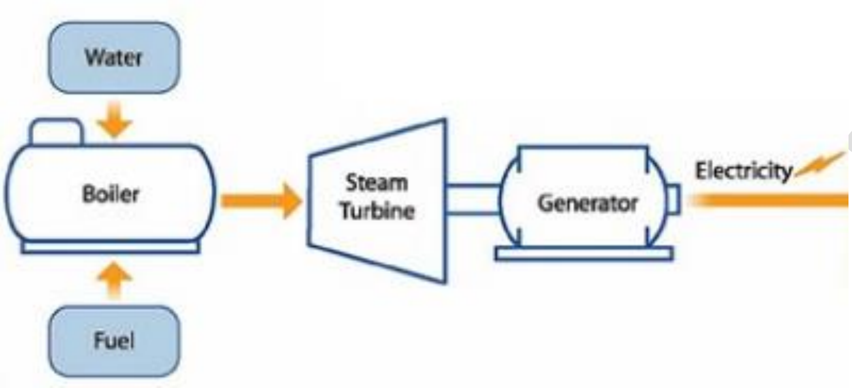
Chapter Four

Steam Turbine

4.1 Introduction :

Steam turbine is used to produce power.



Working of steam turbine based power plant

A steam turbine is a prime mover which continuously converts the energy of high-pressure, high temperature steam supplied by a steam generator into shaft work with the low temperature steam exhausted to a condenser.

A steam turbine is basically an assemblage of nozzles and blades.

Choice of steam turbine

The choice of steam turbine depends on the following factors :

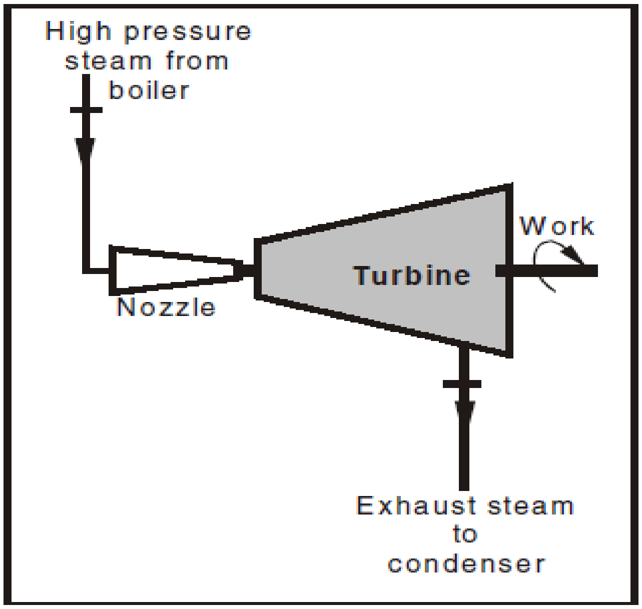
(i) Capacity of plant

(ii) Plant load factor and capacity factor

(iii) Thermal efficiency

(iv) Reliability

(v) Location of plant with reference to availability of water for condensate.



The high pressure steam is expanded in the turbine. During expansion, the rotor (blades) of the turbine rotates, thus giving work output.

Flow through Nozzle:

A nozzle is a duct which the velocity of fluid through it increases at the expense of pressure drop. At the entrance to the nozzle, the velocity of steam is very low but its pressure is very high. In flowing through the nozzle the steam expands, its pressure drops but its velocity increases.

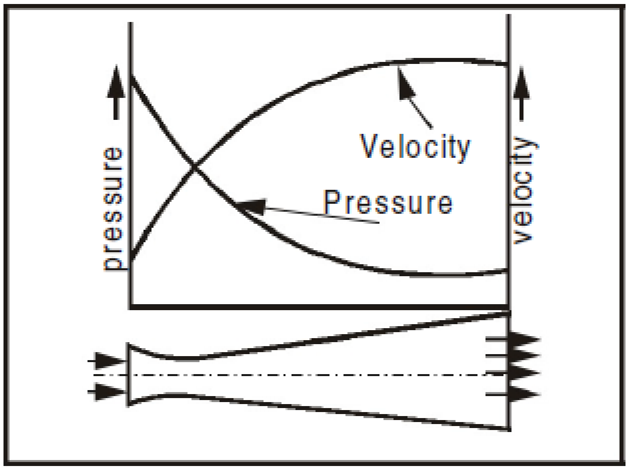


Figure 4.1: Flow through Steam Nozzle

4. 2 Classification of Steam Turbines:

Depending upon the types of blades used and the method of energy transfer from the fluid to the rotor wheel, the turbine may be into two types:

1. Impulse turbine (De-Laval , Curtis and Rateau):

There is no change in the pressure of the steam as it passes through the moving blades. There is change only in the velocity of the steam flow.

Steam at high pressure passes through nozzle where the velocity of steam increases. The high velocity jet of steam strikes on the blades of impulse turbine. The blades change the direction of steam flow without changing its pressure. The force due to change of momentum causes the rotation of the turbine shaft.

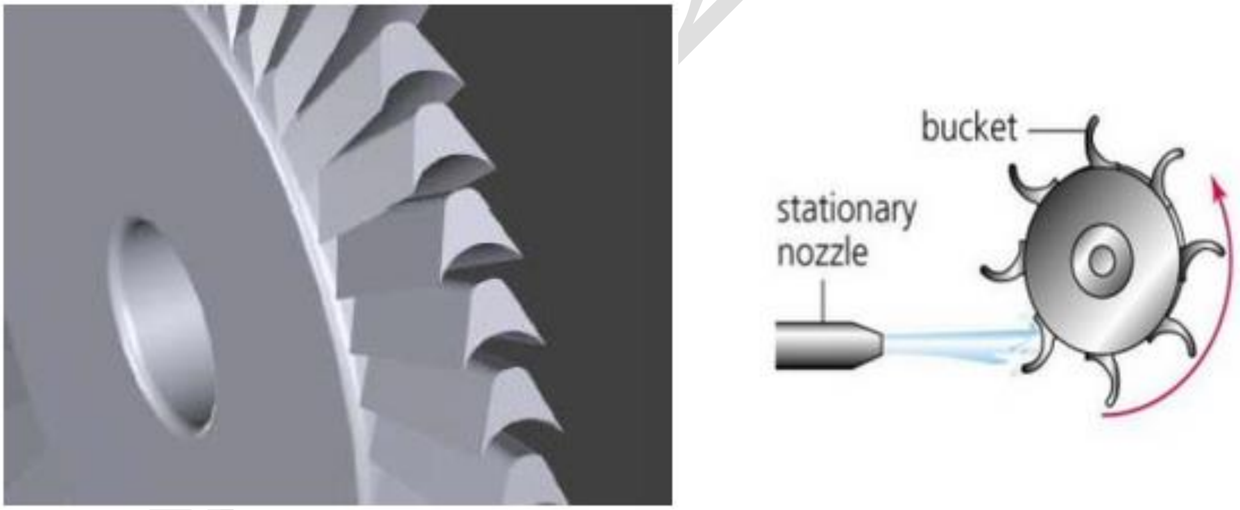


Figure 4.2: Impulse Turbine

2. Reaction turbine: There is change in both pressure and velocity as the steam flows through the moving blades.The steam leaving from a fixed blade (acting as a nozzle) enters into the curved blade at and glides over the inside surface of the blades and leaves from the other edge.

