thrust- 1 Mark** **Blade efficiency- 1 Marks**	[10]	CO5	L3

[CI]	[CCI]	[HOD]

TURBOMACHINES (18ME54)
IAT-1
SOLUTIONS

1 Derive the condition for maximum hydraulic efficiency and write the expression for maximum hydraulic efficiency.

WORK DONE AND HYDRAULIC EFFICIENCY BY A PELTON WHEEL



CONDITIONS

$U_1 = U_2 = U$ (Because tangential flow)

$V_{r_1} = V_{r_2}$ (Because impulse turbine)

$W.K.T$

$$\eta_H = \frac{\dot{m}(V_{W_1}U_1 \pm V_{W_2}U_2)}{\rho g Q H}$$

$Also, \dot{m} = \rho \times Q$

$$\eta_H = \frac{V_{W_1}U_1 \pm V_{W_2}U_2}{gH}$$

$gH = Potential\ Energy$

$But\ in\ turbine, all\ potential\ energy\ is\ converted\ to\ kinetic\ energy$

$$\therefore gH = \frac{1}{2}V_1^2$$

$$\therefore \eta_H = \frac{U(V_{W_1} \pm V_{W_2})}{\frac{1}{2}V_1^2}$$

$From\ OUTLET\ VELOCITY\ TRIANGLE$

$$V_{W_2} = V_{r_2}cos\beta_2 - U$$

$$V_{W_2} = V_{r_1}cos\beta_2 - U \text{ ——— } (1)$$

$From\ INLET\ VELOCITY\ TRIANGLE$

$$V_{r_1} = V_1 - U \text{ ——— } (2)$$

$(2)\ in\ (1)\ implies$

$$V_{W_2} = (V_1 - U)cos\beta_2 - U$$

$$V_{W_1} = V_1$$

$$U(V_{W_1} \pm V_{W_2}) = W$$

$Since\ V_{W2}\ and\ V_{W_1}\ are\ in\ opposite\ directions$

$$W = U(V_{W_1} + V_{W_2})$$

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

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

$$W = U(V_1 - U)(1 + cos\beta_2) \text{ ——— } (3)$$

$It\ was\ assumed\ that\ V_{r_1} = V_{r_2}$

$Due\ to\ losses\ in\ blade, V_{r_1} \neq V_{r_2}$

$Also\ V_{r_2} < V_{r_1}$

$\therefore a\ new\ term\ C_b\ is\ defined$

C_b *which is also called Co − efficient of blade is defined as ratio of* V_{r_2} *to* V_{r_1}

$$C_b = \frac{V_{r_2}}{V_{r_1}}$$

If C_b *is considered in the derivation, then the equation (3) will be,*

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

$$W.K.T\ \eta_H = \frac{W}{\frac{1}{2}V_1^2}$$

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

$$\boldsymbol{\eta_H = \frac{2U(V_1 - U)(1 + C_b \cos\beta_2)}{V_1^2}} \quad \text{———— (4)}$$

Condition for MAXIMUM HYDRAULIC EFFICIENCY

The condition for maximum efficiency can be obtained by using MAXIMA condition

$$\frac{d\eta_H}{dU} = 0$$

$$\frac{d\eta_H}{dU} = \frac{d}{dU}\left(\frac{2(UV_1 - U^2)(1 + C_b \cos\beta_2)}{V_1^2}\right)$$

$$\frac{d\eta_H}{dU} = \frac{2(1 + C_b \cos\beta_2)}{V_1^2}\frac{d}{dU}(UV_1 - U^2)$$

