Session 16
Turbine Blading

Outline

- Introduction
- Work diagram
- Blade staging
- Efficiency of blade
- Blade material
- Calculation examples

Introduction

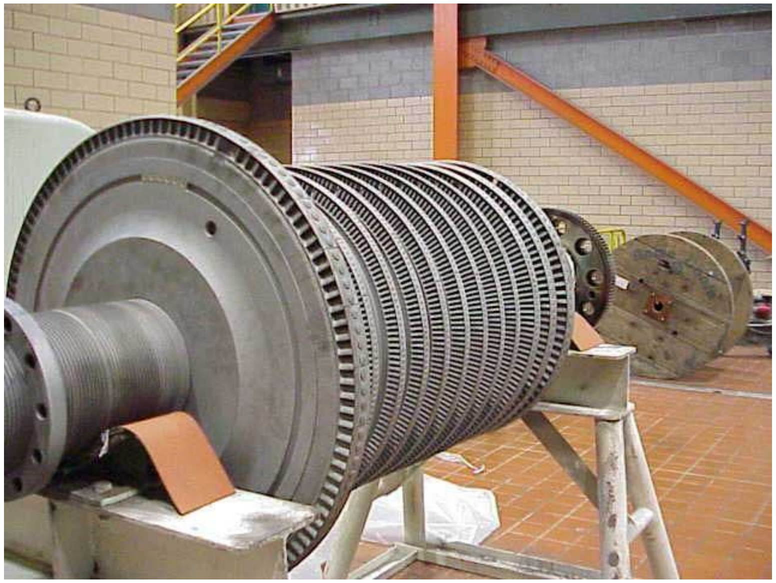
Blade is component of turbine which gives energy from the fluid to the rotor wheel

There are two parts:

a. Rotor (moving blades)
b. Stator (fixed blades)

Introduction

Rotor

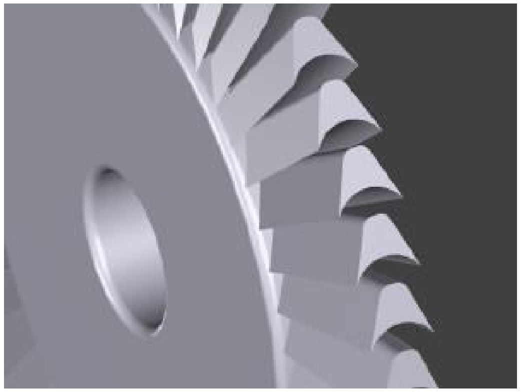


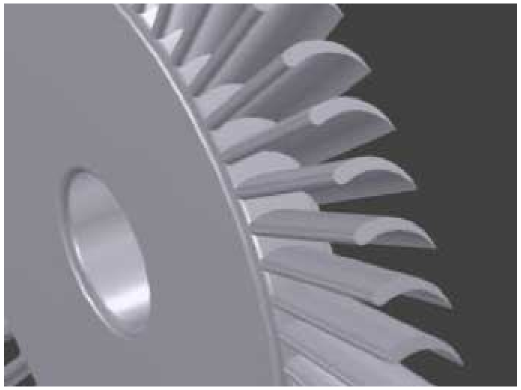
Stator

Introduction

Impulse turbine

All pressure drops of steam occur in nozzle and there is no pressure drop as steam flows through the passage between two blades