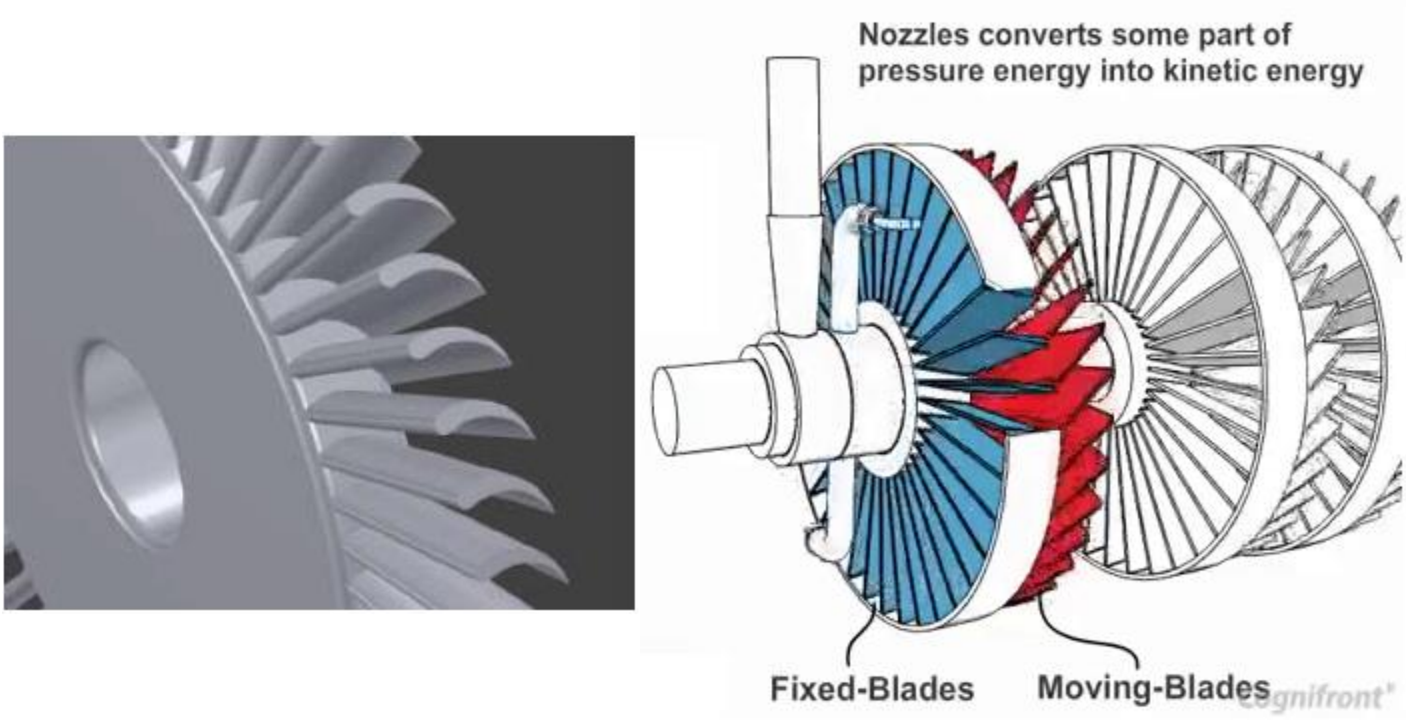


Figure 4.3: Reaction Turbine

4. 3 Principle Operation of Simple Impulse Turbine

The *single-stage impulse turbine* is also called the *de Laval turbine* after its inventor. The turbine consists of a single rotor to which impulse blades are attached. The steam is fed through one or several convergent-divergent nozzles which do not extend completely around the circumference of the rotor, so that only part of the blades is impinged upon by the steam at any one time. The nozzles also allow governing of the turbine by shutting off one or more them.

The single-stage impulse turbine has been shown in Fig. 4.4.

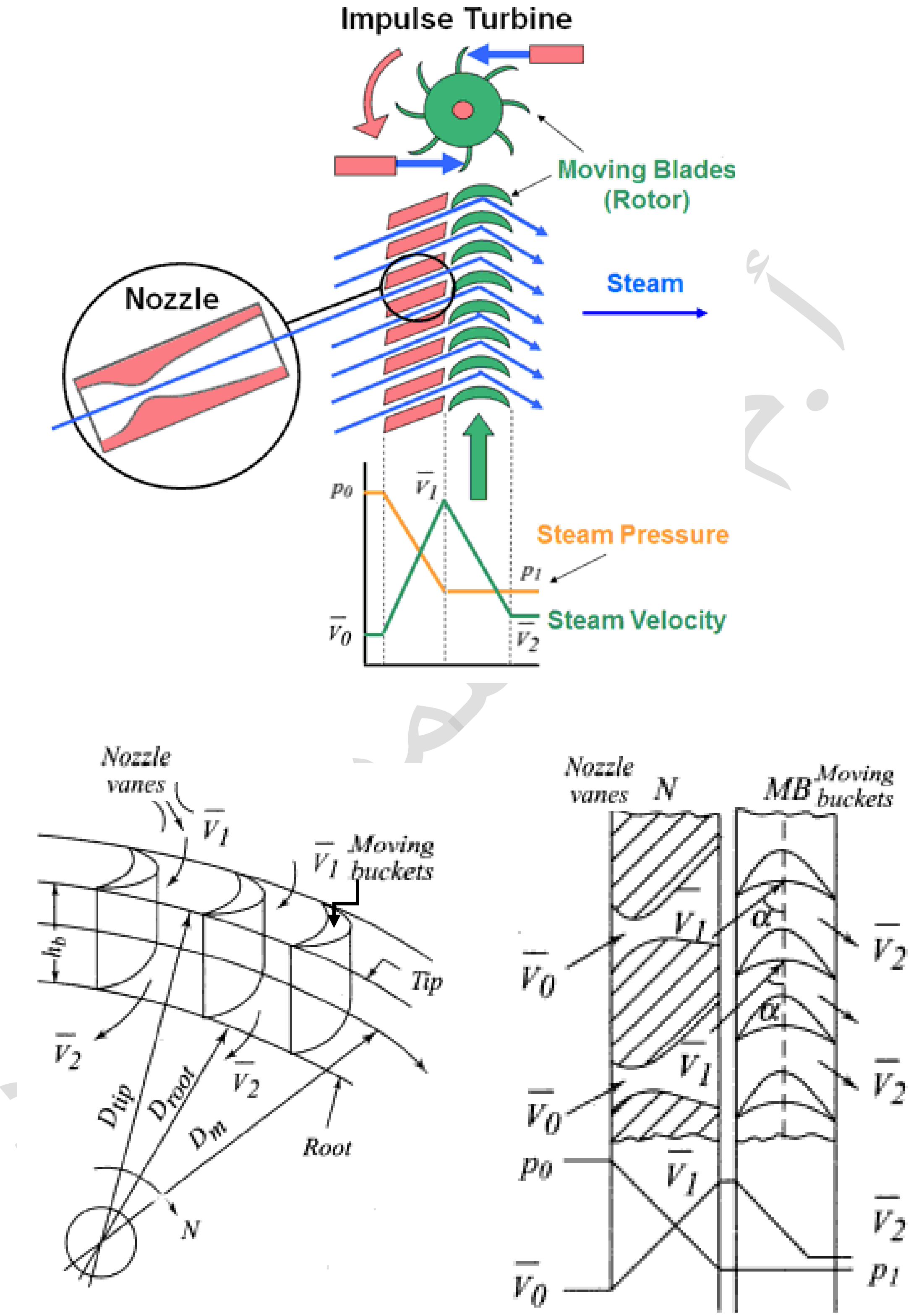


Figure 4.4: Single– Stage Impulse Turbine (De-Laval)

4. 3 .1 Velocity Diagram for Impulse Turbine

The velocity diagram for a single-stage impulse has been shown in Fig. 4.5. Figure 4.5 shows the velocity diagram indicating the flow through the turbine blades.

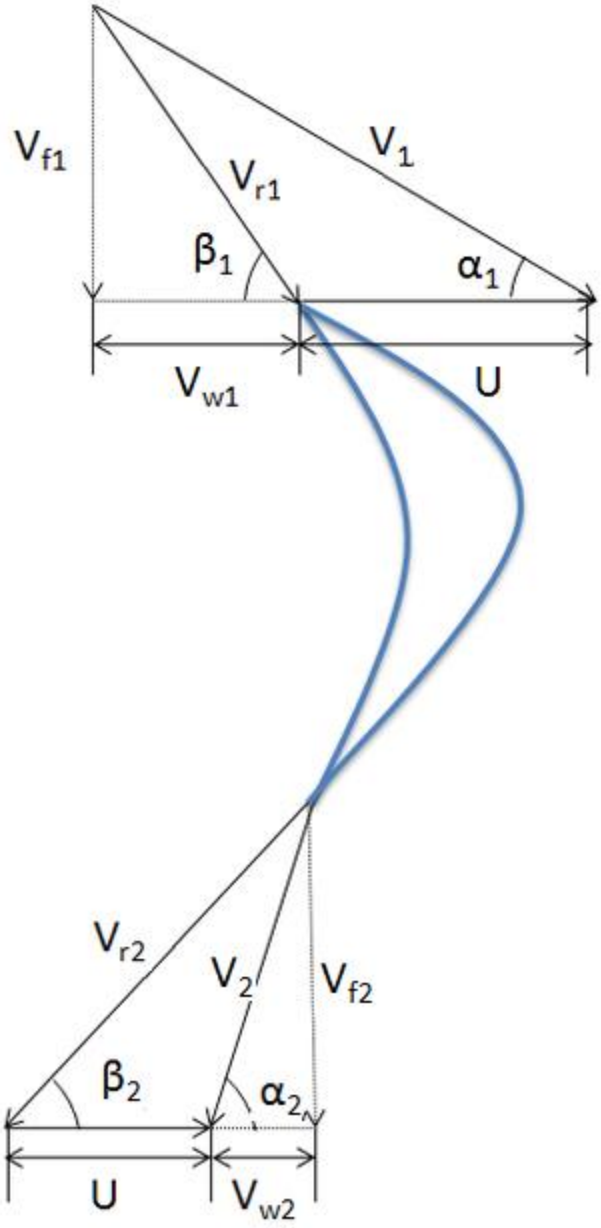


Figure 4.5: Single– Stage velocity diagram Impulse Turbine (De-Laval)

A velocity triangle paves the way for a better understanding of the relationship between the various velocities. In the adjacent figure we have:

V_1 and V_2 are the absolute velocities at the inlet and outlet respectively.

