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Internal Assessment Test 1 – Nov 2021

Sub:	TURBO MACHINES					Sub Code:	18ME54	Branch:	MECHANICAL	
Date:	11/11/2021	Duration:	90 min's	Max Marks:	50	Sem/Sec:	5^{th} Sem A &B		OBE	

		MARKS	CO	RBT
	PART-A: Answer all questions			
1.	Define TurboMachines and with the help of a neat diagram explain different parts of a turbomachine	[10]	CO1	L1
2.	Derive an expression for EULER TURBINE EQUATION	[10]	CO2	L3
3.	Draw different types of inlet and outlet velocity triangle and write the expression for degree of reaction, Utilization factor and derive the relationship between degree of reaction and utilization factor	[10]	CO2	L3
	PART-B: Answer any 2 questions			
4.	The velocity of steam outflow from a nozzle in a DELAVAL turbine is 1200 m/s. The nozzle angle being 22°. If the rotor blades are equiangular and the rotor tangential speed is 400 m/s, compute (i) The rotor blade angles (ii) The tangential force on blade ring (iii) Power output (iv) Utilization factor. Assume $V_{r_1} = V_{r_2}$	[10]	CO2	L3

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5.	At a nozzle exit of a steam turbine, the absolute velocity is 300 m/s. The rotor speed is 150 m/s at a point where the nozzle angle is 18°. If the outlet rotor angle is 3.5° less than the inlet blade angle, find the power output from a stage for steam flow rate of 8.5 kg/s. Assume $V_{r_1} = V_{r_2}$, also find utilization factor	[10]	CO2	L3
6.	The axial component of air velocity at the exit of an axial flow reaction stage is 180 m/s and the nozzle inclination is 27°. Find the rotor blade angles at inlet and outlet if degree of reaction is 50% and blade speed is equal to that of axial component.	[10]	CO2	L3

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5.	At a nozzle exit of a steam turbine, the absolute velocity is 300 m/s. The rotor speed is 150 m/s at a point where the nozzle angle is 18°. If the outlet rotor angle is 3.5° less than the inlet blade angle, find the power output from a stage for steam flow rate of 8.5 kg/s. Assume $V_{r_1} = V_{r_2}$, also find utilization factor	[10]	CO5	L3
6.	The axial component of air velocity at the exit of an axial flow reaction stage is 180 m/s and the nozzle inclination is 27°. Find the rotor blade angles at inlet and outlet if degree of reaction is 50% and blade speed is equal to that of axial component.	[10]	CO5	L3

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Internal Assessment Test 1 – Nov 2021- SCHEME

Sub:	TURBO MACHINES					Sub Code:	18ME54	Branch:	MECHANICAL
Date:	11/11/2021	Duration:	90 min's	Max Marks:	50	Sem/Sec:	5^{th} Sem A &B		OBE

		MARKS	CO	RBT
	PART-A: Answer all questions			
1.	Define TurboMachines and with the help of a neat diagram explain different parts of a turbomachine **Definition-3 Marks** **Diagram- 3 Marks** **Explanation- 4 Marks**	[10]	CO1	L1
2.	Derive an expression for EULER TURBINE EQUATION **Diagram-2 Marks** **Derivation- 8 Marks**	[10]	CO2	L3
3.	Draw different types of inlet and outlet velocity triangle and write the expression for degree of reaction, Utilization factor and derive the relationship between degree of reaction and utilization factor **4 diagrams- 4 Marks** **Expression for R- 1 Mark** **Expression for ϵ – 1 Mark** **Derivation- 4 Marks**	[10]	CO2	L3
	PART-B: Answer any 2 questions			
4.	The velocity of steam outflow from a nozzle in a DELAVAL turbine is 1200 m/s. The nozzle angle being 22°. If the rotor blades are equiangular and the rotor tangential speed is 400 m/s, compute (i) The rotor blade angles (ii) The tangential force on blade ring (iii) Power output (iv) Utilization factor. Assume $V_{r_1} = V_{r_2}$ **Velocity Triangle- 2 Marks** **Rotor blade angle- 2 Marks** **Tangential Force- 2 Marks** **Power Output- 2 Marks** **Utilization Factor- 2 Marks**	[10]	CO2	L3
5.	At a nozzle exit of a steam turbine, the absolute velocity is 300 m/s. The rotor speed is 150 m/s at a point where the nozzle angle is 18°. If the outlet rotor angle is 3.5° less than the inlet blade angle, find the power output from a stage for steam flow rate of 8.5 kg/s. Assume $V_{r_1} = V_{r_2}$, also find utilization factor **Diagram- 2 Marks** **Power output- 4 Marks** **Utilization Factor- 4 Marks**	[10]	CO2	L3
6.	The axial component of air velocity at the exit of an axial flow reaction stage is 180 m/s and the nozzle inclination is 27°. Find the rotor blade angles at inlet and outlet if degree of reaction is 50% and blade speed is equal to that of axial component. **Diagram- 2 Marks** **Blade angles- 8 Marks**	[10]	CO2	L3

