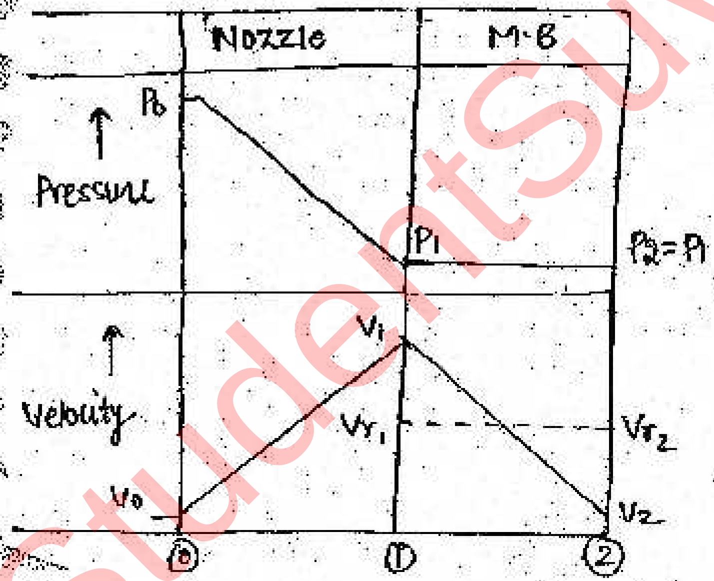
# STEAM TURBINE :-

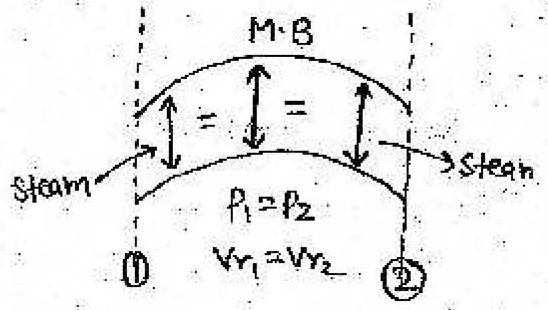
It is a prime mover which convert heat energy of steam into mechanical work which is utilised for electricity generation. Steam turbine used are axial flow in order to handle large volume of steam for heavy power requirement.