V_{f1} and V_{f2} are the flow velocities at the inlet and outlet respectively.

V_{w1} and V_{w2} are the swirl velocities at the inlet and outlet respectively, in the moving reference.

V_{r1} and V_{r2} are the relative velocities at the inlet and outlet respectively.

U or V_b are the velocities of the blade at the inlet and outlet

α is the guide vane angle and β is the blade angle.

Tangential force on a blade

$$F_u = \dot{m}(V_{w1} - Vw2)$$

or,

$$F_u = \dot{m}\Delta V_w$$

$$\text{Power developed} = \dot{m}U\Delta V_w$$

Blade efficiency

It is ratio of power developed by the turbine to the energy entering the blade per second.

$$\eta_{\text{blade}}\ (\text{or})\ \eta_{\text{diagram}} = \frac{\dot{m}\,(V_{w1} + V_{w2})\,V_b}{\frac{1}{2}\,\dot{m}\,V_1^2} = \frac{2\,(V_{w1} + V_{w2})\,V_b}{V_1^2}$$

Maximum blade efficiency $\eta_{\text{blade (max)}} = \cos^2\alpha$

Blade speed ratio

$$\rho = \text{Blade speed ratio} = \frac{V_b}{V_1}$$

$$\text{Optimum } \rho = \frac{V_b}{V_1} = \frac{\cos\alpha}{2}$$

Stage efficiency: η_{stage}

It is the ratio of work done/sec in one stage to the isentropic heat (enthalpy) drop in one stage.

$$\text{stage efficiency} = \eta_s = \frac{\textit{Work done by the rotor}}{\textit{Isentropic enthalpy drop}}$$

$$\eta_{stage} = \frac{(V_{w1} + V_{w2})\, V_b}{(\Delta h) \times 1000}$$

$$\eta_s = \eta_b \times \eta_n \qquad [\eta_n = \textit{Nozzle efficiency}]$$

If blade friction coefficient (K) is given then $V_{r2} = KV_{r1}$

Unless otherwise stated, we can take $V_{r1} = V_{r2}$

4.4 Compounding in Impulse Turbine

If high velocity of steam is allowed to flow through one row of moving blades, it produces a rotor speed of about 30000 rpm which is too high for practical use.

It is therefore essential to incorporate some improvements for practical use and also to achieve high performance. This is possible by making use of more than one set of nozzles, and rotors, in a series, keyed to the shaft so that either the steam pressure or the jet velocity is absorbed by the turbine in stages. This is called compounding.

In an Impulse steam turbine compounding can be achieved in the following three ways:

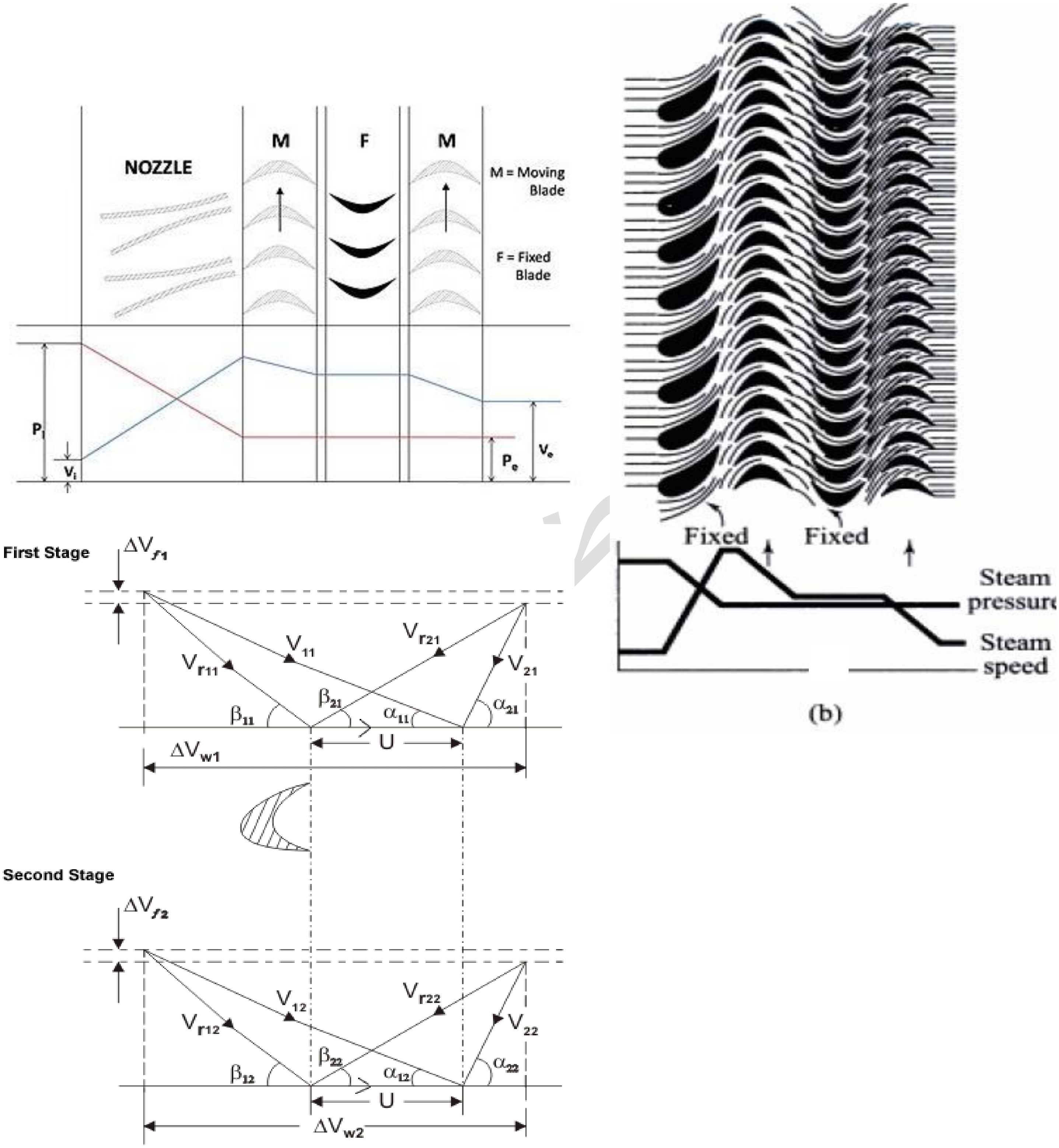
1. Velocity compounding

2. Pressure compounding

3. Pressure-Velocity Compounding

1. Velocity compounding

The *Curtis stage* turbine, as it came to be called, is composed of one stage of nozzles as the single-stage turbine, followed by two rows of moving blades instead of one. These two rows are separated by one row of fixed blades attached to the turbine stator, which has the function of redirecting the steam leaving the first row of moving blades to the second row of moving blades. A Curtis stage impulse turbine is shown in Fig. 4.6 with schematic pressure and absolute steam-velocity changes through the stage. In the Curtis stage, the total enthalpy drop and hence pressure drop occur in the nozzles so that the pressure remains constant in all three rows of blades.



(b)

Figure 4.6: Schematic Diagram of Curtis Stage Impulse Turbine

where,

P_i = pressure of steam at inlet

V_i = velocity of steam at inlet

P_o = pressure of steam at outlet

V_o = velocity of steam at outlet

In the above figure there are two rings of moving blades separated by a single of ring of fixed blades. As discussed earlier the entire pressure drop occurs in the nozzle, and there are no subsequent pressure losses in any of the following stages. Velocity drop occurs in the moving blades and not in fixed blades.

Disadvantages of Velocity Compounding

- Due to the high steam velocity there are high friction losses
- Work produced in the low-pressure stages is much less.
- The designing and fabrication of bsexyes which can withstand such high velocities is difficult.

2. Pressure Compounding of Impulse Turbine

The pressure compounded Impulse turbine is also called as Rateau turbine, after its inventor. This is used to solve the problem of high blade velocity in the single-stage impulse turbine.

It consists of alternate rings of nozzles and turbine blades. The nozzles are fitted to the casing and the blades are keyed to the turbine shaft.

In this type of compounding the steam is expanded in a number of stages, instead of just one (nozzle) in the velocity compounding. It is done by the fixed blades which act as nozzles. The steam expands equally in all rows of fixed blade. The steam coming from the boiler is fed to the first set of fixed blades i.e. the nozzle ring. The steam is partially expanded in the nozzle ring. Hence, there is a partial decrease in pressure of the incoming steam. This leads to an increase in the velocity of the steam. Therefore the pressure decreases and velocity increases partially in the nozzle.