$$\frac{d\eta_H}{dU} = \frac{2(1 + C_b \cos\beta_2)}{V_1^2} \times (V_1 - 2U)$$

$$\frac{2(1 + C_b \cos\beta_2)}{V_1^2} \times (V_1 - 2U) = 0$$

$$\frac{2(1 + C_b \cos\beta_2)}{V_1^2} \neq 0$$

$$\therefore (V_1 - 2U) = 0$$

$$\Longrightarrow V_1 = 2U$$

$$\therefore U = \frac{1}{2}V_1 \longleftarrow$$

This is the condition for maximum hydraulic effciency

Hydraulic efficiency is given by

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

Substituting $V_1 = 2U$ *in above equation*

$$\eta_H = \frac{2U(2U - U)(1 + C_b \cos\beta_2)}{(2U)^2}$$

$$\eta_H = \frac{2U(U)(1 + C_b \cos\beta_2)}{(2U)^2}$$

$$\eta_H = \frac{2U^2(1 + C_b \cos\beta_2)}{4U^2}$$

$$\boldsymbol{\eta_{H_{MAX}} = \frac{1 + C_b \cos\beta_2}{2}}$$

This is the equation for maximum hydraulic efficiency

If $C_b = 1$, *then*

$$\boldsymbol{\eta_{H_{max}} = \frac{1 + \cos\beta_2}{2}}$$

It can be seen from the above equation that for η_H *to be 1,* β_2 *should be* $0°$

2 A three jet PELTON WHEEL is required to generate 10000 kW under a head of 400m. The blade angle at outlet is 15° and the reduction in the relative velocity while passing over the blade is 5%. If the overall efficiency is 80%, CV = 0.98,ϕ = 0.46, then find: (i) Diameter of jet (ii) Total flow (iii) Force excerted by jets on blades

SOLUTION

DATA

n=3
SP=10000 kW
H=400 m
β2=15°
Cb=0.95
ηo=0.8
Cv=0.98
ϕ=0.46

TO FIND

d=?
Q=?
F=?

a) **Total flow (Q)**

$$\eta_o = \frac{SP}{\rho g Q H} \Rightarrow 0.8 = \frac{10000 \times 10^3}{1000 \times 9.81 \times Q \times 400} \Rightarrow \boldsymbol{Q = 3.18 \frac{m^3}{s}}$$

b) **Diameter of Jet:**

$$Q = n\frac{\pi}{4}d^2 V_1$$

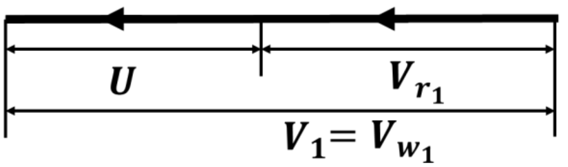
$$V_1 = C_v\sqrt{2gH} \Rightarrow 0.98 \times \sqrt{2 \times 9.81 \times 400} \Rightarrow V_1 = 86.81\frac{m}{s}$$

$$3.18 = 3 \times \frac{\pi}{4} \times d^2 \times 86.81 \Rightarrow \boldsymbol{d = 0.125m}$$

c) **Force exerted by each jet**

$$F_{each\ jet} = \frac{\dot{m}(V_{W_1} \pm V_{W_2})}{No\ of\ jets} = \frac{\rho Q(V_{W_1} \pm V_{W_2})}{n}$$

INLET VELOCITY TRIANGLE

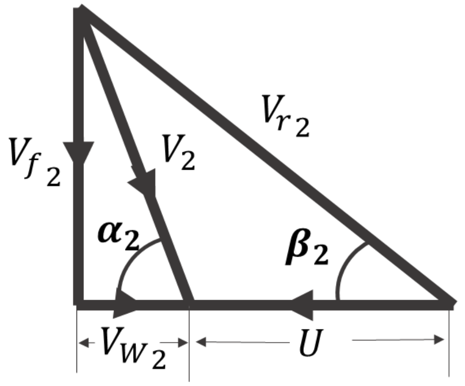


VW1=V1=86.81ms

$$U = \phi\sqrt{2gH} \Rightarrow U = 0.46\sqrt{2 \times 9.81 \times 400} \Rightarrow U = 40.75\frac{m}{s}$$

$$V_{r_1} = V_1 - U = 86.81 - 40.75 = 46.06\frac{m}{s}$$

ASSUMING THE OUTLET VELOCITY TRIANGLE AS



Since C_b is given, $V_{r_2} = C_b V_{r_1} \Longrightarrow V_{r_2} = 0.95 \times 46.06 = 43.757 \frac{m}{s}$