## Classification :-

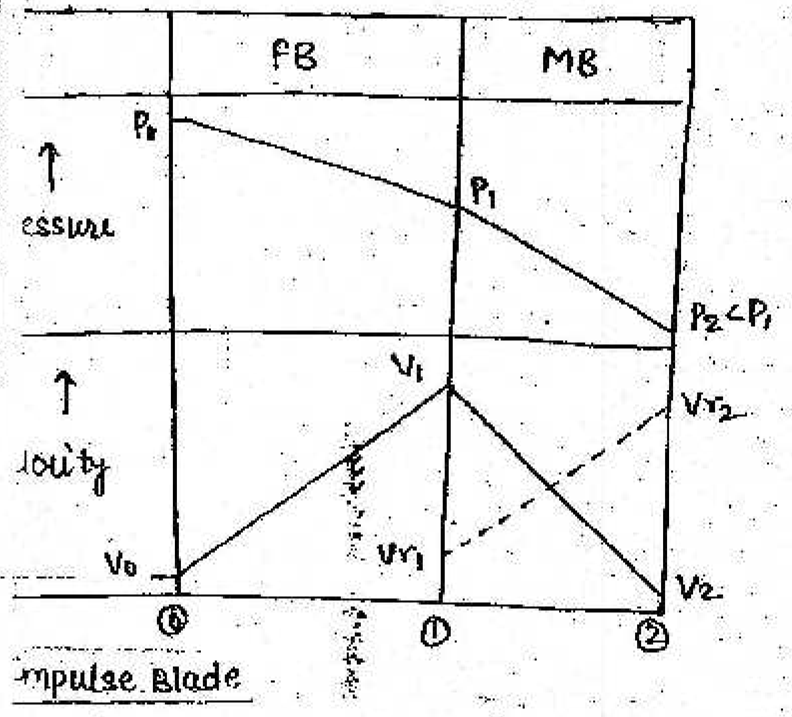
### Based on working principle :-

$\boxed{\text{Impulse}}$

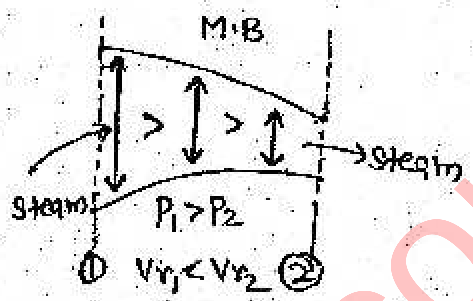


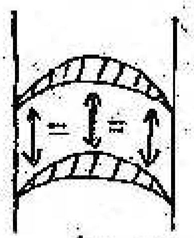



## Reaction




Impulse Blade



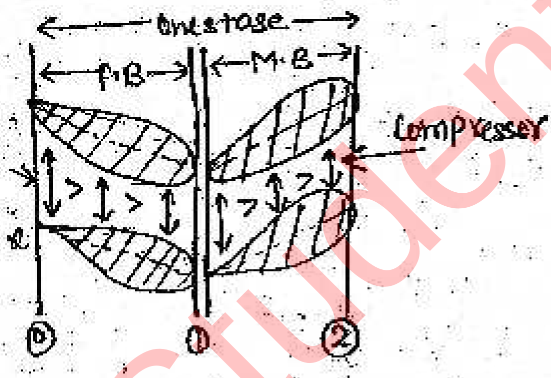
(Profile type)

Axial Flow compressor

$$\boxed{(V_{w_2} - V_{w_1})u = \left(\frac{V_2^2 - V_1^2}{2}\right) + \left(\frac{V_{r_1}^2 - V_{r_2}^2}{2}\right)}$$

Steam Turbine

$$\boxed{(V_{w_1} - V_{w_2})u = \underbrace{\left(\frac{V_1^2 - V_2^2}{2}\right)}_{\text{Impulse}} + \underbrace{\left(\frac{V_{r_2}^2 - V_{r_1}^2}{2}\right)}_{\text{Reaction}}}$$




Aerofoil type
unsymmetrical

For impulse turbine :- $V_{r_1} = V_{r_2}$

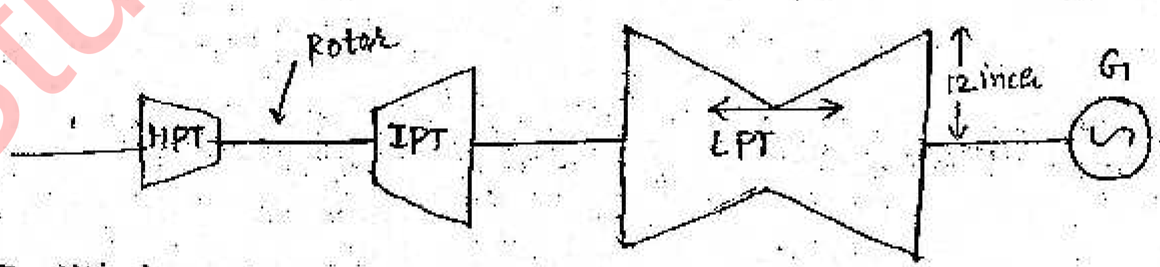
$$\boxed{(V_{w_1} - V_{w_2})u = \left(\frac{V_1^2 - V_2^2}{2}\right)}$$

| Impulse | Reaction |
| --- | --- |
| Pressure drop takes place only in the nozzle and there is no pressure drop in the moving blade. | Pressure drop takes place both fixed as well as moving blade |
| The x-sectional passage b/w the blade is kept constant from inlet to outlet. | The blade x-sectional passage is made converging type from inlet to outlet. |
| Profile type symmetrical blade are used. | Aerofoil type unsymmetrical blade are used. |
| Power developed and $\eta$ is less. | power developed and $\eta$ is more. |
| Blade design and manufacturing is simple so impulse stages are cheaper. | Blade design and manufacturing is complicated so the reaction stages are costly. |
| Partial admission of steam through nozzle. | Alround admission of steam through fixed blade. |
| preferred for small power need with low investment. | Preferred for large power need with heavy investment. |