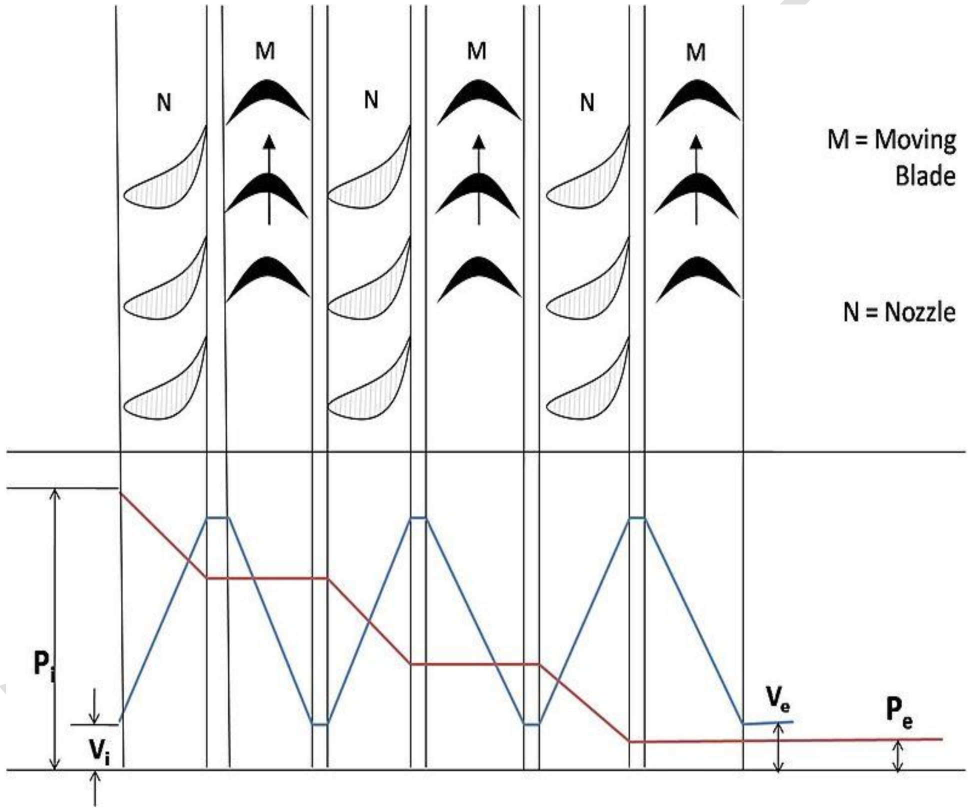


Figure 4.7: Schematic Diagram of Pressure compounded Impulse Turbine

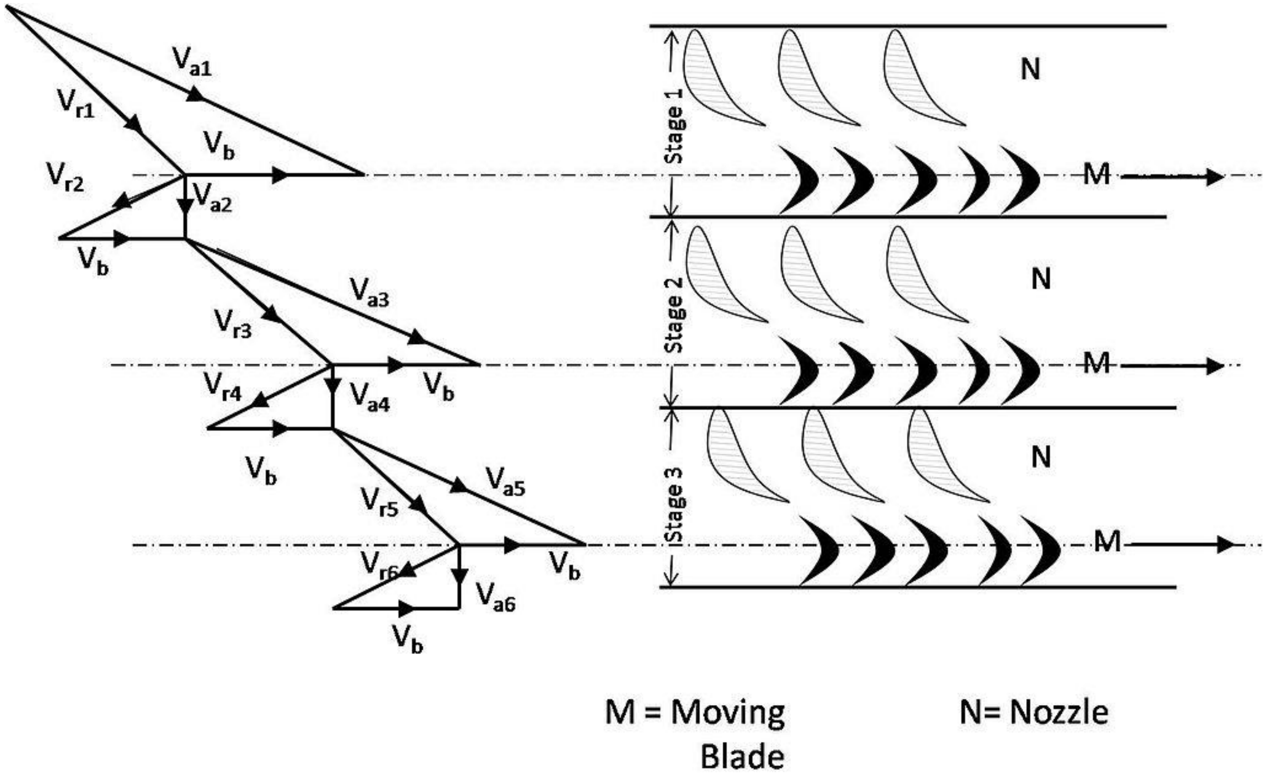


Figure 4.8: Velocity Diagram of Pressure compounded Impulse Turbine

3. Pressure-Velocity compounded Impulse Turbine

It is a combination of the above two types of compounding. The total pressure drop of the steam is divided into a number of stages. Each stage consists of rings of fixed and moving blades. Each set of rings of moving blades is separated by a single ring of fixed blades. In each stage there is one ring of fixed blades and 3-4 rings of moving blades. Each stage acts as a velocity compounded impulse turbine.

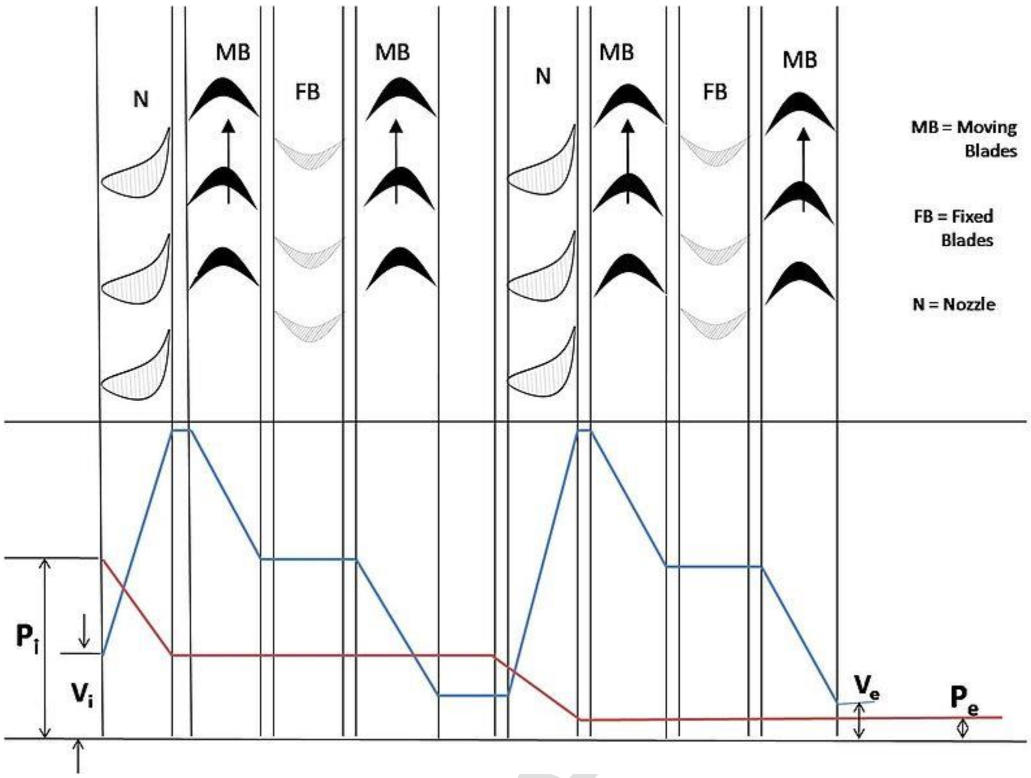


Figure 4.9: Schematic Diagram of Pressure-Velocity compounded Impulse Turbine

4.5 Reaction turbine: (Also called Impulse-Reaction turbine)

In the *reaction turbine*, the rotor blades themselves are arranged to form convergent nozzles. This type of turbine makes use of the reaction force produced as the steam accelerates through the nozzles formed by the rotor. Steam is directed onto the rotor by the fixed vanes of the stator. It leaves the stator as a jet that fills the entire circumference of the rotor. The steam then changes direction and increases its speed relative to the speed of the blades. A pressure drop occurs across both the stator and the rotor, with steam accelerating through the stator and decelerating through the rotor, with no net change in steam velocity across the stage but with a decrease in both pressure and temperature, reflecting the work performed in the driving of the rotor.

