$$R = \frac{(U_1^2 - U_2^2) - (V_{r_1}^2 - V_{r_2}^2)}{2} \Big/ \left(\frac{V_1^2 - V_2^2}{2} + \frac{(U_1^2 - U_2^2)}{2} - \frac{(V_{r_1}^2 - V_{r_2}^2)}{2}\right)$$

Degree of reaction.

$$R = \frac{\frac{V_1^2 - V_2^2}{2} + \frac{(U_1^2 - U_2^2)}{2} - \frac{V_{r_1}^2 - V_{r_2}^2}{2} - \frac{V_1^2 - V_2^2}{2}}{W}$$

$$= 1 - \frac{V_1^2 - V_2^2}{2W}$$

$$\frac{V_1^2 - V_2^2}{2W} = 1 - R$$

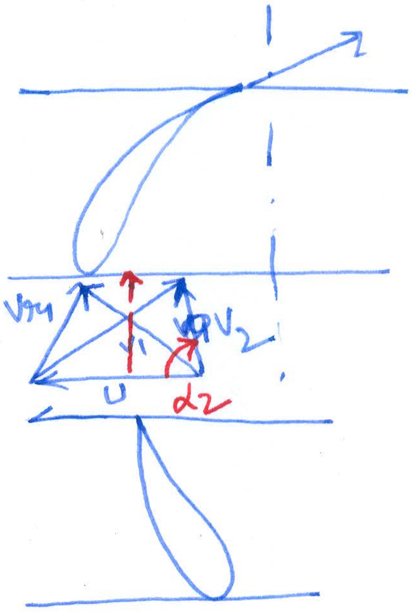
$$\boxed{W = \frac{V_1^2 - V_2^2}{2(1-R)}}$$

$R = 0$ $\quad 0 \le R < 1$

$R \neq 1$

$$\frac{V_1^2 - V_2^2}{2} = \frac{V_1^2 - V_2^2}{2(1-R)} (1-R)$$

$$\frac{U_1^2 - U_2^2}{2} - \frac{V_{r_1}^2 - V_{r_2}^2}{2} = \frac{V_1^2 - V_2^2}{2(1-R)} \cdot R$$



Utilization factor

$$\epsilon = \frac{W}{W + \frac{V_2^2}{2}} \Rightarrow W_a$$

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

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

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

V_2

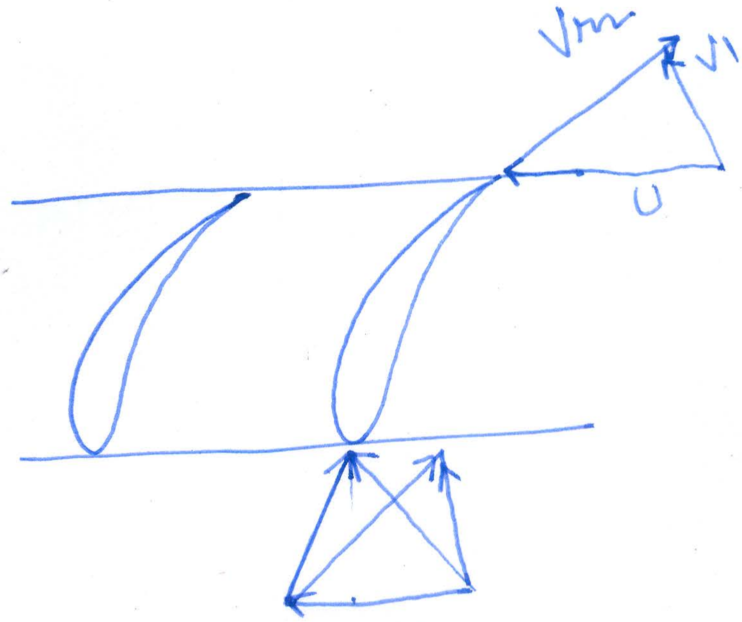
$$Q = \frac{\pi}{4}(D_h^2 - D_t^2) V_n$$