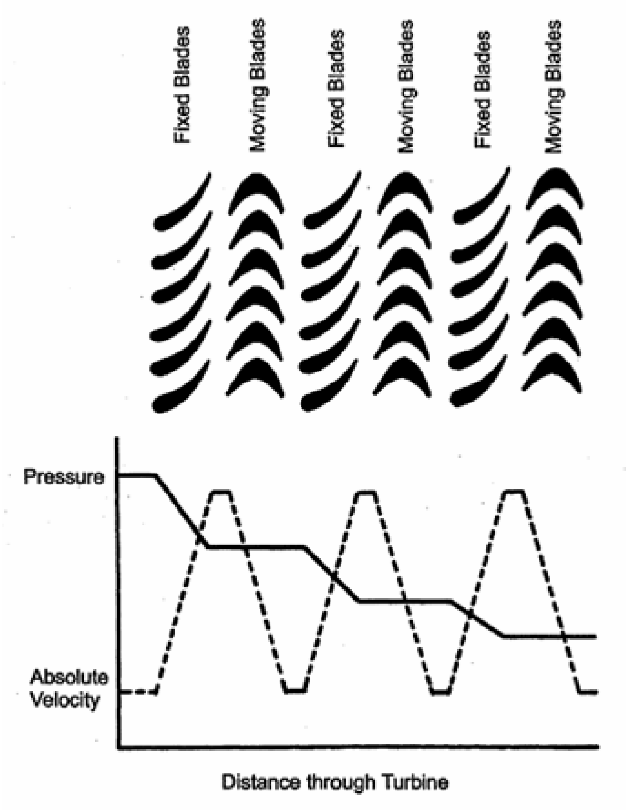




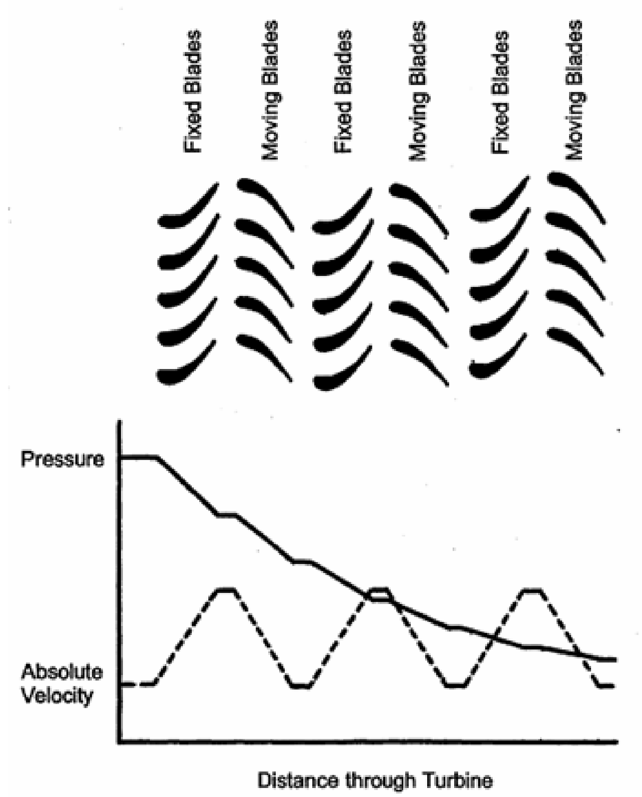
Reaction turbine

In this turbine, pressure drop occurs both in the nozzle or the fixed row of blades, as well as in the moving row of blades, since the moving blade channels are also of the nozzle shape

