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CMRIT

Internal Assessment Test 2 -Dec. 2022

Sub:	Turbomachines					Sub Code:	18ME54	Branch:	Mech
Date:	03.12.2022	Duration:	90 min's	Max Marks:	50	Sem/Sec:	V/A		OBE

Answer All the Questions

		MARKS	CO	RBT
1	Derive alternate form of Euler's turbine equation and explain the significance of each energy component.	[10]	CO2	L3
2	For an inlet blade angle of 45º, blade speed at exit is twice of that at inlet and inlet whirl velocity of zero, prove that $R = (2 + cot\beta_2)/4$ for a radial outward flow turbine, where R is the degree of reaction and β_2 is blade exit angle.	[10]	CO2	L3
3	Derive the theoretical Head- Capacity (H-Q) relation in case of radial flow pump (Centrifugal), H $= u_2^2 - \frac{u_2^2.Q.cot\beta_2}{A_2}$, where, β_2= discharge blade angle with respect to tangential direction. Explain the effect of discharge angle on it.	[10]	CO2	L3
4	Define the terms Degree of reaction (R) and utilization factor ϵ.	[5]	CO2	L2
5	Draw the inlet and exit velocity triangles for an axial flow machine for the following cases. (i) R < 0. (ii) R = 1 (iii) R > 1.	[15]	CO2	L2

C.I **C.C.I** **HOD**

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Solutions key

1.

Let

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 called radial velocity in case of radial flow machines and axial velocity in case of axial flow machines.

V_w = tangential velocity, i.e. tangential component of absolute velocity V.

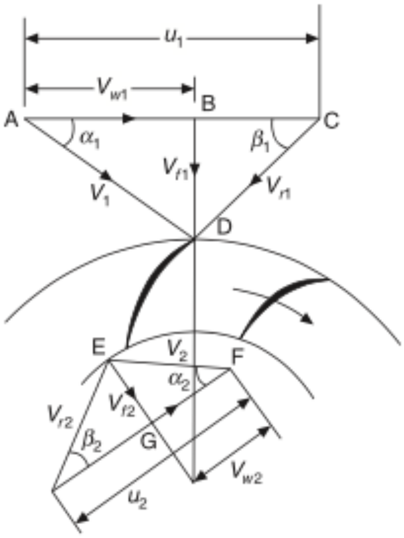


Figure 2.2 Parts of rotor of generalized turbomachine with inlet and outlet velocity triangles.

From inlet velocity triangle ABD (Figure 2.2),

$$V_{f1}^2 = V_1^2 - V_{w1}^2 \tag{2.3}$$

Now consider the triangle BCD,

$$V_{f1}^2 = V_{r1}^2 - (u_1 - V_{w1})^2$$

or

$$V_{f1}^2 = V_{r1}^2 - u_1^2 - V_{w1}^2 + 2u_1V_{w1} \tag{2.4}$$

Equating Eqs. (2.3) and (2.4),

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

or

$$u_1V_{w1} = \frac{(V_1^2 + u_1^2 - V_{r1}^2)}{2} \tag{2.5}$$

Similarly,

$$u_2 V_{w2} = \frac{(V_2^2 + u_2^2 - V_{r2}^2)}{2} \tag{2.6}$$

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

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

$$= \frac{(V_1^2 - V_2^2) + (u_1^2 - u_2^2) + (V_{r2}^2 - V_{r1}^2)}{2g_c} \tag{2.7}$$

First component

$(V_1^2 - V_2^2)/2g_c$ is the change in absolute kinetic energy. Due to this, a change in the dynamic head or dynamic pressure of the fluid takes place through the machine. The exit velocity V_2, i.e. exit K.E. is negligible in some turbomachines and considerable in other turbomachines, particularly in power absorbing turbomachines like pumps and compressors. In power absorbing turbomachines, energy is transferred from rotor to fluid, therefore there is an increase in K.E. at the rotor exit. A diffuser converts this K.E. into static pressure rise.

Second component

$(u_1^2 - u_2^2)/2g_c$ is the change in centrifugal energy of the fluid in the motion. This is due to the change in the radius of rotation of the fluid. This causes a change in static head of the fluid through the rotor.