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TURBOMACHINES (18ME54)

IAT-1

SOLUTIONS

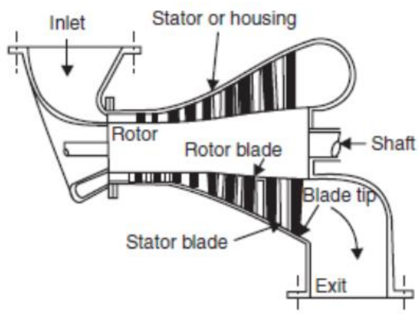
1) Define TurboMachines and with the help of a neat diagram explain different parts of a turbomachine

SOLUTION

Definition of a Turbo machine

A turbo machine is a device in which energy transfer occurs between a flowing fluid and rotating element due to dynamic action. This results in change of pressure and momentum of the fluid.

Parts of a turbo machine



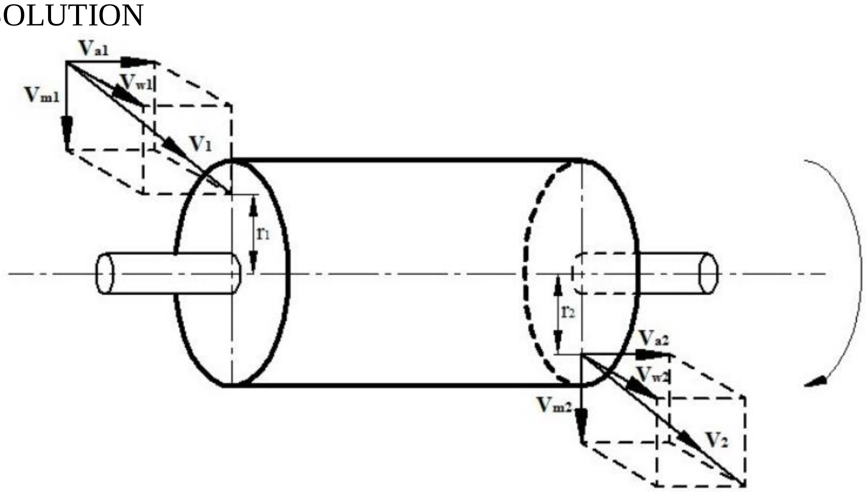
The principle components of a turbo machine are:

1. **Rotating element** (vane, impeller or blades) – operating in a stream of fluid.
2. **Stationary elements** – which usually guide the fluid in proper direction for efficient energy conversion process.
3. **Shaft** – This either gives input power or takes output power from fluid under dynamic conditions and runs at required speed.
4. **Housing** – to keep various rotating, stationery and other passages safely under dynamic conditions of the flowing fluid.

E.g. Steam turbine parts and Pelton turbine parts.

2) Derive an expression for EULER TURBINE EQUATION

SOLUTION



In order to derive equations in design of turbomachine, Newton's Second law in a form applicable to rotating systems can be used.

Let V1 be the absolute velocity of fluid entering the machine at a radius r1. Since V1 is a vector, it can be resolved into 3 components mutually perpendicular to each other.

The 3 components are:

1) Axial Component (Va)

This Component is parallel to the axis of rotation of the machine. The change in magnitude of this component gives rise to axial thrust, which in turn pushes the machine in the longitudinal direction. This is taken care by the thrust bearings.