Work diagram

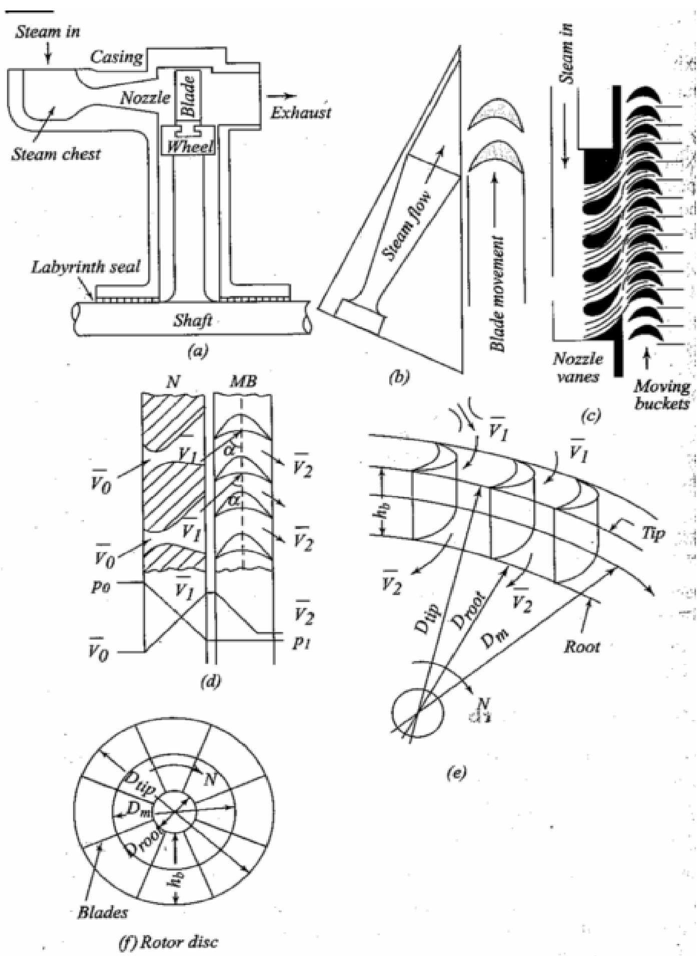


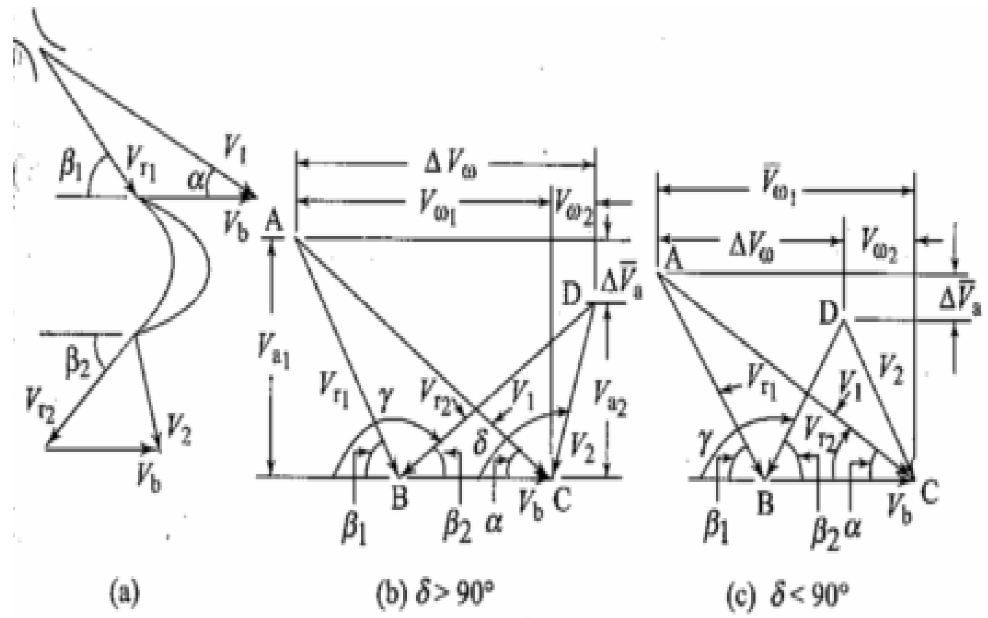
Impulse turbine



Reaction turbine

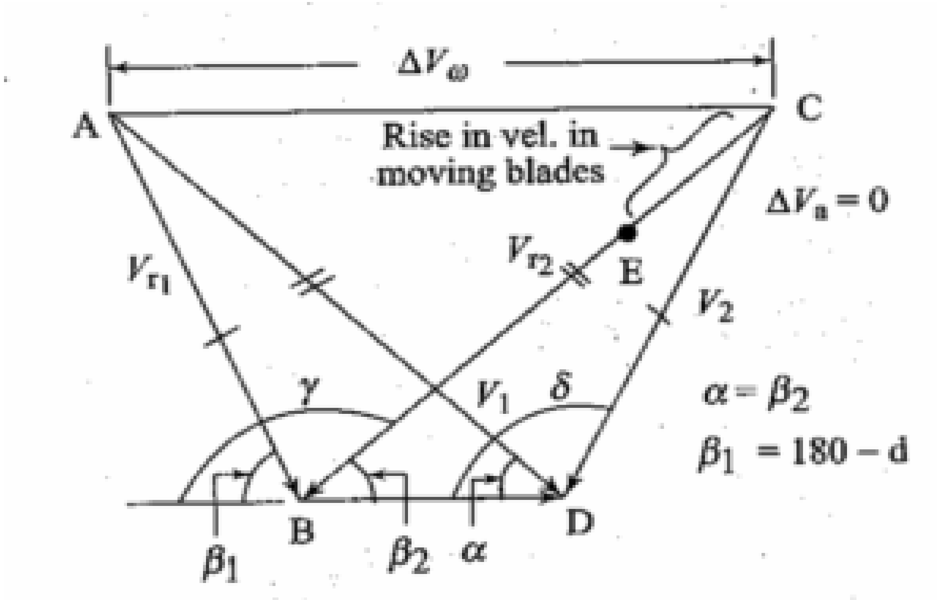
Work diagram





Impulse turbine

Work diagram



Reaction turbine

Blade staging

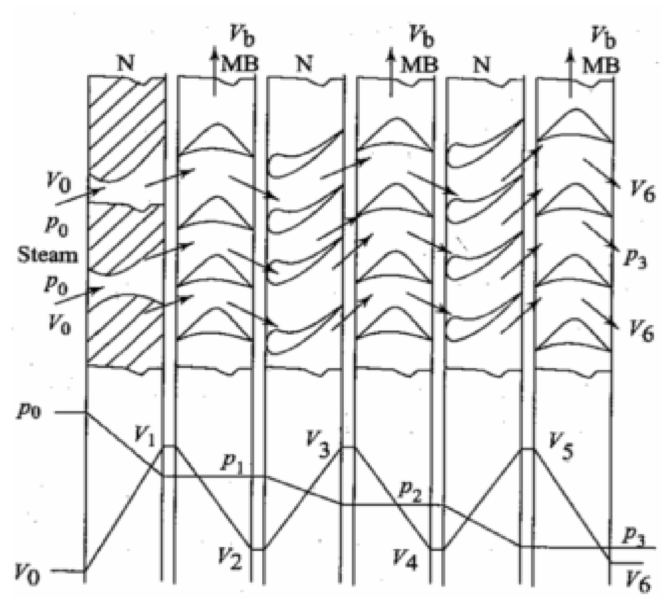
Basically, there are two ways of compounding steam turbines :

1. Pressure compounding or Rateau staging
2. Velocity compounding or Curtis staging

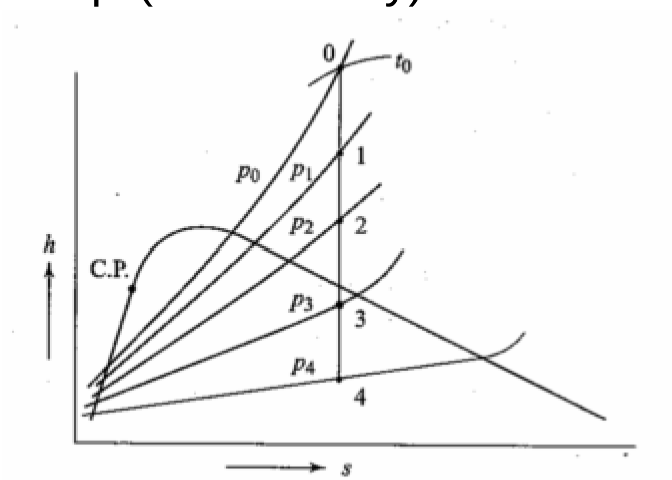
Blade staging

1. Rateau staging

   The pressure compounding or rateau staging corresponds to putting a number of simple impulse stage in series. The total enthalpy drop is divided equally among the stages. The pressure drops only in the nozzle. There is no pressure drop (theoretically) while steam