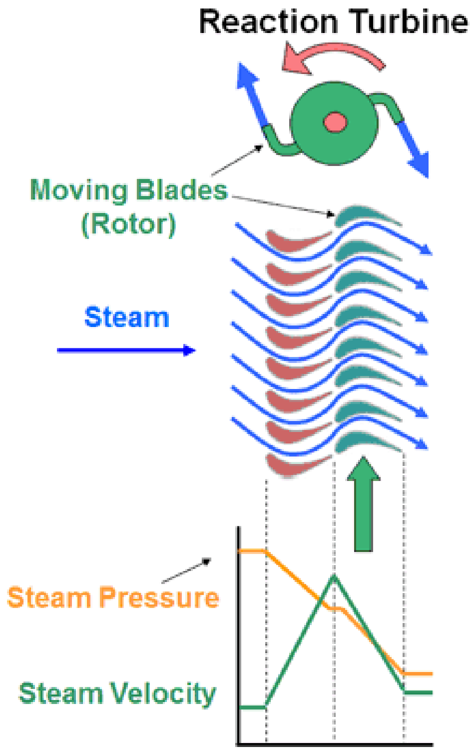
In reaction turbine, steam expands both in fixed and moving blades continuously as the steam passes over them. The pressure drop and heat drop occurs continuously over both moving and fixed blades.

The example for reaction turbine is Parson’s turbine.

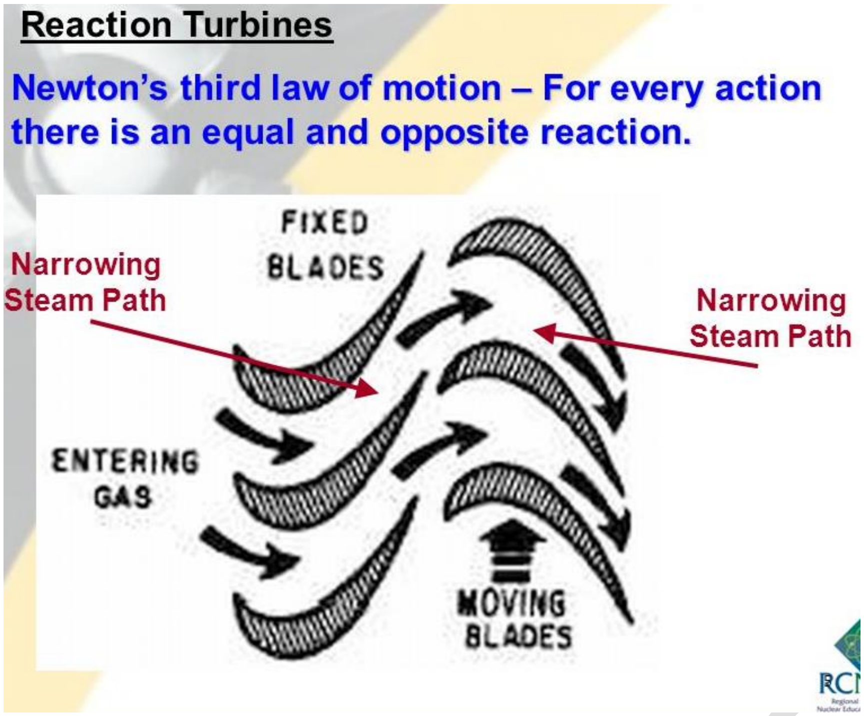
The steam expands while flowing over the moving blades and thus gives reaction to the moving blades.

Hence this turbine is known as reaction turbine

Number of stages, each stage consisting of set of fixed and moving blades.

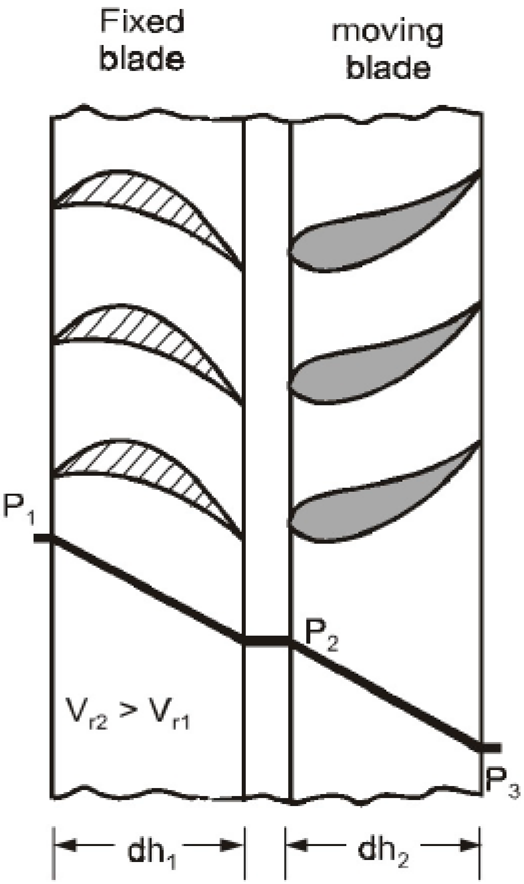


4. 5 .1 Velocity Diagram for Reaction Turbine



Reaction Turbines

Newton's third law of motion – For every action there is an equal and opposite reaction.



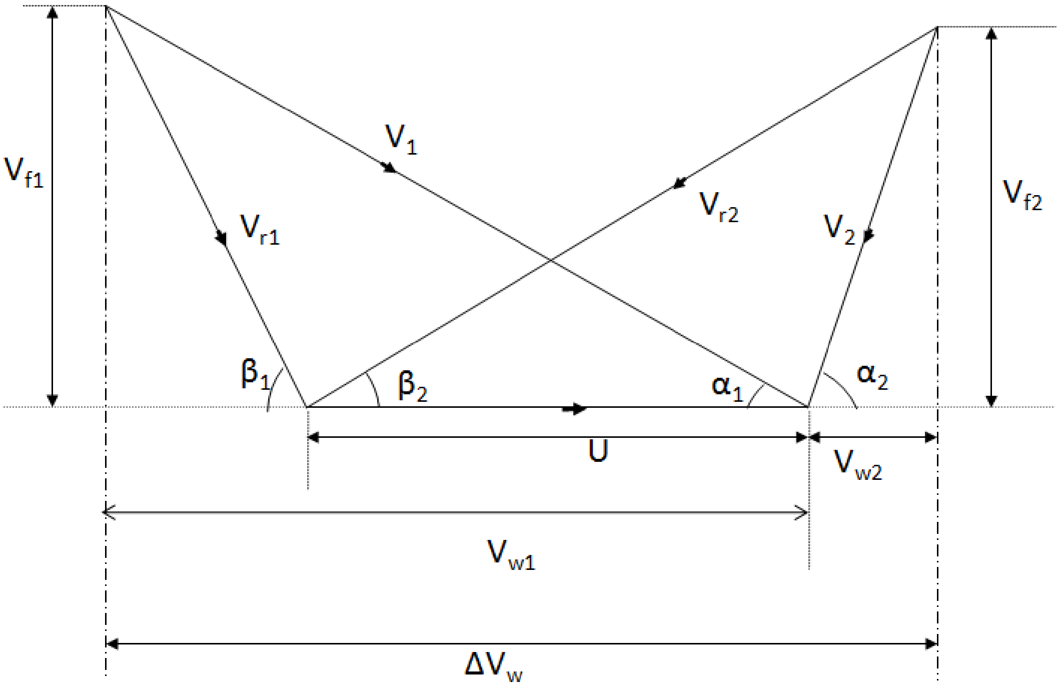


Figure 4.10: Schematic Diagram of Reaction Turbine

4. 5 .2 Degree of Reaction

The degree of reaction is defined as the ratio of isentropic heat drop in the moving blades to isentropic heat drop in the entire stage of reaction turbine.