2) Radial Component (Vm)

This component is perpendicular to the axis of rotation or parallel to the radius of the turbomachine. The change in magnitude of this component gives rise to radial thrust, which exerts force in the lateral direction. This in turn may bend the shaft. This is taken care by the journal bearings

3) Tangential Component (Vw)

This component is along the tangential direction of the rotor (perpendicular to both radius and axis of rotation of the machine). The change in magnitude of this component gives rise to change in angular momentum of the fluid and has an effect on the net torque exerted. Neither the radial component nor the axial component will produce any effect on the net torque on the rotor. Hence, only tangential component is considered in energy transfer of turbomachine.

The Power developed by the turbomachine is given by,

$$P = \frac{2\pi N T}{60} \ (W). \quad \text{———} \ (1)$$

where, $T \Rightarrow$ Torque developed by the machine

$N \Rightarrow$ Speed in RPM.

The torque developed is given by.

$$T = \text{Force} \times \text{Radius} \quad \text{———} \ (2)$$

According to Newton's Second law,

Force (F) = Rate of change of momentum.

$$F = \dot{m}_1 V_{w_1} - \dot{m}_2 V_{w_2}. \quad \text{———} \ (3)$$

Assuming, $\dot{m}_1 = \dot{m}_2 = \dot{m}$.

$$③ \Rightarrow F = \dot{m}[V_{w_1} - V_{w_2}] \text{ ——— } ④$$

Since the Radii changes from r_1 to r_2 from inlet to outlet, we need to consider corresponding radius for corresponding momentum terms. Applying this and substituting eqn ④ in ②, we get.

$$② \Rightarrow T = \dot{m}[V_{w_1} r_1 - V_{w_2} r_2] \text{ ——— } ⑤$$

Substituting Eqn ⑤ in ①, we get,

$$P = \frac{2\pi N}{60} \dot{m}[V_{w_1} r_1 - V_{w_2} r_2] \text{ ——— } ⑥$$

But, $\dfrac{2\pi N r_1}{60} = u_1$ and $\dfrac{2\pi N r_2}{60} = u_2$.

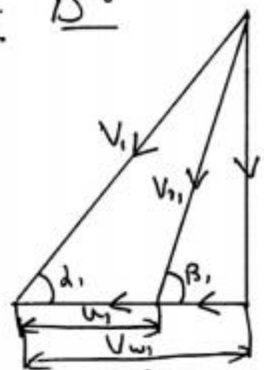
$$\therefore ⑥ \Rightarrow \boxed{P = \dot{m}[V_{w_1} u_1 - V_{w_2} u_2]} \text{ ——— } ⑦$$

But ~~word~~ Work done per unit mass is obtained as follows.

$$\therefore \boxed{E = \frac{P}{\dot{m}} = V_{w_1} u_1 - V_{w_2} u_2} \left[J/kg \right].$$

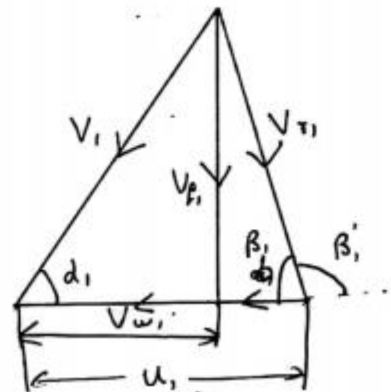
3) Draw different types of inlet and outlet velocity triangle and write the expression for degree of reaction, Utilization factor and derive the relationship between degree of reaction and utilization factor

Inlet D'e



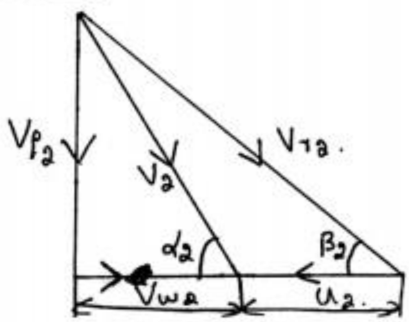
(a)

(or)