Three pressure (or Rateau) stages in series

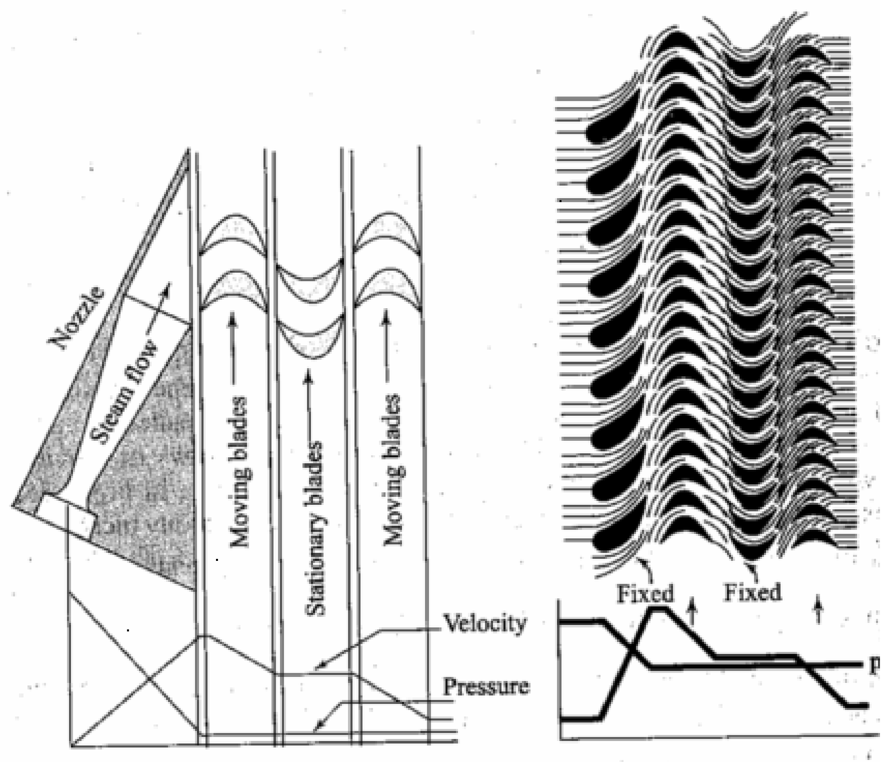


Enthalpy drop per stage in a 4-stage turbine

Blade staging

2. Curtis stage

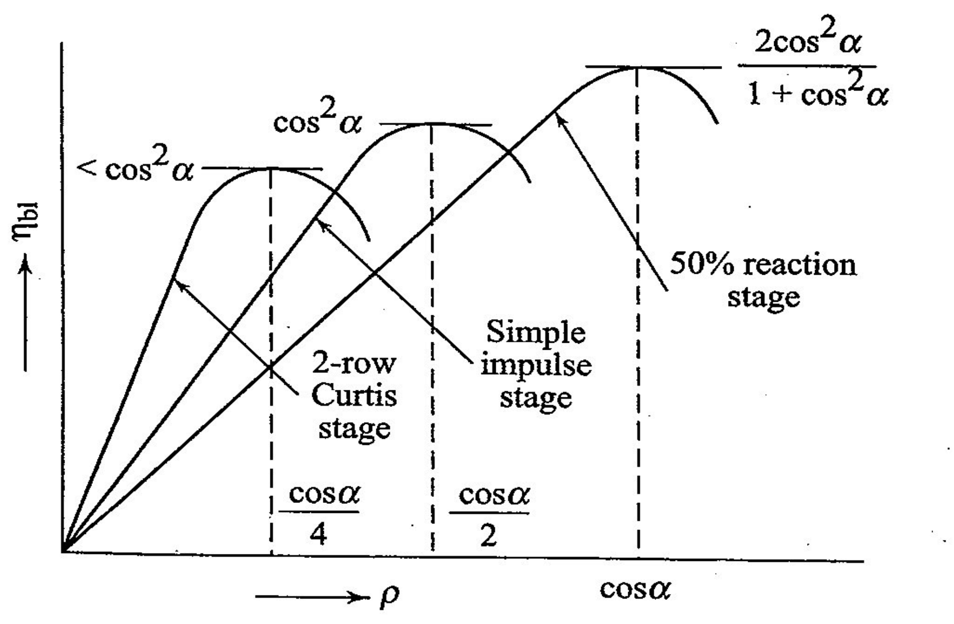
In velocity compounding or curtis staging, all the pressure drop and hence, enthalpy drop of steam take place in a single row of nozzle and the resultant kinetic energy of steam is absorbed by the wheel in a number of rows of moving blades with guide blades in between two such rows



(a) (b)