Third component

$(V_{r2}^2 - V_{r1}^2)/2g_c$ is the change in relative kinetic energy due to the change in relative velocity. This causes a change in static head of the fluid across the rotor.

2.

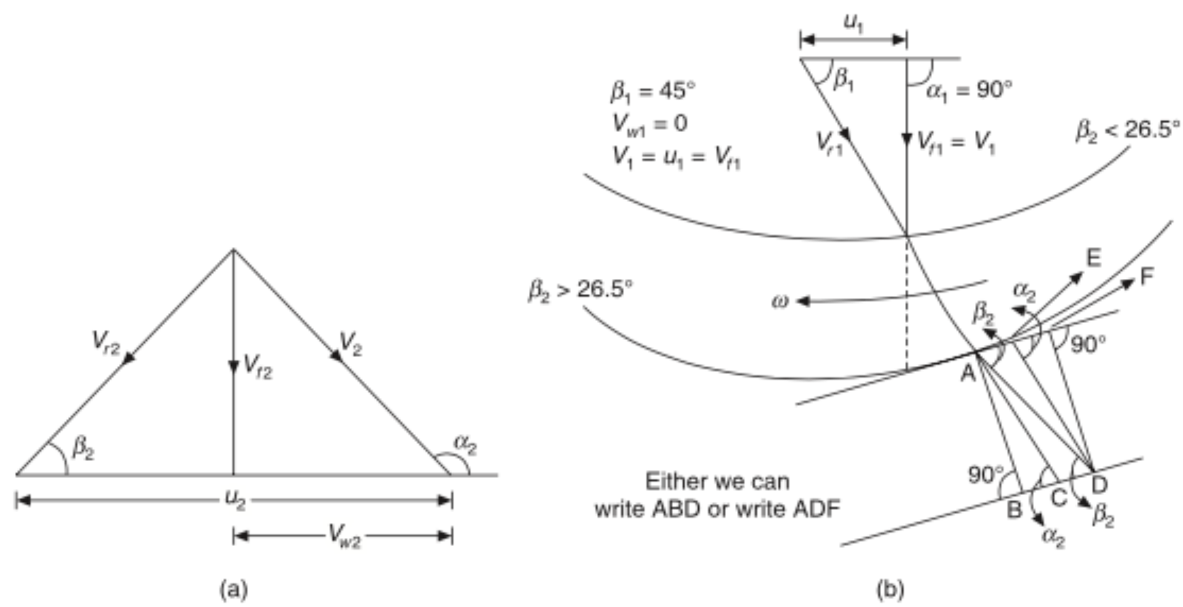


Figure 2.4 shows velocity triangles for various values of discharge angle β_2. The analysis is based on the following assumptions.

- Centrifugal effect at outlet = 2 × centrifugal effect at inlet, i.e. $u_2 = 2u_1$
- Radial velocity is constant (flow velocity)

  i.e. $$V_{f1} = V_{f2} = V_f$$
- No tangential component at inlet

  i.e. $$V_{w1} = 0; \quad \alpha_1 = 90°; \quad V_{f1} = V_1$$
- Inlet fluid angle, i.e. inlet blade angle is 45°.

  ∴ $$V_{f1} = V_{f2} = u_1 = V_1 = V_f$$
- The outlet blade angle β_2 (outlet fluid angle) is variable.
- Applying the 3rd condition to Eq. (2.2), we get

$$\text{W.D.} = \frac{-V_{w2}u_2}{g_c} \text{ J/kg} \tag{2.16}$$

From Figure 2.4(a),

$$\text{W.D.} = \frac{-u_2(u_2 - V_f \cot \beta_2)}{g_c}$$

$$\text{W.D.} = \frac{-2V_f(2V_f - V_f \cot \beta_2)}{g_c} \qquad (u_2 = 2u_1 = 2V_f)$$