## Based on shaft orientation :-

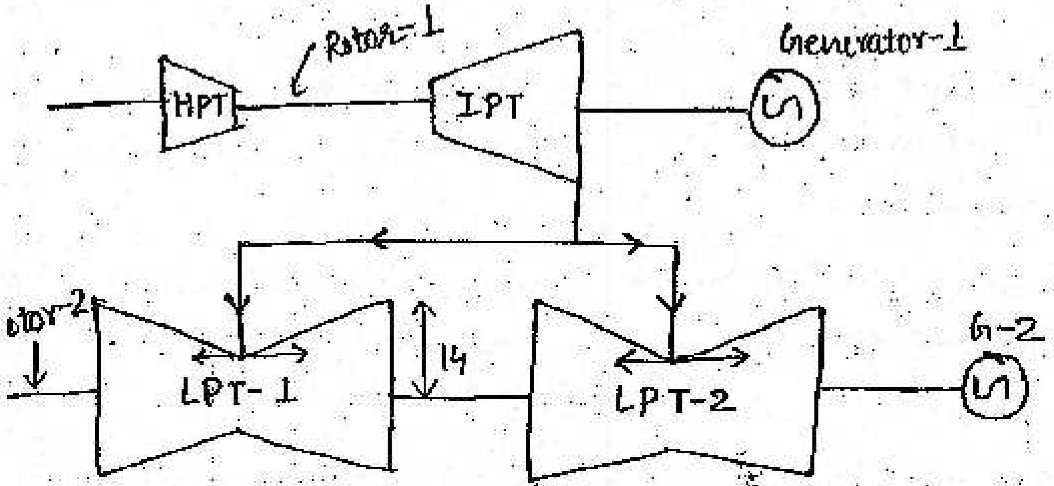
① Tandem compounded (TC)

TC2F12




In this type of assembly all the turbines are connected to a single Rotor attached to a single generator.

2) Cross compounded (CC) :-




In this type of assembly two seperate shaft are used to run two seperate Generator normally at different speed. It is preferred where volume to be handled in the lower stages is large.

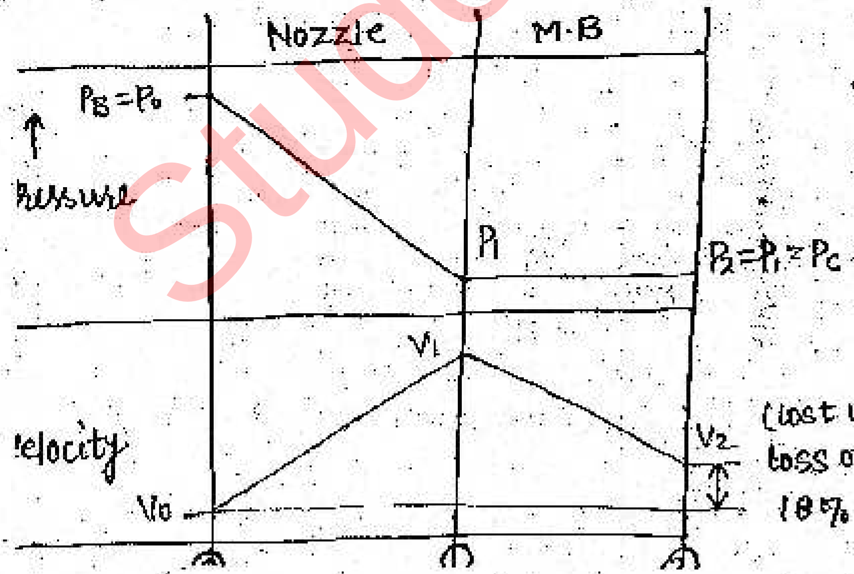
Turbine specification :-

Turbine specified by shaft orientation followed by steam flow path for LPT and finally LPT last stage blade height in inch.