Blade staging

Graphic of efficiency of turbine wheel at first stage



Efficiency of blade

Tangential thrust

$P_t = \omega_s \cdot \Delta V_\omega$

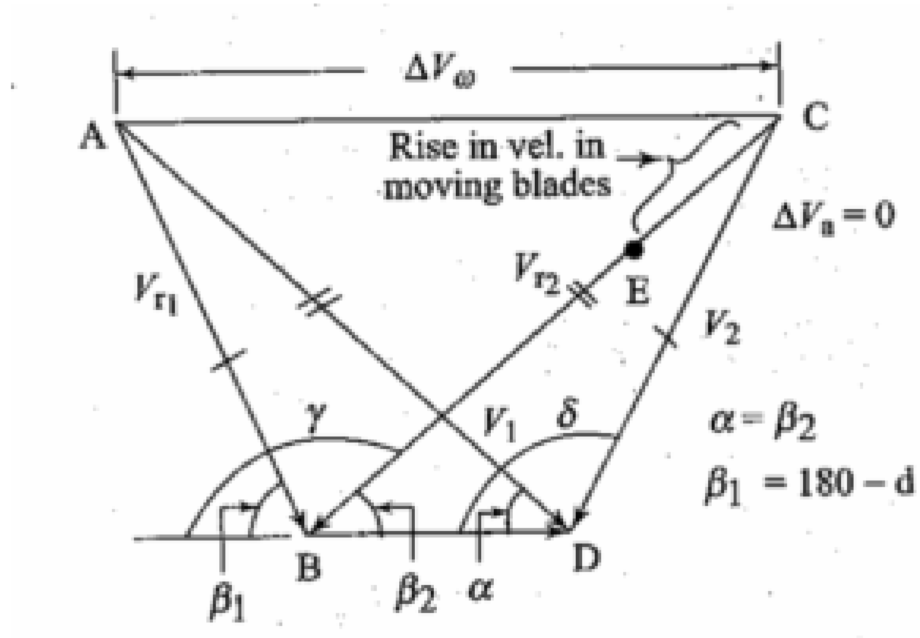
Axial thrust

$P_a = \omega_s \cdot \Delta V_a$

Where ω_s = steam flow rate

Blading or diagram efficiency

$\eta_D = 2 \Delta V_\omega V_b / V_1^2$



Blade materials

The material properties that are generally of most interest when choosing the optimum material for a particular cutting application include:

- Wear Resistance
- Toughness or Shock Resistance
- Corrosion Resistance
- Influence on Edge Characteristics
- Shape Control during Heat Treatment
- Cost
- Availability

Blade materials

Materials most commonly used in blade applications include:

- 1095 Carbon Steel
- Heat-Treated Stainless Steel
- 301 Stainless, 17-4 & 17-7 PH Stainless
- High Speed Steels
- Tool Steels
- Extreme-Wear Tool Steels
- Tungsten Carbide
- High-Performance Zirconia Ceramic
- Coatings

Calculation examples

1. The velocity of steam entering a simple impulse turbine is 1000, and the nozzle angle is 20^o. The mean peripheral velocity of blade is 400 m/s and the blades are symmetrical. If the steam is to enter the blades without a shock, what will be the blade angles?

a. Neglecting the friction effects on the blades, calculate the tangential force on the blades and the diagram power for a mass flow of 0.75 kg/s. Estimate also the axial thrust and diagram efficiency

b. If the relative velocity at exit is reduced by friction to 80 % of that at inlet, estimate the axial thrust, diagram power and diagram efficiency.

No.1

Solution Given: $V_1 = 1000$ m/s, $V_b = 400$ m/s, $\alpha = 20°$, $\beta_1 = \beta_2$, ω_s
0.75 kg/s (Fig. E7.9)

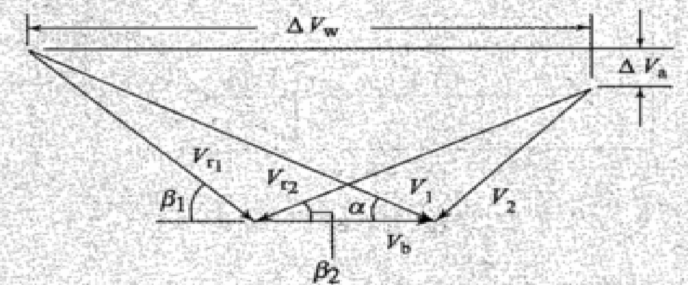


Fig. E7.9

(a) $k_b = 0$

$$V_{r1} \sin \beta_1 = V_1 \sin \alpha$$

$$V_{r2} \cos \beta_1 = V_1 \cos \alpha - V_b$$

$$\beta_1 = \tan^{-1}\left[\frac{V_1 \sin\alpha}{V_1 \cos\alpha - V_b}\right] = \tan^{-1}\frac{1000 \sin 20°}{1000 \cos 20° - 400}$$

$$= \tan^{-1}\frac{342}{940 - 400} = 32.35° = \beta_2 \qquad \textit{Ans}$$

$$V_{r1} \sin 32.35° = 342$$

$$\therefore \quad V_{r1} = 639.25 \text{ m/s} = V_{r2}$$

$$\Delta V_w = V_{r1} \cos \beta_1 + V_{r2} \cos \beta_2 = 2V_{r1} \cos \beta_1$$

$$= 2 \times 639.25 \times \cos 20° = 1080.07 \text{ m/s}$$

$$\Delta V_a = V_{r1} \sin \beta_1 - V_{r2} \sin \beta_2 = 0$$

Tangential thrust is $P_t = \omega_s \, \Delta V_\omega = 0.75 \times 1080.07 = 810.05$ N

Diagram power, $\dot{W}_D = P_t \times V_b = 810.05 \times 400 = 324.02$ kW *Ans*

Diagram efficiency, $\eta_D = \dfrac{324.02 \text{ kW}}{\frac{1}{2} \times 0.75 \times 1000^2 \times 10^{-3} \text{ kW}}$

$= 0.864$ or 86.4% *An*

Axial thrust, $P_a = \omega_s \, \Delta V_a = 0$ *An*

(b) $k_b = 0.8$

$$V_{r2} = 0.8\, V_{r1} = 0.8 \times 639.25 = 511.4 \text{ m/s}$$

$$\Delta V_w = 639.25 \cos 32.35° + 511.4 \cos 32.35° = 972.06 \text{ m/s}$$

Axial thrust, $P_a = \omega_s (V_{r1} \sin \beta_1 - V_{r2} \sin \beta_2)$

$= 0.75 \times 127.85 \sin 32.35° = 51.3$ N *An*

Diagram power, $\dot{W}_D = 0.75 \times 972.06 \times 400 = 291.62$ kW *An*

Diagram efficiency, $\eta_D = \dfrac{291620}{\frac{1}{2} \times 0.75 \times 1000^2}$