From outlet velocity triangle,

$$\cos \beta_2 = \frac{U + V_{W_2}}{V_{r_2}}$$

$$U + V_{W_2} = V_{r_2} \cos \beta_2$$

$$V_{W_2} = V_{r_2} \cos \beta_2 - U \Longrightarrow (43.757 \times cos 15) - 40.75$$

$$\boldsymbol{V_{W_2} = 1.51 \frac{m}{s}}$$

Since V_{W_2} is positive the assumed velocity triangle is correct.

$$\therefore F_{each\ jet} = \frac{\dot{m}(V_{W_1} \pm V_{W_2})}{No\ of\ jets} = \frac{\rho Q(V_{W_1} \pm V_{W_2})}{n}$$

$$F_{each\ jet} = \frac{1000 \times 3.18 \times (86.81 + 1.51)}{3}$$

$$\boldsymbol{F_{each\ jet} = 93619.2\ N}$$

3 A double jet PELTON WHEEL is required to generate 7500 kW when the available head at the base of the nozzle is 400m. The jet is deflected through 165° and the relative velocity of the jet is reduced by 15% in passing over the buckets. Determine (i) Diameter of jet (ii) Total flow (iii) Force excerted by jets on blades.

Assume Generator efficiency of 95%, Overall efficiency as 80%, blade speed ratio as 0.47, nozzle velocity c-efficient as 0.98.

7. $n = 2$

$P_g = 7500\,kW$

$H = 400m$

$\theta = 165°$; $\beta_2 = 180 - 165 = 15°$

$C_b = 1 - 0.15 = 0.85$

$\eta_g = 95\% = 0.95$

$\eta_o = 80\% = 0.8$

$\phi = 0.47$

$C_v = 0.98$

$\eta_g = \frac{P_g}{SP} \Rightarrow$

$\therefore SP = \frac{P_g}{\eta_g} = \frac{7500 \times 10^3}{0.95}$

$SP = 7894736.842\,W$

$SP = 7894.73\,kW$

(ii) Total flow

$Q = ?$

$\eta_o = \frac{SP}{\rho Q g H} \Rightarrow 0.8 = \frac{7894736.842}{1000 \times 9.81 \times Q \times 400}$

$Q = 2.514\,m^3/s$

$Q = \frac{\pi}{4} \cdot n \cdot d^2 \cdot V_1$

$V_1 = C_v \sqrt{2gH}$

$= 0.98\sqrt{2 \times 9.81 \times 400}$

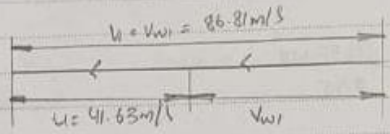
$V_1 = 86.81\,m/s$

$\therefore 2.514 = \frac{3.14}{4} \times 2 \times d^2 \times 86.81$

$d = 0.1358\,m$ is the diameter of jet

(iii) $F_{each\ jet} = m(V_{w_1} \pm V_{w_2}) \Rightarrow \rho Q (V_{w_1} \pm V_{w_2})$