$$= \frac{-2V_f^2\ (2 - \cot \beta_2)}{g_c} \tag{2.16a}$$

$$= \frac{2V_f^2\,(\cot \beta_2 - 2)}{g_c} \tag{2.17}$$

From Figures 2.4(a) and (b) (Figure 2.4(b) inlet triangle and Figure 2.4(a) or (b) exit triangle),

$$V_{r2}^2 = V_{f2}^2 + (V_{f2} \cot \beta_2)^2 = V_{f2}(1 + \cot^2\beta_2)$$

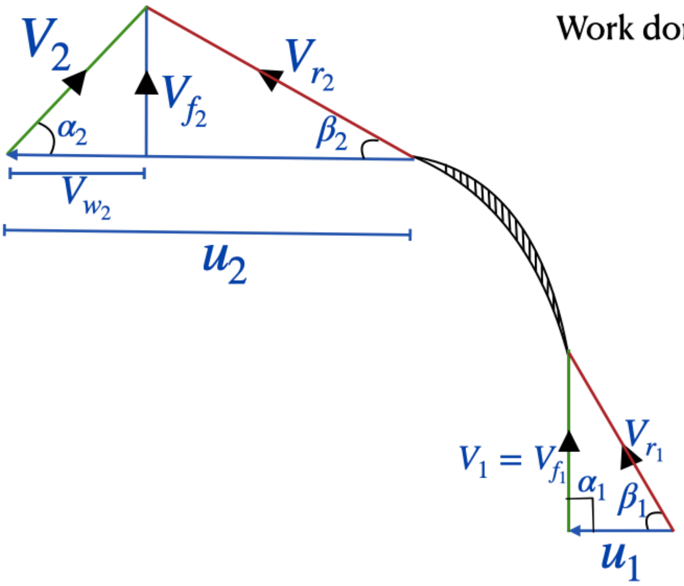
$$V_{r1}^2 = V_{f1}^2 + u_1^2 = 2V_{f1}^2 = 2V_f^2 \qquad (\because\ V_{f1} = u_1)$$

Substituting the above data and Eq. (2.16a) in Eq. (2.13), we have

$$R = \frac{(V_f^2 - 4V_f^2) + V_f^2(1 + \cot^2\beta_2) - 2V_f^2}{2\cancel{g_c} \times \dfrac{-2V_f^2\ (2 - \cot \beta_2)}{\cancel{g_c}}}$$

3. Theoritical Head – Capacity relationship

Theoretical Head - Capacity Relation ship



For radial entry , $V_{w_1} = 0$

Work done (W) $= V_{w_2} . u_2 - V_{w_1} . u_1 = V_{w_2} . u_2$

<u>From outlet triangle</u>

$$tan\beta_2 = \frac{V_{f_2}}{u_2 - V_{w_2}}$$

$$u_2 - V_{w_2} = \frac{V_{f_2}}{tan\beta_2}$$

$$V_{w_2} = u_2 - \frac{V_{f_2}}{tan\beta_2}$$

$$W = \left(u_2 - \frac{V_{f_2}}{tan\beta_2}\right)u_2 \longrightarrow (1)$$

Energy transferred per unit mass of fluid = gH $\longrightarrow$ (2)

Equating (1) and (2)

$$gH = \left(u_2 - \frac{V_{f_2}}{tan\beta_2}\right)u_2$$

Head generated

$$H = \frac{\left(u_2 - \frac{V_{f_2}}{tan\beta_2}\right)u_2}{g}$$

(Or)