$= 0.7776$ or 77.76% *Ans.*

Calculation examples

2. An impulse steam turbine has a number of pressure stages, each having a row of noxxles and a single ring of blades. The nozzle angle in the first stage is 20^o and the blade exit angle is 30^o with references to the plane of rotation. The mean blade speed is 130 m/s and the velocity of steam leaving the nozzle is 330 m/s

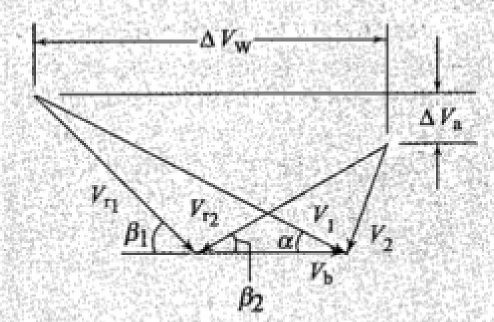
a. Taking the blade friction factor as 0.8 and a nozzle efficiency of 0.85, determine the work done in the stage per kg of steam and the stage efficiency.

b. If the steam supply to the first stage is at 20 bar, 250^oC and the condenser pressure is 0.07 bar, estimate the number of stage required, assuming that the stage efficiency and the work done are the same for all stages and that the reheat factor is 1.06.

No.2

Solution

(a) Given: $\alpha = 20°$, $\beta_2 = 30°$, $V_b = 130$ m/s, $V_1 = 330$ m/s (Fig. E7.10a)



$$\tan \beta_1 = \frac{V_1 \sin\alpha}{V_1 \cos\alpha - V_b} = \frac{330 \sin 20°}{330 \cos 20° - 130} = 0.627$$

$\beta_1 = 32.075°$

$$V_{r1} = \frac{V_1 \sin\alpha}{\sin\beta_1} = \frac{330 \times 0.342}{0.531} = 212.53 \text{ m/s}$$

$V_{r2} = 0.8 \times 212.53 = 170.025$ m/s

$\Delta V_w = V_{r1} \cos \beta_1 + V_{r2} \cos \beta_2$

$= 212.53 \cos 32.075° + 170.025 \cos 30° = 372.334$ m/s

$W_D = \omega_s \Delta V_\omega V_b = 1 \times 327.334 \times 130 = 42.55$ kJ/kg *Ans.*

$$\eta_{b1} = \eta_D = \frac{2\Delta V_w V_b}{V_1^2} = \frac{2 \times 327.334 \times 130}{330 \times 330}$$

$= 0.7815$ or 78.15%

$\eta_{stage} = \eta_n \times \eta_{b1} = 0.85 \times 0.7815 = 0.664$ or 66.4% *Ans.*

(b) $\eta_{internal} = \eta_{stage} \times$ reheat factor $= 0.664 \times 1.06$

$= 0.7041$ or 70.41%

$h_1 = 2902.3$ kJ/kg (Fig. E7.10b)

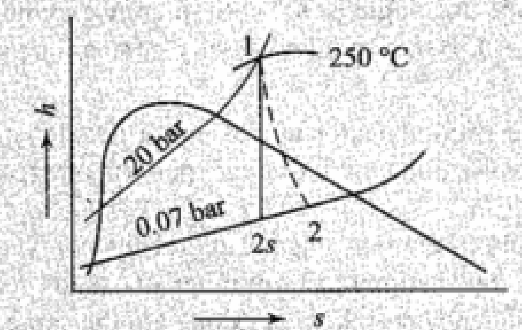


Fig. E7.10(b)

$s_1 = 6.5466 = s_{2s} = 0.5582 + x_{2s}\, 7.7198$

$x_{2s} = 0.7757$

$h_{2s} = 163.16 + 0.7757\,(2409.54) = 2032.29$ kJ/kg

$h_1 - h_2 = 0.7041\,(h_1 - h_{2s}) = 0.7041\,(2902.3 - 2032.3)$

$= 612.57$ kJ/kg

$$\therefore \text{ Number of stages, } n = \frac{(\Delta h)_{total}}{(\Delta h)_{stage}} = \frac{612.57}{42.55}$$

$= 14.39$ or 15 stages *Ans.*

Calculation examples

3. In a stage of an impulse turbine provided with single row wheel, the mean diameter of the blade ring is 800 mm and the speed of rotation is 3000 rpm. The steam issues from the nozzle with a velocity of 300 m/s and the nozzle angle is 20^o. The rotor blades are equiangular and the blade friction factor is 0.86. What is the power developed in the blading when the axial thrust on the blades is 140 N.