→ Inlet velocity triangle for Pelton wheel will be given as →



$V_1 = V_{w_1} = 86.81 m/s$

$u = \phi \sqrt{2gH}$

$= 0.47 \sqrt{2 \times 9.81 \times 400}$

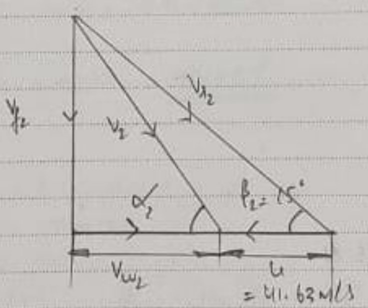
$u = 41.63 m/s$

$V_{r_1} = V_1 - u$

$= 86.81 - 41.63$

$V_{r_1} = 45.18 m/s$

→ Assuming outlet velocity triangle to be



$V_{r_2} = \xi V_{r_1}$

$= 0.85 \times 45.18$

$V_{r_2} = 38.403 m/s$

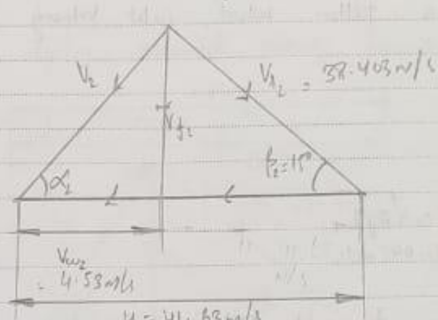
From outlet velocity triangle

$\cos\beta_2 = \frac{V_{w_2} + u}{V_{r_2}} \Rightarrow \cos 15° = \frac{V_{w_2} + 41.63}{38.403}$

$V_{w_2} = -4.53 m/s$

Since V_{w_2} is negative, assumed outlet velocity triangle is wrong.

→ correct outlet velocity triangle is



$\therefore F = \frac{(1000 \times 2.514 \times 0.83)(86.81 - 4.53)}{2}$ [V_{w_2} & V_{w_1} are in same direction]

$F_{each\ jet} = 103174.56 N$

$= 103.17 kN$

4 The following data refers to a hydraulic power plant. Tail race level to reservoir level = 175m. Head loss in penstock = 17.5m. Flow rate = 2.5 m^3/s, Head utilized by the turbine =135m, Leakage losses = 100 litre/s, Power loss due to mechanical friction= 75 kW. Find (i) Hydraulic Efficiency, (ii) Volumetric efficiency (iii) Overall Efficiency (iv) Mechanical efficiency (v) Brake power

$H_g = 175m$

$h_f = 17.5m$

$Q = 2.5 m^3/s$

$H_e = 135m$

$Q_{loss} = 100 L/s = 100 \times 10^{-3} = 0.1 m^3/s$

$P_{loss} = 75 kW = 75000 W$

$H = H_g - h_f = 175 - 17.5$

$H = 157.5 m$

a) Hydraulic Efficiency, $\eta_H = \frac{\text{Head utilized by turbine}}{\text{Net head}} = \frac{H_e}{H}$

$\eta_H = \frac{135}{157.5}$

$\eta_H = 0.8571 = 85.71\%$

b) Volumetric Efficiency, $\eta_v = \frac{\text{Actual vol of water striking turbine}}{\text{Theoretical vol. of water striking turbine}}$

$\eta_v = \frac{Q - Q_{loss}}{Q} = \frac{2.5 - 0.1}{2.5} = 0.96 = 96\%$

c) Mechanical Efficiency, $\eta_{mech} = \frac{\text{Shaft Power}}{\text{Power Developed by Turbine}}$

Actual hydraulic efficiency, $\eta_{Hact} = \eta_v \times \eta_H$

$= 0.96 \times 0.857 = 0.822 = 82.2\%$

$\eta_{Hact} = \frac{\text{Power developed by turbine}}{\rho \times g \times Q_{actual} \times H}$

$\eta_{Hact} = \frac{P_{turb}}{\rho \times g \times Q_{act} \times H} \Rightarrow 0.822 = \frac{P_{turb}}{1000 \times 9.81 \times 2.4 \times 157.5}$