$V_2 \quad \alpha_2 = 90^\circ$

$V_2 = V_1 \sin\alpha_1$

$$\epsilon_m = \frac{V_1^2(1 - \sin^2\alpha_1)}{V_1^2(1 - R\sin^2\alpha_1)}$$

$$= \frac{\cos^2\alpha_1}{1 - R\sin^2\alpha_1}$$



$$\pi_1 = \frac{gH}{N^2D^2}$$

$$\phi = \frac{U_1}{V_1}$$

$$= \frac{1}{\phi^2}$$

$$\omega = U_1 V_{u_1} - U_2 V_{u_2}$$

$$\phi = \frac{U_1}{V_1} = \frac{U_1 V_{u_1}}{V_1 V_{u_1}}$$

$$= \frac{V_1^2 - V_2^2}{2(1-R) V_1^2 \cos\alpha_1}$$

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

$$\boxed{\phi = \frac{\cos\alpha_1}{2(1-R)}}$$

ω

$V_1 = 100$ m/s ~~Wt~~; $\omega_a = \frac{V_1^2}{2} = 5000$ J/kg

R=0	α_1	ϕ	ε_m	ω
0	10	0.49	0.9	4849
0.5	10	0.98		4920
0	25			4107
0.5	25			4509

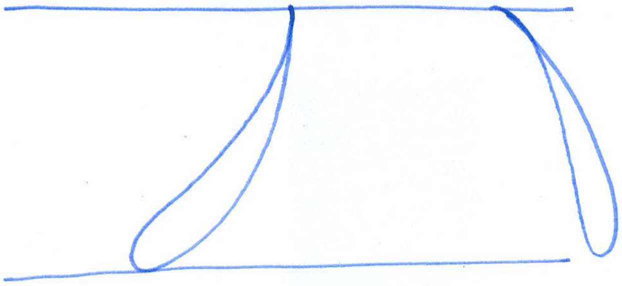
$$\varepsilon_m = \frac{\cos^2\alpha_1}{1 - R\sin^2\alpha_1}$$