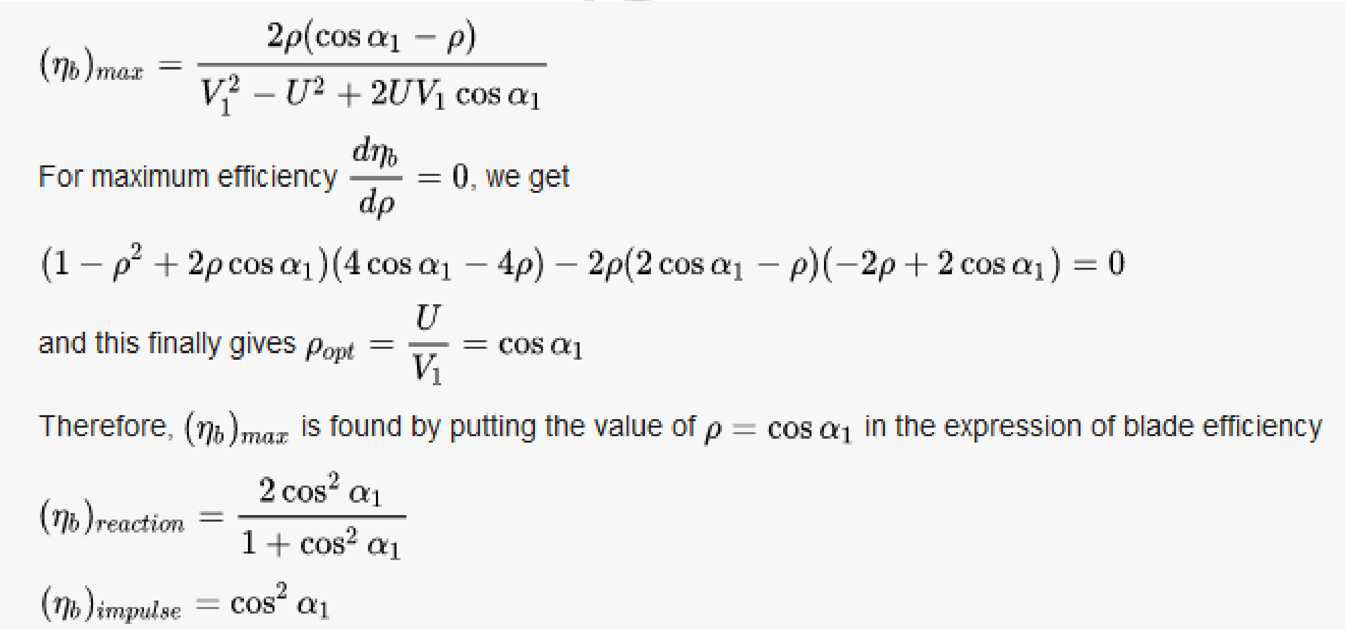
$$\text{Degree of reaction} = \frac{\Delta h \text{ in moving blade}}{\Delta h \text{ in moving blade} + \Delta h \text{ in fixed blade}}$$

A very widely used design has half degree of reaction or 50% reaction and this is known as **Parson's turbine**. This consists of symmetrical rotor and stator blades. For this turbine the velocity triangle is similar and we have:

$$\alpha_1 = \beta_2 , \beta_1 = \alpha_2$$

$$V_1 = V_{r2} , V_{r1} = V_2$$

4. 5 .3 Comparing Efficiencies of Impulse and Reaction turbines



$$(\eta_b)_{max} = \frac{2\rho(\cos\alpha_1 - \rho)}{V_1^2 - U^2 + 2UV_1\cos\alpha_1}$$

For maximum efficiency $\frac{d\eta_b}{d\rho} = 0$, we get

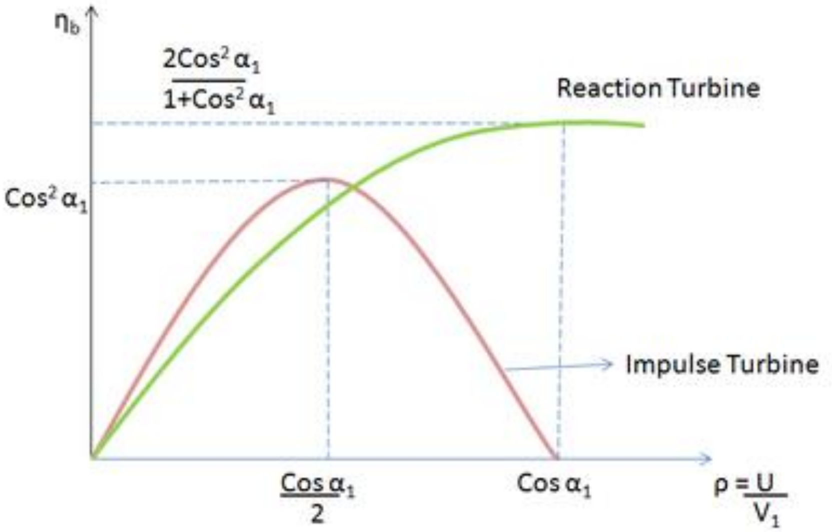
$$(1 - \rho^2 + 2\rho\cos\alpha_1)(4\cos\alpha_1 - 4\rho) - 2\rho(2\cos\alpha_1 - \rho)(-2\rho + 2\cos\alpha_1) = 0$$

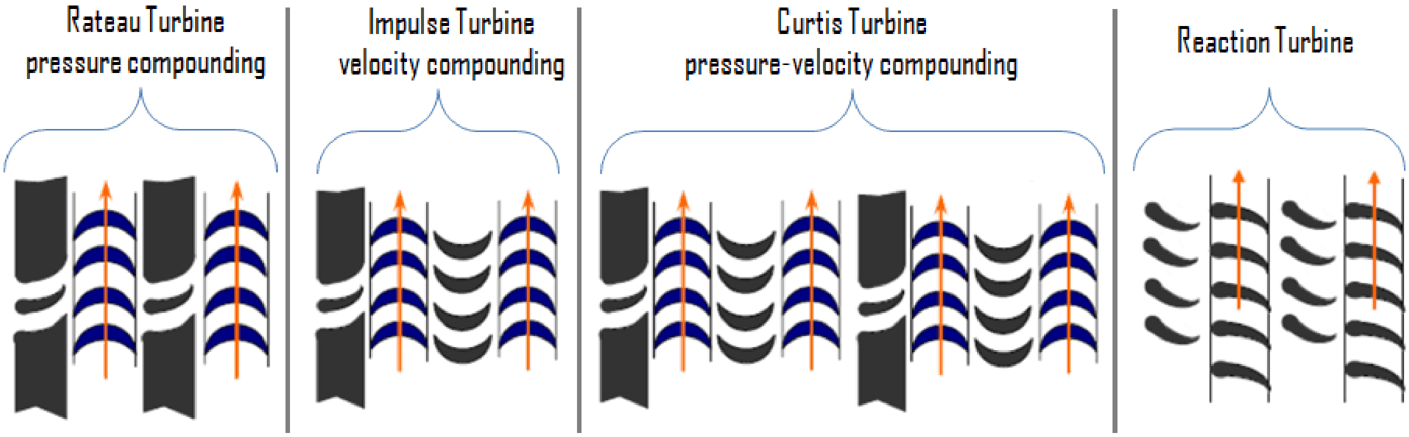
and this finally gives $\rho_{opt} = \frac{U}{V_1} = \cos\alpha_1$

Therefore, $(\eta_b)_{max}$ is found by putting the value of $\rho = \cos\alpha_1$ in the expression of blade efficiency

$$(\eta_b)_{reaction} = \frac{2\cos^2\alpha_1}{1 + \cos^2\alpha_1}$$

$$(\eta_b)_{impulse} = \cos^2\alpha_1$$


η_b
$\frac{2\cos^2\alpha_1}{1+\cos^2\alpha_1}$
Reaction Turbine
$\cos^2\alpha_1$
Impulse Turbine
$\frac{\cos\alpha_1}{2}$
$\cos\alpha_1$
$\rho = \frac{U}{V_1}$


Rateau Turbine
pressure compounding
Impulse Turbine
velocity compounding
Curtis Turbine
pressure-velocity compounding
Reaction Turbine

4. 6 Losses in steam turbines

1. **Admission losses:**

The decrease in kinetic energy is due to the following reasons

- Viscous forces between steam particles
- Heat loss from steam before entering the nozzle
- Deflection of flow in the nozzle
- Boundary layer development in the nozzle
- Turbulence in the nozzle
- The friction in the nozzle

2. **Leakage losses**

3. **Friction losses:** Frictional resistance is offered during flow of steam through nozzles on moving and stationary blades

4. **Exhaust loss:** The energy content of steam is not fully utilized in the turbine. Despite of being at very low pressure the exhaust coming out of the turbine and entering the condenser carries some of kinetic energy and useful enthalpy, which is direct energy loss.

5. **Radiation and convection losses:** The steam turbine operates at a relatively high temperature; therefore some of the heat energy of steam is radiated and convected from the body of the turbine to its surrounding.