No.3

Solution

$$V_b = \frac{\pi D_m N}{60} = \frac{\pi \times 0.80 \times 3000}{60} = 125.6 \text{ m/s}$$

$$V_1 = 300 \text{ m/s}, \ \alpha = 20$$

$$\tan \beta_1 = \frac{V_1 \sin\alpha}{V_1 \cos\alpha - V_b} = \frac{300 \sin 20^\circ}{300 \cos 20^\circ - 125.6} = \frac{102.61}{281.91 - 125.6}$$

$$= 0.6565$$

$$\beta_1 = 33.3^\circ = \beta_2$$

$$V_1 \sin \alpha = V_{r1} \sin \beta_1$$

$$102.61 = V_{r1} \sin 33.3^\circ$$

$$V_{r1} = 187 \text{ m/s}$$

$$V_{r2} = 0.86 \times 187 = 161 \text{ m/s}$$

Axial thrust,

$$P_a = \omega_s (V_{r1} \sin \beta_1 - V_{r2} \sin \beta_2)$$

$$= \omega_s V_{r1} \sin \beta_1 (1 - k_b)$$

$$= \omega_s \times 187 \sin 33.3^\circ (1 - 0.86)$$

$$= \omega_s \times 14.3654 = 140 \text{ N}$$

$$\omega_s = 9.7456 \text{ kg/s}$$

$$\Delta V_w = V_{r2} \cos \beta_2 + V_{r1} \cos \beta_1 = V_{r1} \cos \beta_1 (1 + k_b)$$

$$= 187 \cos 33.3^\circ \times 1.86 = 290.71 \text{ m/s}$$

$$\text{Power developed} = 9.7456 \times 290.71 \times 125.6 \times 10^{-3}$$

$$= 355.84 \text{ kW}$$ *Ans.*

Calculation examples

4. The nozzles of the impulse stage of a turbine receive steam at 15 bar and 300^{o}C and discharge it at 10 bar. The nozzle efficiency is 95% and the nozzle angle is 20^{o}. The blade speed is that required for maximum work, and the inlet angle of the blades is that required for entry of the steam without a shock. The blade exit angle is 5^{o} less than the inlet angle. The blade friction factor is 0.9. Calculate for a steam flow of 1350 kg/h, a. the axial thrust, b. the diagram power, c. the diagram efficiency

No.4

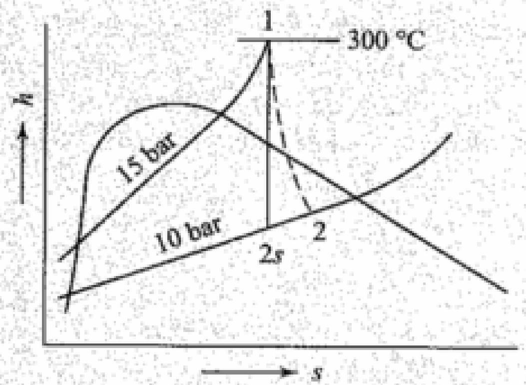
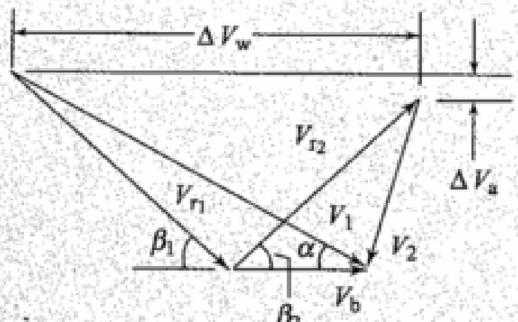


Fig. E7.12(a)

$$s_1 = 6.9224 \text{ kJ/kg K} = s_{2s}$$
$$(s_g)10 \text{ bar} = 6.5828 \text{ kJ/kg K}$$
$$s_{2s} > (s_g)10 \text{ bar}$$



The state "2*s*" is in the superheated region

$$t_{2s} = 250\ °\text{C},\ h_{2s} = 2943.1 \text{ kJ/kg}$$
$$V_1 = 44.72\,[(3038.9 - 2943.1)0.95]^{1/2} = 426.63 \text{ m/s}$$
$$\frac{V_b}{V_1} = \frac{\cos\alpha}{2} = \frac{\cos 20°}{2} = 0.4699$$
$$\therefore \quad V_b = 426.63 \times 0.4699 = 200.45 \text{ m/s}$$
$$\tan\beta_1 = \frac{V_1 \sin\alpha}{V_1\cos\alpha - V_b} = \frac{145.916}{200.45} = 0.7279$$
$$\beta_1 = 36°$$
$$\therefore \quad \beta_2 = 36 - 5 = 31°$$
$$V_{r1} = \frac{V_1 \sin\alpha}{\sin\beta_1} = 248.25 \text{ m/s}$$

$$V_{r2} = k_b V_{r1} = 223.42 \text{ m/s}$$
$$\Delta V_\omega = V_{r1}\cos\beta_1 + V_{r2}\cos\beta_2 = 392.35 \text{ m/s}$$
$$\Delta V_a = V_{r1}\sin\beta_1 - V_{r2}\sin\beta_2 = 30.85 \text{ m/s}$$

a) Axial thrust, $\quad P_a = \frac{1350}{3600} \times 30.85 = 11.57 \text{ N} \quad$ *Ans.*

angential thrust, $\quad P_t = \frac{1350}{3600} \times 392.35 = 147.13 \text{ N}$

b) Diagram power, $\quad \dot{W}_D = 147.13 \times 200.45 \times 10^{-3}$

$\quad = 29.492 \text{ kW} \quad$ *Ans.*

c) Diagram efficiency $\eta_D = \dfrac{29492}{\frac{1}{2} \times \frac{1350}{3600} \times (426.63)^2}$

$\quad = 0.864 \quad$ or $\quad 86.4\% \quad$ *Ans.*

Calculation examples

5. The following particulars refer to a two-row velocity-compounded impulse wheel :

- Steam velocity at nozzle exit = 600 m/s
- Nozzle angle = 16 ^{o}
- Mean blade velocity = 120 m/s
- Exit angles : first moving blades = 18^{o}, fixed guide blades = 22^{o}. second row moving blades = 36^{o}
- Steam flow = 5 kg/s
- Blade friction coefficient = 0.85