Ex:- for above $\boxed{CC4F14}$

## IMPULSE TURBINE :-

1) Simple Impulse (Delaval Turbine) :-




$\boxed{V \propto \sqrt{\Delta P}}$

$V_1 \approx 1100$ to $1200$ m/s

$u = \frac{V_1}{2} \approx 550$ to $600$ m/s

$u = \frac{\pi D N}{60}$

$N = 15000$ to $30000$ rpm

(lost velocity) loss of velocity 10% to 20%

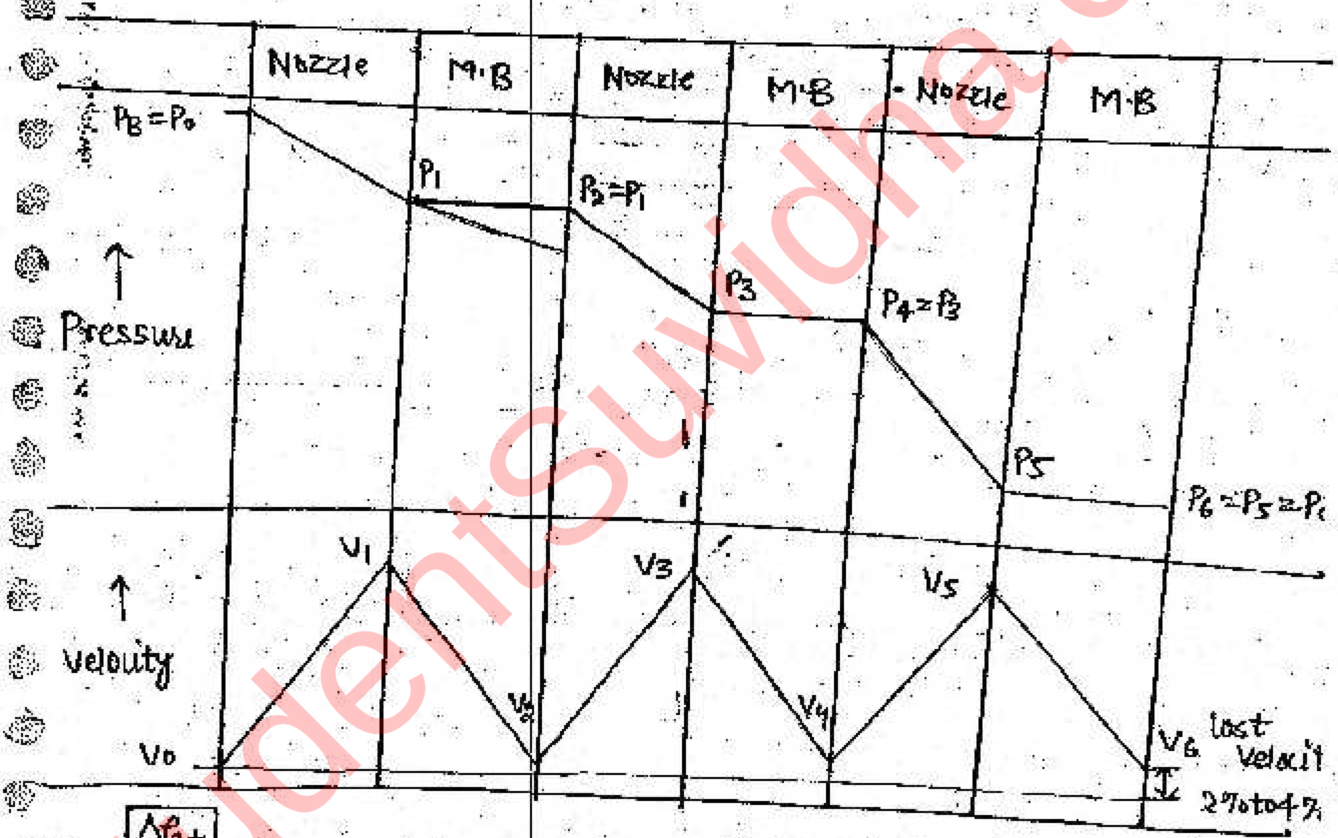
Due to high rpm it is not practically used

It is a first working impulse turbine and it is consist of single set of nozzle and moving blade. The total enthalpy drop takes place in a single nozzle which gives high (very) rotational speed exceeding much above the practical limit of electricity generation.