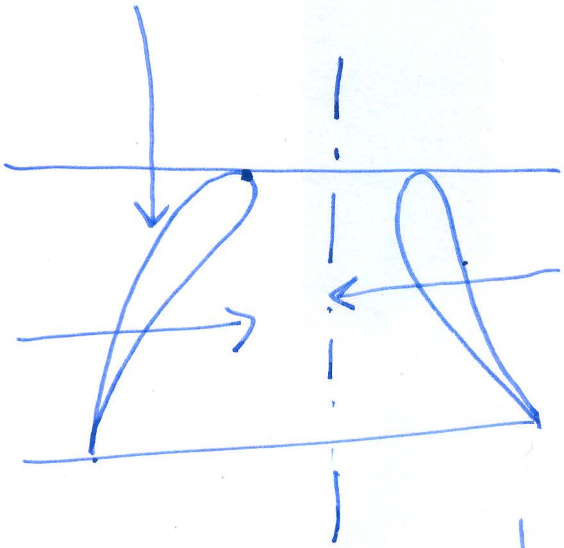
$$U_1 = \frac{2\pi N}{60} \times D_1$$

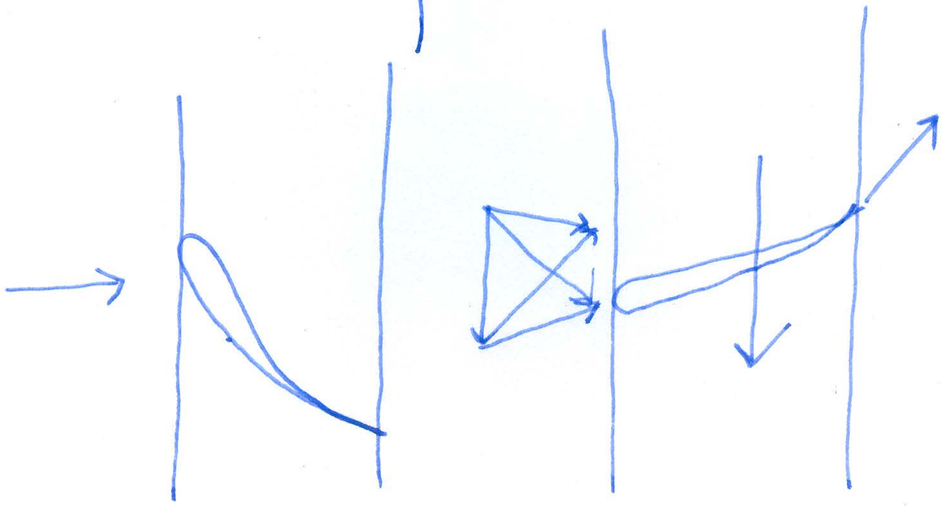
49 ND_1

98 ND_1

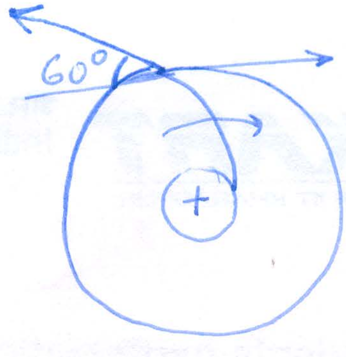
$\propto V_1^2$







3/Pai



$D_1 = 20$ cm

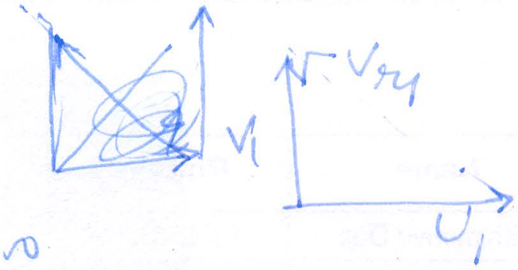
$D_2 = 50$ cm

$\beta_2 = 60°$.

$\alpha_1 = 90°$

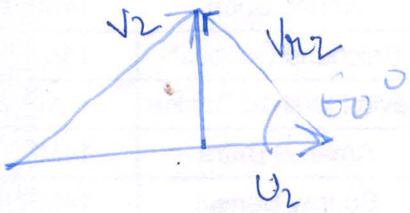
$V_{n_1} = V_{n_2} = 10$ m/s

$N = 800$ rpm.



$U_1 = \frac{\pi D_1 N}{60} = \frac{\pi \times 20 \times 800}{60}$

$= 8.4$



$\tan\beta_1 = \frac{V_1}{U_1} = \frac{10}{8.4} = 1.19$

$\beta_1 =$ ~~49~~ $\underline{50}$

$U_2 = \frac{\pi D_2 N}{60} = \frac{\pi \times 50 \times 800}{60 \times 100} = 20.94.$

$10 =$ ~~U_2~~ $V_{r_2} \sin 60 \Rightarrow V_{r_2} = 11.55$ m/s

$V_{u_2} = U_2 - V_{r_2} \cos 60 = 20.94 - 11.55 \times \cos 60$

$= 15.2$ m/s

$\tan\alpha_2 = \frac{V_{n2}}{V_{u2}} = \frac{10}{15.2} =$ $\quad \underline{\alpha_2 = 33.3}$

$\omega = U_1$ ~~V_{u1}~~ $- U_2 V_{u_2} = -20.94 \times 15.2$

$= \underline{-0.32 \text{ kJ/kg}}$

Review Questions

1. What is a vane-congruent flow? By means of neat sketches, show the vane-congruent flow for at least two types of radial flow blades and one type of axial flow blades. *(Refer Section 3.2.3)*
2. What is the purpose of air foil shapes for blades? *(Refer Section 3.2)*
3. Derive the Euler turbine equations. Do the equations hold good for pumps/compressors? *(Refer Section 3.3)*
4. Distinguish between impulse and reaction processes in turbomachines. Give examples. *(Refer Section 3.5)*
5. Explain the term utilization factor. *(Refer Section 3.6)*
6. Prove that $\in = \dfrac{V_1^2 - V_2^2}{V_1^2 - RV_2^2}$ *(Refer Section 3.6)*
7. Prove that $\phi = \dfrac{\cos \alpha_1}{2(1-R)}$ *(Refer Section 3.7)*
8. Compare the impulse and reaction ($R = 0.5$) machines. *(Refer Section 3.7)*

Exercises

(For the sake of practice, nonstandard speeds are also used in problems.)