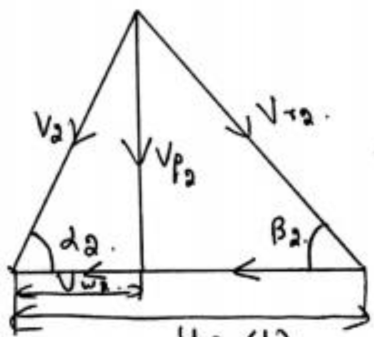
(b)

Outlet D'e



(c)

(or)



(d)

$$R = \frac{\frac{1}{2}\left[(U_1^2 - U_2^2) + (V_{r_2}^2 - V_{r_1}^2)\right]}{\frac{1}{2}\left[(V_1^2 - V_2^2) + (U_1^2 - U_2^2) + (V_{r_2}^2 - V_{r_1}^2)\right]}.$$

$$\varepsilon = \frac{E_{utilized}}{E_{avail}} = \frac{1/2\left[(V_1^2 - V_2^2) + (U_1^2 - U_2^2) + (V_{r_2}^2 - V_{r_1}^2)\right]}{1/2\left[\underline{V_1^2} + (U_1^2 - U_2^2) + (V_{r_2}^2 - V_{r_1}^2)\right]}$$

$E_{utilized}$

Relationship between Utilization factor and Degree of Reaction

$$\text{Degree of Reaction} = R = \frac{(U_1^2 - U_2^2) + (V_{r_2}^2 - V_{r_1}^2)}{(V_1^2 - V_2^2) + (U_1^2 - U_2^2) + (V_{r_2}^2 - V_{r_1}^2)}.$$

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Let, $(U_1^2 - U_2^2) + (V_{r_2}^2 - V_{r_1}^2) = S.$

$(V_1^2 - V_2^2) = D.$

$$\Rightarrow R = \frac{S}{D+S} \Rightarrow (D+S)R = S.$$

$$\Rightarrow DR + SR = S. \Rightarrow DR = S - SR \Rightarrow DR = S(1-R).$$

$$\Rightarrow S = \frac{R}{1-R} D$$

$$\text{Utilization Factor} = \mathcal{E} = \frac{(V_1^2 - V_2^2) + (U_1^2 - U_2^2) + (V_{r_2}^2 - V_{r_1}^2)}{V_1^2 + (U_1^2 - U_2^2) + (V_{r_2}^2 - V_{r_1}^2)} \quad \text{—— (2)}$$

Substitute (1) in (2)

$$\Rightarrow \mathcal{E} = \frac{(V_1^2 - V_2^2) + \frac{R}{1-R}(V_1^2 - V_2^2)}{V_1^2 + \frac{R}{1-R}(V_1^2 - V_2^2)}$$

$$\Rightarrow \mathcal{E} = \frac{(1-R)(V_1^2 - V_2^2) + R(V_1^2 - V_2^2)}{(1-R)V_1^2 + R(V_1^2 - V_2^2)}$$

$$= \frac{V_1^2 - V_2^2 - \cancel{RV_1^2} + \cancel{RV_2^2} + \cancel{RV_1^2} - \cancel{RV_2^2}}{V_1^2 - \cancel{RV_1^2} + \cancel{RV_1^2} - RV_2^2}$$

$$\boxed{\mathcal{E} = \frac{V_1^2 - V_2^2}{V_1^2 - RV_2^2}}$$

4) The velocity of steam outflow from a nozzle in a DELAVAL turbine is 1200 m/s. The nozzle angle being 22°. If the rotor blades are equiangular and the rotor tangential speed is 400 m/s, compute (i) The rotor blade angles (ii) The tangential force on blade ring (iii) Power output (iv) Utilization factor. Assume $V_{r_1} = V_{r_2}$

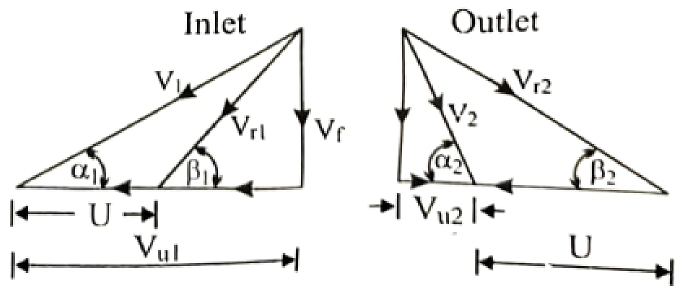
Solution : Delaval turbine is a axial flow type impulse turbine.