## Compounding of impulse turbine :-

It is a method to decrease high rotational speed of single impulse turbine to bring into practical limit for electricity generation.

(a) Pressure compounded (Rateau turbine) →




$\boxed{\Delta h_t}$

For Delaval $\quad V \propto \sqrt{\Delta h_t}$

For Rateau $\quad$ 4 stages

$$\Delta h_s = \frac{\Delta h_t}{4}$$

$$V' \propto \sqrt{h_s}$$

$$V' \propto \sqrt{\frac{\Delta h_t}{4}}$$

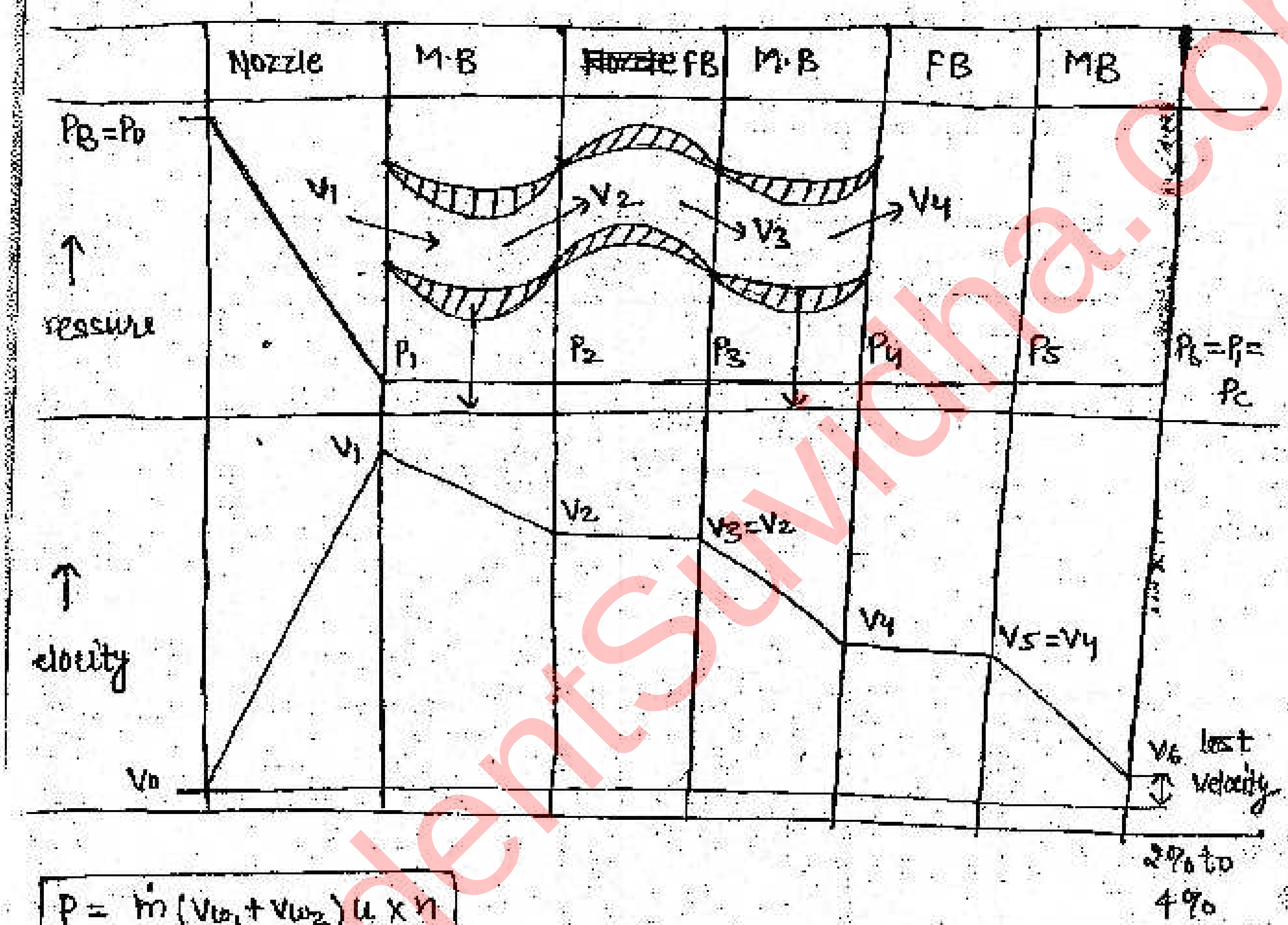
$$\boxed{V' \propto \frac{V}{2}}$$

If n stages of pressure compounded

$$\boxed{V_{Rateau} = \frac{V_{Delaval}}{\sqrt{n}}}$$

In this type of turbine compounding is done for the pressure of steam i.e total pressure drop is arranged in more than one stages and it stage consist of a set of nozzle and moving blade. As the enthalpy drop in each stages is less it decreases the rotational speed to the practical limit.

