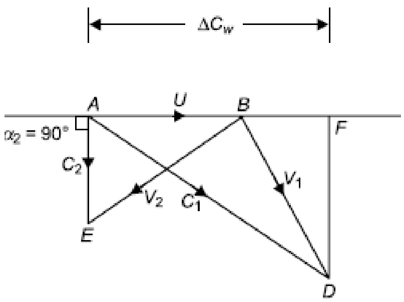
Example (5.3) A single stage of simple impulse turbine produces 120 kW at blade speed of 150 m/s when steam mass flow rate is 3 kg/s. Steam enters moving blade at 350 m/s and leaves the stage axially. Considering velocity coefficient of 0.9 and smooth steam entry without shock into blades, determine the nozzle angle and blade angles. Calculate axial thrust force and blade efficiency.

Solution:



Given: V_1=350 m/s, $\alpha2$=90^o, V_b=150m/s, K=0.9, m^o=3 kg/s, power=120 kW

$$power = m^o \times V_b \times \Delta V_w \rightarrow \Delta V_w = \frac{power}{m^o \times V_b} = \frac{120 \times 10^3}{3 \times 150}$$

$\Delta V_w = 267\ m/s$

From velocity triangle

$$\Delta V_w = V_{w1} + V_{w2} = V_{w1} + 0 \rightarrow V_{w1} = 267\ m/s$$

$$V_{w1} = V_1 \times \cos\alpha1 \rightarrow \alpha1 = \cos^{-1}\left(\frac{V_{w1}}{V_1}\right) = \cos^{-1}\left(\frac{267}{350}\right)$$

$$\alpha1 = 40.36^0$$

$$V_{f1} = V_1 \times \sin\alpha1 = V_{r1} \times \sin\beta1$$

$$\sin\beta1 = \left[\frac{V_1 \times \sin\alpha1}{V_{r1}}\right] \qquad \ldots\ldots \text{(a)}$$

$$V_{w1} = V_1 \times \cos\alpha1 = V_b + V_{r1} \times \cos\beta1$$

$$\cos\beta1 = \frac{V_1 \times \cos\alpha1 - V_b}{V_{r1}} \qquad \ldots\ldots \text{(b)}$$

Divide eq.(a) by eq.(b),

$$\tan\beta1 = \left[\frac{(V_1 \times \sin\alpha1)/V_{r1}}{(V_1 \times \cos\alpha1 - V_b)/V_{r1}}\right] \rightarrow \beta1 = \tan^{-1}\left[\frac{350 \times \sin 40.36}{350 \times \cos 40.36 - 150}\right]$$

$$\beta1 = 62.75^o$$

From eq. (a)

$$V_{r1} = \frac{V_1 \times \sin\alpha1}{\sin\beta1} = \frac{350 \times \sin 40.36}{\sin 62.75} = 255\ m/s$$

$$K = \frac{V_{r2}}{V_{r1}} \rightarrow V_{r2} = K \times V_{r1} = 0.9 \times 255$$

$$V_{r2} = 202.5\ m/s$$

$$V_{w2} = V_2 \times \cos\alpha2 = V_{r2} \times \cos\beta2 - V_b$$

$V_{r2} \times \cos\beta 2 = V_b$

$\beta 2 = \cos^{-1}\left[\frac{V_b}{V_{r2}}\right] = \cos^{-1}\left[\frac{150}{202.5}\right]$

$\beta 2 = 49^o$

$\Delta V_f = V_{f1} - V_{f2} = V_{r1} \times \sin\beta 1 - V_{r2} \times \sin\beta 2$

$\Delta V_f = 255 \times \sin 62.75 - 202.5 \times \sin 49 = 53.9\ m/s$

$thrust = m^o \times \Delta V_f = 3 \times 53.9 = 161.6\ N$

$\eta_{blade} = \frac{2V_b \times \Delta V_w}{V_1^2} = \frac{2\times 150\times 267}{350^2} \rightarrow \eta_{blade} = 65.4\%$

Example (5.4) An impulse turbine with blade speed =150 m/s, absolute velocity of steam at blade exit =85 m/s at an angle of 80^o, blade velocity coefficient =0.82, mass flow rate =2 kg/s. If the blade is equiangular, find the blade angles, the absolute velocity of steam at entrance, the axial thrust and the heat drop in the nozzle.

Solution:

Given:

$V_b = 150\ m/s\ ,\ V_2 = 85\ m/s\ ,\ \alpha_2 = 80^o, K = 0.82\ , m^o = 2\ kg/s\ , \beta_1 = \beta_2$

$V_{w2} = V_2 \times \cos\alpha 2 = V_{r2} \times \cos\beta 2 - V_b$

$V_{w2} = 85 \times \cos 80 = V_{r2} \times \cos\beta 2 - 150$

$V_{r2} \times \cos\beta 2 = 164.7$ …. (a)

$V_{f2} = V_2 \times \sin\alpha 2 = V_{r2} \times \sin\beta 2$

$V_{r2} \times \sin\beta 2 = 85 \times \sin 80 = 83.7$ … (b)

Divide (b) by (a),

$\frac{V_{r2}\times\sin\beta 2}{V_{r2}\times\cos\beta 2} \rightarrow \beta 2 = \tan^{-1}\frac{83.7}{164.7} \rightarrow \beta 2 = 27^o$

$\beta 2 = \beta 1 = 27^o$

From (a) $V_{r2} = \frac{164.7}{\cos 27} \rightarrow V_{r2} = 185\ m/s$

$K = \frac{V_{r2}}{V_{r1}} \rightarrow V_{r1} = \frac{V_{r2}}{K} = \frac{185}{0.82} \rightarrow V_{r1} = 225.4\ m/s$

$V_{w1} = V_1 \times \cos\alpha 1 = V_{r1} \times \cos\beta 1 + V_b$

$V_1 \times \cos\alpha 1 = 225.4 \times \cos 27 + 150$

$V_1 \times \cos\alpha 1 = 350.8$ …. (c)

$V_{f1} = V_1 \times \sin\alpha 1 = V_{r1} \times \sin\beta 1$

$V_1 \times \sin\alpha 1 = 225.4 \times \sin 27$

$V_1 \times \sin\alpha 1 = 102.3\ m/s$ …. (d)

Divide (d) by (c),

$\frac{V_1\times\sin\alpha 1}{V_1\times\cos\alpha 1} \rightarrow \alpha 1 = \tan^{-1}\frac{102.3}{350.8} \rightarrow \alpha 1 = 16.26^o$

From (c) $V_1 = \frac{350.8}{\cos 16.26} \rightarrow V_1 = 365.36\ m/s$

$thrust = m^o \times \Delta V_f = m^o \times (V_{f2} - V_{f1}) = 2 \times (83.7 - 102.3)$

$thrust = -36.7\ N$

$enthalpy\ drop = change\ in\ kinetic\ energy = \frac{1}{2} V_1^2$

$(\Delta h_{0-1})_{nozzle} = \frac{1}{2} \times (365.36)^2 = 66.744 \times 10^3\ \frac{m^2}{s^2}\ or\ \frac{j}{kg}$

$$\Delta h_{nozzel} = 66.744\ \frac{kj}{kg}$$