Determine

a. The tangential thrust

b. The axial thrust

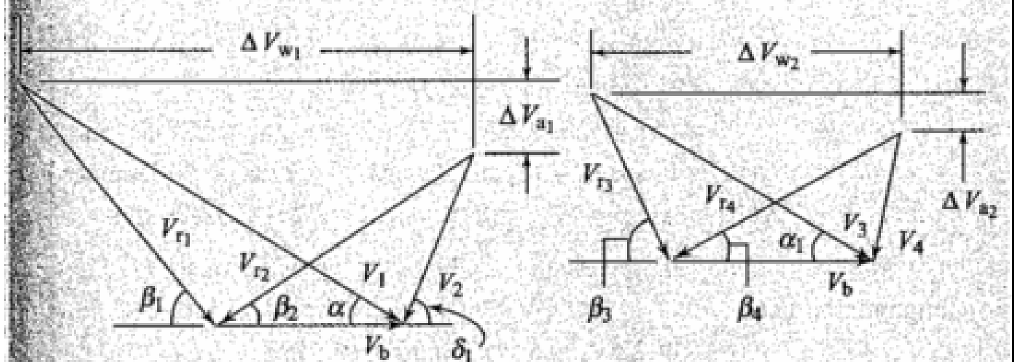
c. The power developed

d. The diagram efficiency

No.5

Solution

$V_b = 120$ m/s, $V_1 = 600$ m/s, $\alpha = 16°$, $\beta_2 = 18°$, $k_b = 0.85$, $\alpha_1 = 22°$, $\beta_4 = 36°$ (Fig. E7.13)



$$\tan\beta_1 = \frac{V_1 \sin\alpha}{V_1\cos\alpha - V_b} = \frac{600\sin 16°}{600\cos 16° - 120}$$

$$= \frac{165.382}{576.757 - 120} = 0.362$$

$$\beta_1 = 19.9°$$

$$V_{r1} = \frac{V_1 \sin\alpha}{\sin\beta_1} = \frac{165.382}{0.34} = 485.78 \text{ m/s}$$

$$V_{r2} = 0.85 \times 485.78 = 412.91 \text{ m/s}$$

$$\tan\delta_1 = \frac{V_{r_2}\sin\beta_2}{V_{r_2}\cos\beta_2 - V_b} = \frac{412.9\sin 18°}{412.9\cos 18° - 120} = \frac{127.593}{272.69} = 0.468$$

$$\therefore \quad \delta_1 = 25.1°$$

$$V_2 = \frac{127.593}{\sin 25.1°} = 301.06 \text{ m/s}$$

$$V_3 = 0.85 \times 301.06 = 255.9 \text{ m/s}$$

$$\Delta V_{w_1} = V_{r_1}\cos\beta_1 + V_{r_2}\cos\beta_2 = V_1\cos\alpha + V_2\cos\delta_1$$
$$= 576.757 + 301.06\cos 25.1° = 849.44 \text{ m/s}$$

$$\Delta V_{a_1} = V_1\sin\alpha - V_2\sin\delta_1 = 165.382 - 301.06\sin 25.1°$$
$$= 37.79 \text{ m/s}$$

$$\tan\beta_3 = \frac{V_3\sin\alpha_1}{V_3\cos\alpha - V_b} = \frac{255.9\sin 22°}{255.9\cos 22° - 120}$$

$$= \frac{95.86}{117.266} = 0.8175$$

$$\beta_3 = 39.26°$$

$$V_{r_3} = \frac{V_3\sin\alpha_1}{\sin\beta_3} = \frac{95.86}{\sin 39.26°} = 151.46 \text{ m/s}$$

$$V_{r_4} = 0.85 \times 151.46 = 128.74 \text{ m/s}$$

$$\Delta V_{w_2} = V_{r_3}\cos\beta_3 + V_{r_4}\cos\beta_4$$
$$= 151.46\cos 39.26° + 128.74\cos 36° = 221.42 \text{ m/s}$$

$$\Delta V_{a_2} = V_3\sin\alpha_1 - V_{r4}\sin\beta_4 = 93.86 - 75.67 = 20.19 \text{ m/s}$$

$$\Sigma\Delta V_w = \Delta V_{w_1} + \Delta V_{w_2} = 849.44 + 221.42 = 1070.86 \text{ m/s}$$

$$\Sigma\Delta V_a = \Delta V_{a_1} + \Delta V_{a_2} = 37.79 + 20.19 = 57.98 \text{ m/s}$$

(a) Tangential thrust,

$$P_t = \omega_s \Sigma\Delta V_w = 5 \times 1070.86 \times 10^{-3} \text{ kN}$$
$$= 5.354 \text{ kN} \qquad \textit{Ans.}$$

(b) Axial thrust,

$$P_a = \omega_s \Sigma\Delta V_a = 5 \times 57.98 \times 10^{-3} \text{ kN}$$
$$= 0.29 \text{ kN} \qquad \textit{Ans.}$$

(c) Power developed

$$\dot{W}_D = P_t \times V_b = 5.354 \times 120$$
$$= 642.48 \text{ kW} \qquad \textit{Ans.}$$

(d) Diagram efficiency,

$$\eta_D = \frac{2\Delta V_\omega V_b}{V_1^2} = \frac{2 \times 1070.86 \times 120}{600 \times 600}$$
$$= 0.7139 \quad \text{or} \quad 71.39\% \qquad \textit{Ans.}$$