b) <u>Velocity compounded (Curtis Turbine)</u> :- [theoretically more efficient than pressure compounded]




$$\boxed{P = \dot{m}(V_{w_1} + V_{w_2})u \times n}$$

In this type of turbine compounding is done for the velocity of steam i.e total velocity drop is arranged in more than one stage and each stage consist of a set of fixed and moving blade. There is a single nozzle in which total pressure drop takes place and the high kinetic energy is converted into work in more than one stages.

(1) Simple Impulse → Deleval

(2) Pressure compounded → Rateau

(3) velocity compounded → Curtis

(4) 50 % Reaction → Parson's

(5) 100 % Reaction → Hero's

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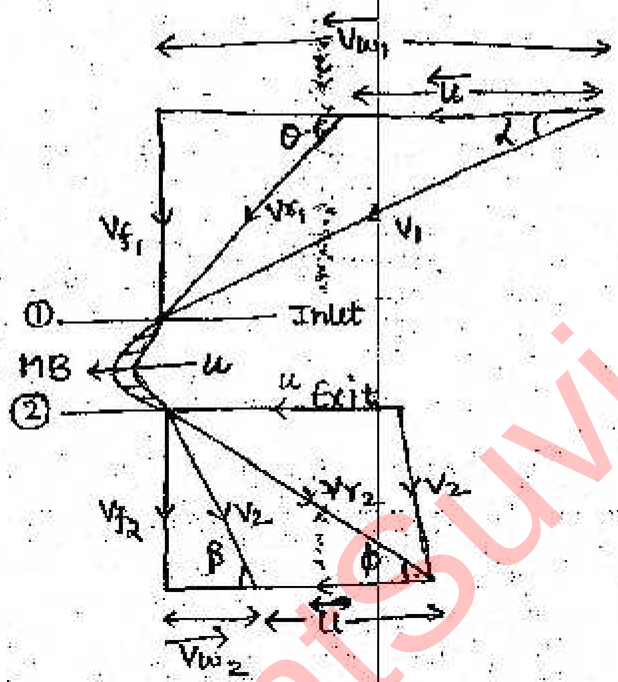
Velocity Diagram for impulse turbine :-




where $\alpha$ is known as nozzle angle or fixed blade outlet angle or absolute velocity angle at inlet