$$H = \frac{u_2}{g}\left(u_2 - \frac{V_{f_2}}{tan\beta_2}\right)$$

Volume flow rate or capacity,

$$Q = A_2 . V_{f_2} \qquad \text{Where, } A_2 = \pi . D_2 . B_2$$

$$V_{f_2} = \frac{Q}{A_2}$$

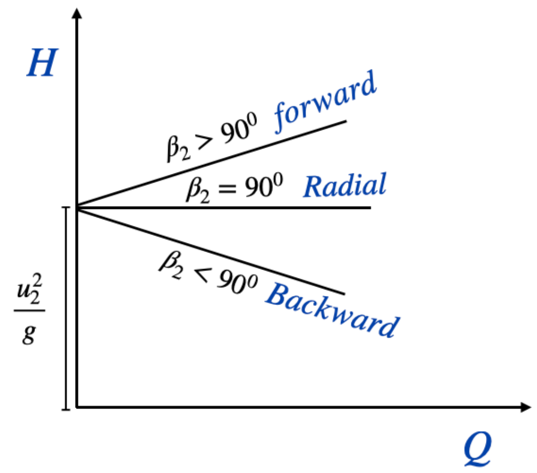
$$H = \frac{u_2}{g}\left(u_2 - \frac{Q . cot\beta_2}{A_2}\right)$$

$$H = \frac{u_2^2}{g} - \frac{u_2 . Q . cot\beta_2}{A_2 . g}$$

For a given machine at a constant speed u_2, A_2 & β_2 are fixed

$$H = K_1 - K_2 . Q \qquad where \quad K_1 = \frac{u_2^2}{g}; \quad K_2 = \frac{u_2 . cot\ \beta_2}{A_2 . g}$$

- K_2 determines whether the slope of H vs Q line is positive or negative.
- if β_2 varies from o to 90°, $cot\ \beta_2$ has a value between ∞ and 0.
- For $\beta_2 > 90^0$, $cot\ \beta_2$ is negative.
- For $\beta_2 = 90^0$, or radial vane,
- H = $\frac{u_2^2}{g}$ = constant and head is constant for all rates of flow.



4. Degree of reaction:

Degree of reaction is the ratio of the work transfer to the rotor caused by static pressure changes, to the total work done in the stage.

$$R = \frac{W_{st}}{W}$$

Utilisation factor:

$$\varepsilon = \frac{\text{Ideal work}}{\text{Energy supplied}} = \frac{\text{Energy utilized}}{\text{Energy available to the rotor}}$$

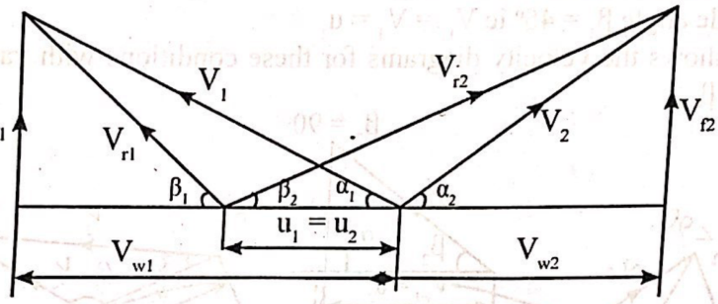
5.

R = 1

$u_1 = u_2$ Axial

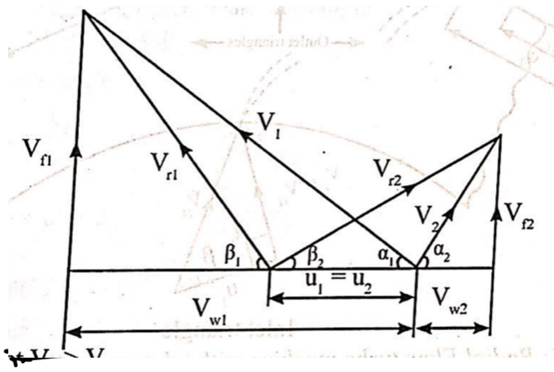
iii) When $R = 1$ we get $V_1 = V_2$ & $V_{r2} > V_{r1}$

$$R = \frac{(u_1^2 - u_2^2) + (V_{r2}^2 - V_{r1}^2)}{(V_1^2 - V_2^2) + (u_1^2 - u_2^2) + (V_{r2}^2 - V_{r1}^2)} = \frac{0 + (V_{r2}^2 - V_{r1}^2)}{0 + 0 + (V_{r2}^2 - V_{r1}^2)} = 1$$



R < 0

when $R<0$;
$V_{r_2} < V_{r_1}$
Also $u_1 = u_2$
(Axial Flow)
m/c.



R > 1

For $R > 1$
* $V_2 > V_1$

ve get $V_2 > V_1$