1. The rotor of a radial flow machine has the inlet diameter of 40 cm and outlet diameter of 90 cm. At the outlet, the blades are radial. The speed of the rotor is 8000 rpm. The fluid enters the rotor in a radial direction. Calculate the inlet blade angle, absolute velocity of fluid at the outlet, and the specific work, if the inlet fluid velocity is 150 m/s. The velocity of flow remains constant in the rotor. Also find the angle of outlet velocity.
2. The blade angles at the entry and exit of an axial flow turbine rotor are 25° each. The blades have a mean diameter of 60 cm and the speed is 3000 rpm. The absolute velocity of fluid at the outlet is axial. Calculate the absolute velocities at the inlet and outlet, angle of inlet velocity, specific work, degree of reaction, and utilization factor. The velocity of flow remains constant in the rotor.
3. The rotor of a radial flow machine has its entry and exit diameters as 20 cm and 50 cm, respectively. Its blades are bent backward so that the blade tangent at the outlet makes an angle of 60° with the blade velocity. The fluid velocity at the inlet is radial, without any whirl component. The flow components remain constant at 10 m/s in the rotor. The speed of the rotor is 800 rpm. Draw the velocity triangles at the inlet and outlet of the rotor. Calculate the blade angle at the inlet and the specific work. Also calculate the specific work when the blade outlet angle is 80°, instead of 60°.
4. In an axial flow machine, the mean diameter of the rotor is 50 cm and the speed of the rotor is 10000 rpm. The fluid enters with a velocity of 380 m/s at 25° to the blade velocity. The blade angle at the outlet is 35°. The flow component remains constant in the rotor. Calculate the specific work and degree of reaction. If the machine is turbine, calculate the utilization factor.
5. The mean diameter of the rotor in an axial flow machine is 0.6 m and the speed is 10000 rpm. The fluid enters the rotor in the axial direction at a velocity of 180 m/s. The fluid leaves the rotor at an angle of 35° with the blade velocity. Calculate the blade angles at the inlet and outlet and the specific work. The flow components do not vary in the rotor.
6. The fluid enters the rotor at a velocity of 60 m/s at a diameter of 90 cm at an angle of 30° with the tangent to the wheel. The wheel speed is 1200 rpm. The absolute exit velocity of the fluid is radial, at a diameter of 30 cm. The flow components remain constant in the rotor. Calculate the blade angles at the inlet and outlet, the specific work, the degree of reaction, and the utilization factor.
7. An axial flow turbine has a mean rotor diameter of 70 cm and the rotor speed is 1000 rpm. The fluid enters with a velocity of 100 m/s at an angle of 28° with the plane of rotor. The blade outlet angle is 28°. Calculate the blade inlet angle, the specific work, the degree of reaction, and the utilization factor.
8. The blade velocity in an axial flow turbine is 125 m/s. The blade angles at the inlet and outlet are 40° and 25°, respectively. The absolute fluid velocity at the inlet is 220 m/s. The relative velocity at the outlet is 50% more than that at the inlet due to expansion. Calculate the angle at which the fluid enters the rotor, specific work, degree of reaction, utilization factor, and axial thrust.
9. Water enters a radial flow pump without any whirl component at a velocity of 12 m/s. The entry diameter of the rotor is 10 cm and the exit diameter is 20 cm. The speed of the rotor is 2000 rpm. Calculate the blade angle at the inlet. The relative velocity of water at the outlet gets reduced to 75% of that at the inlet, due to an increase of flow areas, and the blade outlet angle is 80°. Calculate the specific work and degree of reaction.
10. Air enters a radial flow compressor with a velocity of 50 m/s, without any whirl component. The diameters of the rotor are 30 cm and 60 cm at the inlet and outlet, respectively. The blades are radial at the outlet. Calculate the blade inlet angle, speed of the rotor, and the degree of reaction if the specific work of the rotor is 30 kJ/kg. The flow component of velocity remains constant in the rotor. Repeat the problem, if the outlet blade angle is 75° instead of 90°.
11. A radial flow pump impeller has diameters of 3.5 cm and 8 cm at the inlet and the outlet, respectively. The blades are inclined backward, at 65° to the blade velocity, at the outlet. Water enters the rotor with a velocity of 8 m/s, without any whirl component. The radial components of the velocity remain constant in the rotor. Determine the speed of the rotor to generate a head of 16 m of water. If the speed is 2880 rpm, what is the theoretical head generated?
12. Water enters the rotor of an axial flow pump, without any whirl component. The diameters of the rotor are 45 cm at the blade tip and 10 cm at the hub. The speed of the rotor is 800 rpm. The axial flow component of water velocity is 8 m/s, which may be assumed to remain constant through the entire cross section of flow. Draw the velocity triangles at the inlet of the blade, separately at tip end and hub end, and determine the blade angles at the inlet at both the points. The outlet blade angles are 40° at the tip and 90° at the hub. Calculate the specific works separately at the tip and hub ends of the blade. If the variation of the specific work can be taken as linear between the hub and tip, determine its value at 0.6 times the length of the blade. Taking this value of specific work as an average, uniform value, calculate the theoretical power required to drive the rotor.

Project-Oriented Questions

ON WEB SOLUTIONS AVAILABLE

1. The solved and unsolved examples of this chapter are meant to illustrate the various forms of velocity triangles and the variety of the turbomachines. In addition, their working parameters also present a wide range of values of such parameters. Now, with respect to all the problems, conduct an overall survey of all the parameters, such as (a) speed, (b) specific