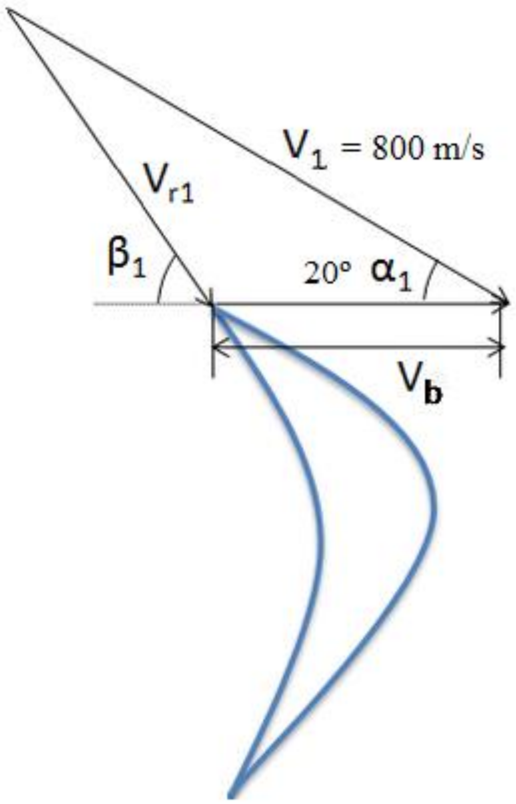
6. Losses due to moisture: The steam passing through the last stage of turbine has high velocity and large moisture content.

EXAMPLE 1

A superheated steam leaves a jet nozzle at 800m/s and with inclined 20º and enters a single stage impulse turbine.

Determine the work output rate of the rotor, the angle of rotor blade and the blade efficiency when the blade rotates at optimum velocity.

<u>SOLUTION</u>:



$$V_B = V_{B,opt} = \frac{V_1 Cos\alpha_1}{2} = \frac{800 * Cos 20}{2}$$

$$V_B = 375.87 m/s$$

$$\dot{W} = 2\dot{m} V_B (V_1 Cos\alpha_1 - V_B)$$

$$W = \frac{\dot{W}}{\dot{m}} = 2V_B (V_1 Cos\alpha_1 - V_B)$$

$$W = 2*375.87(800*Cos20 - 375.87)$$

$$W = 282.55 KJ/Kg$$

$$V_{r1}Cos\beta_1 = V_1 Cos\alpha_1 - V_B$$

$$= 800*Cos20 - 375.87$$

$$V_{r1}Cos\beta_1 = 375.88 \qquad \ldots\ldots\ldots.. 1$$

$$V_{r1}Sin\beta_1 = V_1 Sin\alpha_1$$

$$\therefore V_{r1}Sin\beta_1 = 800*Sin20$$

$$\therefore V_{r1}Sin\beta_1 = 273.61 \qquad \ldots\ldots\ldots\ldots.. 2$$

Dividing 2 to 1 ⇨ $\tan\beta_1 = \frac{273.61}{375.88} = 0.7279$

$\therefore \beta_1 = 36.05^o = \beta_2$ (impulse)

$$V_{r1}Cos36.05 = 375.88$$

$$V_{r1} = 464.8 m/s$$

$$\eta_b = \frac{W}{\frac{1}{2}V_1^2}$$

$$\eta_b = \frac{282.55*1000}{\frac{1}{2}(800)^2}$$

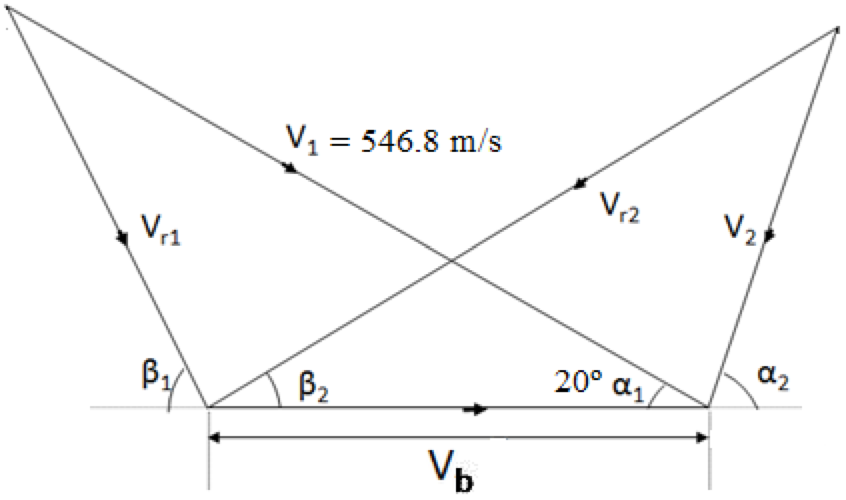
$$\eta_b = 0.8829 = 88.3\%$$

EXAMPLE 2

A steam enter and leave nozzle to an impulse turbine with single stage at 2.5 MPa and 300C° with pressure leave stage at 1.2MPa with 50 kg/s steam flow rate. The steam leave nozzle with angle 20° and speed 546.8m/s. The blade rotates with optimum velocity and has a velocity coefficient of 0.97.

Determine the blade angle, stage power and the efficiencies of blade and stage.

<u>SOLUTION</u>:



$$V_B = V_{B,opt} = \frac{V_1 Cos\alpha_1}{2} = \frac{546.8 * Cos20}{2}$$

$$V_B = 256.9 m/s$$

$$V_{r1} Cos\beta_1 = V_1 Cos\alpha_1 - V_B$$

$$= 546.8 * Cos20 - 256.9$$

$$V_{r1} Cos\beta_1 = 256.9 \quad \ldots\ldots\ldots 1$$

$$V_{r1} Sin\beta_1 = V_1 Sin\alpha_1$$

$$\therefore V_{r1} Sin\beta_1 = 546.8 * Sin20$$

$$\therefore V_{r1} Sin\beta_1 = 187.01 \quad \ldots\ldots\ldots\ldots.. \; 2$$

Dividing 2 to 1 → $\tan\beta_1 = \dfrac{187.01}{256.9} = 0.7279$

$$\therefore \beta_1 = 36.05^o = \beta_2 \text{ (impulse)}$$

$$V_{r1} Cos36.05 = 256.9$$

$$V_{r1} = 317.7 m/s$$

$$V_{r2} = K * V_{r1} = 0.97 * 317.7$$

$$V_{r2} = 308.1 m/s$$

$$V_{r2} Sin\beta_2 = V_2 Sin\alpha_2$$

$$308.1 * Sin36.05 = V_2 Sin\alpha_2$$

$$\therefore V_2 Sin\alpha_2 = 181.3 \quad \ldots\ldots\ldots.. \; 3$$

$$V_{r2} Cos\beta_2 - V_2 Cos\alpha_2 = V_B$$

$$308.1 * Cos36.05 - V_2 Cos\alpha_2 = 256.9$$

$$V_2 Cos\alpha_2 = -7.8 \quad \ldots\ldots.. \; 4$$

From 3, 4

$$\alpha_2 = -87.53^o = 87.53^o \, clockwise$$

$$V_2 = 181.4 m/s$$

$$\dot{W} = \dot{m} V_B (V_1 Cos\alpha_1 - V_2 Cos\alpha_2)$$

$$\dot{W} = 50 * 256.9(546.8 * Cos 20 - 181.4 * Cos 87.53)$$

$$\dot{W} = 6.5 MW$$

$$\eta_b = \frac{\dot{W}}{\frac{1}{2}\dot{m} V_1^2}$$

$$\eta_b = \frac{6.5 * 10^6}{\frac{1}{2} * 50 * (546.8)^2}$$

$$\eta_b = 0.869 = 86.9\%$$

$$\eta_s = \frac{\dot{W}}{\dot{m}\Delta h_s}$$

- Nozzle Inlet → p_N = 2.5 MPa, T_N = 300ºC } h_N = 3008.81 kJ/kg, s_N = 6.6437 kJ/kg. K

- Nozzle Outlet (Blade inlet) → p_B = 1.2 MPa, $s_N = s_B$ = 6.6437 } h_B = 2842.7 kJ/kg

$$\Delta h_s = h_N - h_B$$

$$= 3008.81 - 28427$$

$\Delta h_s = 166.11$ kJ/kg

$$\therefore \eta_s = \frac{\dot{W}}{\dot{m}\,\Delta h_s} = \frac{6.5*10^6}{50*166.11*1000}$$

$$\therefore \eta_s = 0.782 = 78.2\%$$

EXAMPLE 3

A Superheated steam leave nozzle to a reaction turbine at 400m/s with inclined 25º. Steam strikes the rotor blade of 2m, 1m at tip and root diameter respectively. The reaction turbine operates with maximum velocity at tip blade. Determine :

1. The No. of revaluation per minutes of the rotor blade
2.The angle of blade rotor at tip , mean and root
3. The work done per unit mass at the mean diameter.