$P_{turb} = 3048123.96 W$

$= 3048.12 kW$

$SP = P_{turb} - P_{loss}$

$= 3048.12 - 75$

$SP = 3040.623 kW$

$\eta_{mech} = 0.9975 = 99.75\%$

d) overall efficiency, $\eta_o = \eta_{Hact} \times \eta_{mech}$

$= 0.822 \times 0.997$

$= 0.8199 = 81.99\%$

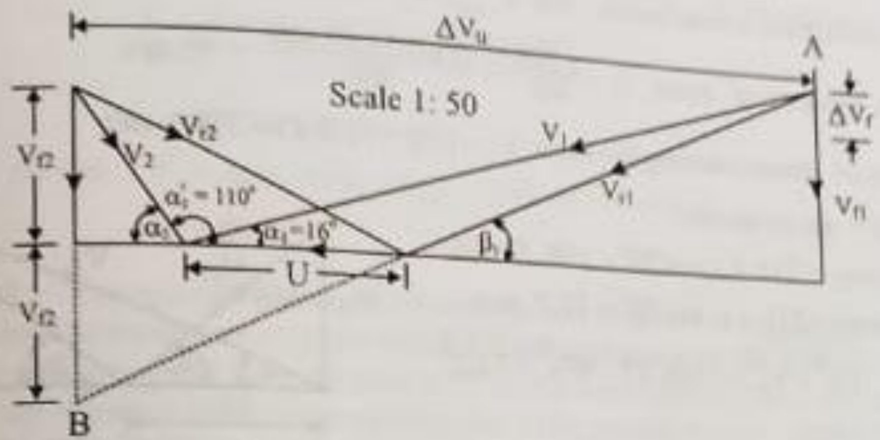
e) Brake Power $= SP = 3040.62 kW$

5 Steam flows through a nozzle with a velocity of 450 m/s at a direction which is inclined at 16° to the wheel tangent. Steam comes out of the nozzle with a velocity of 100 m/s in the direction of 110° with the direction of blade motion. The blades are equiangular and the steam flow rate is 10 kg/s. Find (i) Power developed (ii) Axial thrust (iii) Blade efficiency

Solution :Given: $V_1 = 450$ m/s, $\alpha_1 = 16°$, $V_2 = 100$ m/s, $\alpha_2^1 = 110°$, $\alpha_2 = 70°$ $\beta_1 = \beta_2$,
$\dot{m} = 10$ kg/s. *Find*: P, P_f, F_a, η_b, C_b.

Graph construction : For the selected scale, draw V_1 w.r.t α_1 and V_2 w.r.t α_2 and find the value of V_{f1} & V_{f2}. To get β_1 and β_2, produce V_{f2} in backward direction & draw the line from the apex 'A' of inlet velocity triangle which cuts at V_{f2} produced backward at B.

Now measure β_1 and β_2 and find out the tangential velocity of rotor.



From Graph: $U = 167$ m/s, $V_{r1} = 293$ m/s, $V_{r2} = 222$ m/s

$$\beta_1 = \beta_2 = 25°, \Delta V_f = 30.1 \text{ m/s}, \Delta V_u = 466.8 \text{ m/s.}$$

(i) **Power developed,** $P = \frac{\dot{m}}{g_c} \times U \Delta V_u = \frac{10 \times 167 \times 466.8}{1000} = 780$ kW

(ii) **Power loss to friction :** $P_f = \frac{\dot{m}}{g_c} \times \Delta h_f$

Δh_f = Pressure Energy loss due to friction in the rotor $= 1/2g_c [(V_{r1}^2 - V_{r2}^2)]$

$$\Delta h_f = \frac{(293^2 - 222.0^2)}{2 \times 1000} = 18.28 \text{ kJ/kg}$$

$\therefore$ Power loss, $P_f = \dot{m}\ \Delta h_f = 10 \times 18.28 = 182.8$ kW

(iii) **Axial thrust,** $F_a = \frac{\dot{m}}{g_c} \Delta V_f = \frac{10 \times 30.1}{1} = 301$ N

(iv) **Rotor Efficiency :** $\eta_b = \frac{2U\ \Delta V_u}{V_1^2} = \frac{2 \times 167 \times 466.8}{450^2} = 77\%$

(v) **Blade velocity coefficient :** $C_b = \frac{V_{r2}}{V_{r1}} = \frac{222}{293} = 0.758$