Given :- $V_1 = 1200$ m/s

$\alpha_1 = 22^0$

$U = 400$ m/s

To Find : β_1, β_2, F_T, P.



From I/L Vel. Δ^{le} :

$$V_{u1} = V_1 \cos\alpha_1 = 1200 \cos 22^0 = 1112.6 \text{ m/s}$$

$$V_f = V_1 \sin\alpha_1 = 1200 \sin 22^0 = 449.5 \text{ m/s}$$

$$\tan\beta_1 = V_{f1}/(V_{u1} - U) = 449.5/(1112.6-400) \text{ or } \beta_1 = 32.20^0 = \beta_2 \quad \text{(Given that } \beta_1 = \beta_2)$$

$$V_{r1} = V_{f1}/(\sin\beta_1) = 449.5/\sin(32.2^0) = 842.5 \text{ m/s} = V_{r2} \quad \text{(given)}$$

From O/L Vel. Δ^{le} :-

$$V_2^2 = V_{r2}^2 + U^2 - 2UV_{r2}\cos\beta_2 = 842.5^2 + 400^2 - 842.5 \times \cos(32.2^0) \times 2 \times 400.$$

$$V_2 = 547 \text{ m/s}$$

$$V_{u2} = (V_{r2}\cos\beta_2 - U) = 842.5 \cos(32.2^0) - 400 = 312.9 \text{ m/s}$$

(i) Rotor Angles β_1 & β_2 :- $\beta_1 = \beta_2 = \mathbf{32.2^0}$

(ii) Tangential force on rotor :

$$F_t = \dot{m}(V_{u1} + V_{u2})/g_c = \dot{m}(V_{u1} + V_{u2})/g_c \quad \text{(As } V_{u2} \text{ is opposite to } V_{u1})$$

$$F_t = (1112.6 + 312.9)/1 = 1425.5 \text{ N/(kg/s)}$$

(iii) Power (P) :

$$P = \dot{m}\, U(V_{u1} + V_{u2})/g_c$$

or $E = P/\dot{m} = U(V_{u1} + V_{u2})/g_c = 400(1112.6+312.9)/1000$

$E = 570.2$ kJ/kg

or $P = 570.2$ kW/(kg/s)

(iv) Utilization ($\in$):

$$\in = \frac{V_1^2 - V_2^2}{V_1^2 - R V_2^2} = \frac{V_1^2 - V_2^2}{V_1^2} \qquad (R = 0 \text{ for Impulse m/c})$$

$$= \frac{1200^2 - 547^2}{1200^2}$$

$$\in = 0.79$$

OR

$$\in = \frac{E}{E + (V_2^2/2g_c)} = \frac{570.2}{570.2 + [547^2/(2 \times 1000)]}$$

$$\in = 0.79.$$

5) At a nozzle exit of a steam turbine, the absolute velocity is 300 m/s. The rotor speed is 150 m/s at a point where the nozzle angle is 18°. If the outlet rotor angle is 3.5° less than the inlet blade angle, find the power output from a stage for steam flow rate of 8.5 kg/s. Assume $V_{r_1} = V_{r_2}$, also find utilization factor

Solution : Given : $V_1 = 300$ m/s

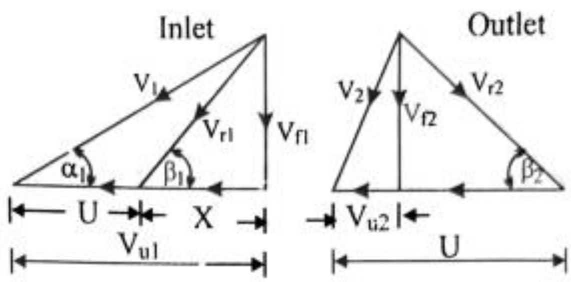
$U = 150$ m/s

$\alpha_1 = 18^0$

$\beta_2 = \beta_1 - 3.5^0$

$\dot{m} = 8.5$ kg/s

$V_{r1} = V_{r2}$



From I/L Vel. Δ^{le}:

$V_{u1} = V_1 \cos\alpha_1 = 300 \cos 18^0 = 285.3$ m/s

$V_{f1} = V_1 \sin 18^0 = 300 \sin 18^0 = 92.7$ m/s

$V_{r1}^2 = V_{f1}^2 + X^2 = V_{f1}^2 + (V_{u1} - U)^2$

$= 92.7^2 + (285.3 - 150)^2$

$V_{r1} = 164$ m/s $= V_{r2}$

$\beta_1 = \tan^{-1}\left(\frac{V_{f1}}{X}\right) = \tan\left(\frac{92.7}{285.3 - 150}\right)$

$\beta_1 = 34.4^0$.