SOLUTION:

SOLUTION.1

$$V_B = V_{B,opt} = V_1 Cos\alpha_1 = 400 * Cos 25$$

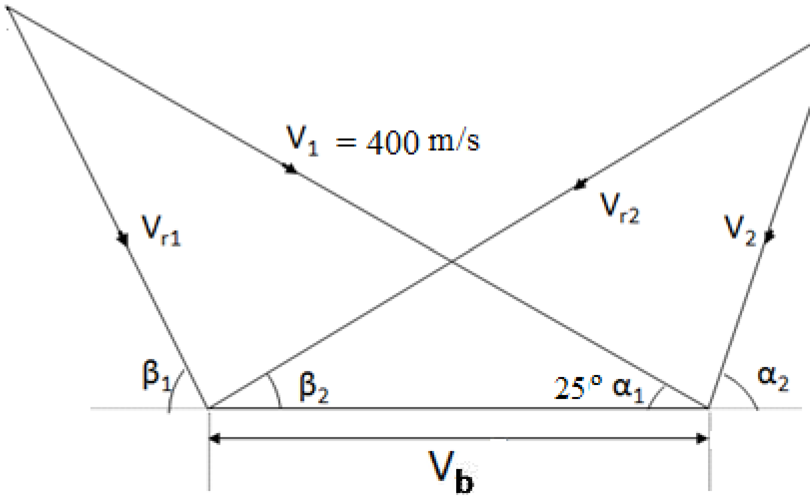
$V_B = 362.5 m/s$ (at tip)

$$V_{B,opt} = \frac{\pi DN}{60}$$

$$362.5 = \frac{\pi * 2 * N}{60}$$

$$N = 3461.6 r.p.m$$

SOLUTION.2



At 50% reaction turbine → $\beta_1 = 90^o$ At optimum V_b

$$\beta_2 = \alpha_1$$

$$V_{r1} = V_2$$

$$V_{r2} = V_1$$

↓ at tip

$$\therefore V_{r2} = V_1 = 400 m/s$$

$$V_{r1} Sin\beta_1 = V_1 Sin\alpha_1$$

$$\therefore V_{r1} Sin90 = 400 * Sin25$$

$$\therefore V_{r1} = 169.09 m/s = V_2$$

at mean point

D_m=1.5m

$$V_B = \frac{\pi DN}{60}$$

$$V_B = \frac{\pi * 1.5 * 3461.6}{60}$$

$$V_B = 271.8 m/s$$

$$V_1 Cos\alpha_1 - V_B = V_{r1} Cos\beta_1$$

$$400 Cos 25 - 271.8 = V_{r1} Cos\beta_1$$

$$90.723 = V_{r1} Cos\beta_1$$

$$V_1 Sin\alpha_1 = V_{r1} Sin\beta_1$$

$$400 Sin 25 = V_{r1} Sin\beta_1$$

$$169.04 = V_{r1} Sin\beta_1$$

$\beta_1 = 61.7^o = \alpha_2$ at mean point

$$\because 169.04 = V_{r1} Sin 61.7$$

$$\therefore V_{r1} = 192 m/s = V_2$$

at root point

D_r=1 m

$$V_B = \frac{\pi DN}{60}$$

$$V_B = \frac{\pi * 1 * 3461.6}{60}$$

$$V_B = 181.2 m/s$$

$$V_1 Cos\alpha_1 - V_B = V_{r1} Cos\beta_1$$

$$400 Cos 25 - 181.2 = V_{r1} Cos\beta_1$$

$$181.323 = V_{r1} Cos\beta_1$$

$$V_1 Sin\alpha_1 = V_{r1} Sin\beta_1$$

$$400 Sin 25 = V_{r1} Sin\beta_1$$

$$169.04 = V_{r1} Sin\beta_1$$

$\beta_1 = 43^o$ at mean point

$$\because 169.04 = V_{r1} Sin 43$$

$$\therefore V_{r1} = 247.86 m/s = V_2$$

$\beta_2 = \alpha_1 = 25^o$ at tip , mean and root

SOLUTION.3

At mean point

$$\frac{\dot{W}}{\dot{m}} = V_B (2 V_1 Cos\alpha_1 - V_B)$$

$$\frac{\dot{W}}{\dot{m}} = 271.8(2 * 362.5 - 271.8)$$

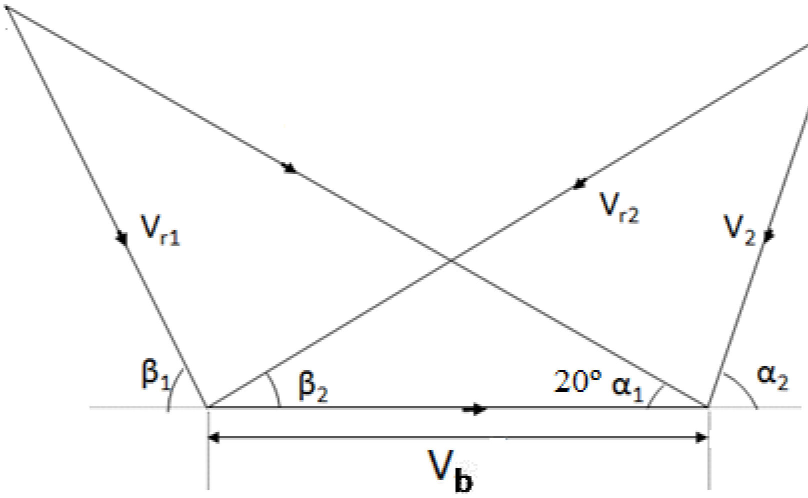
$$\frac{\dot{W}}{\dot{m}} = 123.18 KJ/Kg$$

EXAMPLE 4

A steam enters and leaves a 50% reaction turbine with four stages. Steam operated with 10 MPa and 600C° at inlet and 100 KPa at outlet.

Nozzle inclined with 20°. Determine the work output in KJ per unit mass and the rotor angles.

<u>SOLUTION</u>:



- ❖ Turbine Inlet ⟹ p_{Ti} = 10 MPa, T_{Ti} = 600°C $\Big\}$ h_i = 3625.34 kJ/kg, s_i = 6.9028 kJ/kg. K

- ❖ Turbine Outlet ⟹ p_{To} = 1.2 MPa, $S_o = S_i$ = 6.9028 $\Big\}$ S_f = 1.3025 kJ/kg. K, S_{fg} =6.0568 kJ/kg. K

$$S = S_f + X\, S_{fg}$$

$6.9028 = 1.3025 + X \quad 6.0568$

$X = 0.924$

$h_o = h_f + X\, h_{fg}$

$h_o = 417.44 + 0.924(2258.02)$

$h_o = 2503.8$ kJ/kg

$(\Delta h)_{tot} = h_i - h_o$

$= 3625.34 - 2503.8$

$(\Delta h)_{tot} = 1121.54$ kJ/kg Work output

$$(\Delta h)\text{stage} = \frac{(\Delta h)\text{tot}}{n}$$

$$(\Delta h)\text{stage} = \frac{1121.54}{4}$$

$$(\Delta h)\text{stage} = 280.38 \text{ kJ/kg}$$

$$(\Delta h)\text{stator} = (\Delta h)\text{rotor} = \frac{(\Delta h)\text{stage}}{2}$$

$$(\Delta h)\text{stator} = (\Delta h)\text{rotor} = 140.19 \text{ kJ/kg}$$

$$(\Delta h)\text{stator} = \frac{V_1^2}{2}$$

$$140190 = \frac{V_1^2}{2}$$

$$V_1 = 529.5 m/s$$

$$V_B = V_{B,opt} = V_1 Cos\alpha_1 = 529.5 * Cos 20$$

$$V_{B,opt} = 497.5 m/s$$

At 50% reaction turbine ⇨ $\beta_1 = 90^o$

$$\beta_2 = \alpha_1 = 20^o$$

Power Plant Engineering TUTORIAL SHEET - 4
Steam Turbine

الجامعه المستنصريه – كليه الهندسه
قسم الهندسه الميكانيكيه

1- A superheated steam leaves nozzle to an impulse turbine with single stage at 500m/s. The rotor angle is with angle 45º that operated with optimum speed. Determine the work output in KJ per unit mass and the nozzle angle.
Answers: [100 kJ/kg , 26.56º]

2- A single row impulse turbine develops 150 kW at a blade speed of 175 m/s, using 2.27 kg of steam per second. Steam leaves the nozzle at 400 m/s. Velocity coefficient of blades is 0.9. Steam leaves the turbine blades axially. Determine nozzle angle, blade angles at entry and exit.

3- A steam expands with ideal operation in a 50% reaction turbine. Steam operated with 15 MPa and 600Cº at inlet to 20 KPa at outlet. The turbine operates at an optimum speed of 500m/s knowing that the nozzle inclination angle is 20º. How many stages should be used?. Also determine the work output per unit mass of steam for one stage.
Answers: 5 stages, 276.588kJ/kg

4- A steam with 100 kg/s expands with ideal operation in a 50% reaction turbine. Steam operated with 5 MPa and 400Cº at inlet to 50 KPa at outlet. The nozzle inclination angle is 25º. The turbine operates at an optimum speed of 450m/s. Determines the number of stages should be used and the output power.
Answers: 4 stages, 88.636 MW

5 -In one stage of a reaction steam turbine, both the fixed and moving blades have inlet and outlet blade tip angles of 35 º and 20 º respectively. The mean blade speed is 80 m/s and the steam consumption is 22500 kg/hr. Determine the power developed and stage efficiency if the isentropic heat drops in both fixed and moving rows is 23.5 kJ/kg in the pair.

Answers: 125 kW, 85.1%