O/L Vel. Δ^{le}:

$\beta_2 = \beta_1 - 3.5^0 = 34.4^0 - 3.5^0$ (Given)

$\beta_2 = 31.4^0$

$V_2^2 = V_{r2}^2 + U^2 - 2UV_{r2}\cos\beta_2$

$= 164^2 + 150^2 - 2 \times 150 \times 164 \cos(31.4^0)$

$V_2 = 86$ m/s

$V_{f2} = V_{r2} \sin\beta_2 = 164 \sin(31.4^0)$

$V_{f2} = 85.7$ m/s

$V_{u2} = U - V_{r2}\cos\beta_2 = 150 - 164 \cos 31.4^0$

$V_{u2} = 10$ m/s

(i) Power output (P):

$$P = \frac{\dot{m}}{g_c} U (V_{u1} - V_{u2}) = \frac{8.5 \times 150 (285.3 - 10)}{1 \times 1000} = 351 \text{ kW}$$

(ii) Utilization factor ($\in$):

$$\in = \frac{V_1^2 - V_2^2}{V_1^2 - RV_2^2} = \frac{V_1^2 - V_2^2}{V_1^2} \qquad (\because R = 0)$$

$$= 1 - (V_2/V_1)^2 = 1 - (86/300)^2$$

$$= 0.9178.$$

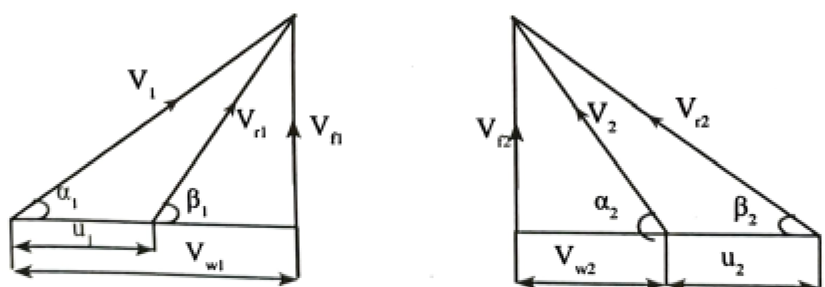
6) The axial component of air velocity at the exit of an axial flow reaction stage is 180 m/s and the nozzle inclination is 27°. Find the rotor blade angles at inlet and outlet if degree of reaction is 50% and blade speed is equal to that of axial component.

Data: $V_{f1} = V_{f2} = 180 \text{ m/s}$,

For 50% reaction $\alpha_1 = \beta_2 = 27°$ and $\alpha_2 = \beta_1 = ?, u = 180 \text{ m/s}$

If, $V_2 = V_{f2}$ $R = ?$

Case(i) When $R = 50\%$



From inlet triangle

$$\tan \alpha_1 = \frac{V_{f1}}{V_{W1}} \Rightarrow \tan 27 = \frac{180}{V_{W1}} \Rightarrow V_{W1} = 353.26 \text{ m/s}$$

$$\text{Again, } \tan \beta_1 = \frac{V_{f1}}{V_{W1} - u_1} = \frac{180}{353.26 - 180} \Rightarrow \beta_1 = 46.09°$$

$$\sin \beta_1 = \frac{V_{f1}}{V_{r1}} \Rightarrow \sin 46.09 = \frac{180}{V_{r1}} \Rightarrow V_{r1} = 249.85 \text{ m/s}$$

$$V_1^2 = V_{W1}^2 + V_{f1}^2 = 353.26^2 + 180^2 \Rightarrow V_1 = 395.5 \text{ m/s}$$