$\beta$ → fixed blade inlet angle or absolute velocity angle at outlet

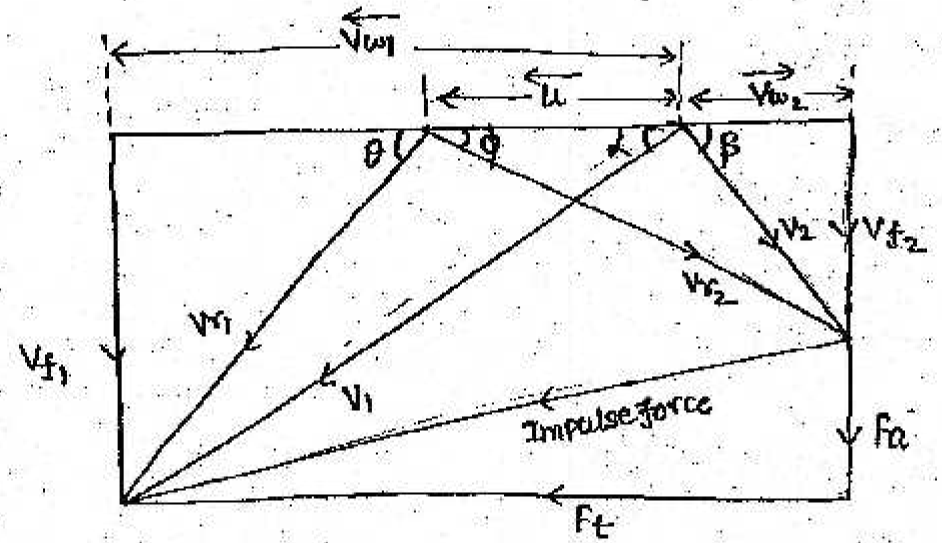
$\theta$ and $\phi$ → blade angle at inlet and outlet.

(✱) Blades are symmetrical or Equiangular

$$\boxed{\theta = \phi}$$

(✱) Blades are frictionless

$$\boxed{V_{r_1} = V_{r_2}}$$




If friction then,

$V_{r2} < V_{r1}$

$\boxed{V_{r2} = K V_{r1}}$

$\boxed{K \approx 0.85 \text{ to } 0.95}$

$W|_{st} = \dot{m}(V_{w1} - V_{w2})u$

but as $V_{w2}$ is opposite in direction.

$\boxed{W|_{st} = \dot{m}(V_{w1} + V_{w2})u}$

If n stages of equal work

$\boxed{W_{total} = \dot{m}(V_{w1} + V_{w2})u\,n}$

(Rim power or Blade power or Diagram power)

(c) Axial force or thrust :-

$\boxed{F_a = \dot{m}(V_{f1} - V_{f2})}$ Newton

⊛ Tangential force or thrust

$\boxed{F_t = \dot{m}(V_{w1} + V_{w2})}$ Newton

⊛ Energy lost in the blade passage due to friction :-

$$= \dot{m}\left(\frac{V_{r1}^2 - V_{r2}^2}{2}\right)$$

⊛ $P = \dot{m}(V_{w1} + V_{w2}) \cdot u$

$\boxed{P = F_t \cdot u}$

PB: A Deleval turbine has a mean rotor Diameter of 0.55 m and it runs at 3300 rpm. The speed ratio is 0.45 $(u/V_1)$ and the nozzle angle at the rotor inlet is 20°. The blade velocity coefficient is 0.91 assuming equiangular blade find the rotor blade angle at inlet and outlet if $\dot{m} = 10$ kg/s. Find the power output and axial thrust.

$N = 3300$ rpm

$D = 0.55$ m

$\rho = \frac{u}{V_1} = 0.45$

$\alpha = 20°$, $K = 0.91$

$\dot{m} = 10$ kg/s

$u = \frac{\pi D N}{60} = 95.03$ m/s

$V_1 = 211.2$ m/s

$V_{w_1} = V_1 \cos\alpha = 198.45$ m/s

$V_{f_1} = V_1 \sin\alpha = 72.23$ m/s

① $\tan\theta = \frac{V_{f_1}}{V_{w_1} - u}$

$\boxed{\theta = 34.93° = \phi}$

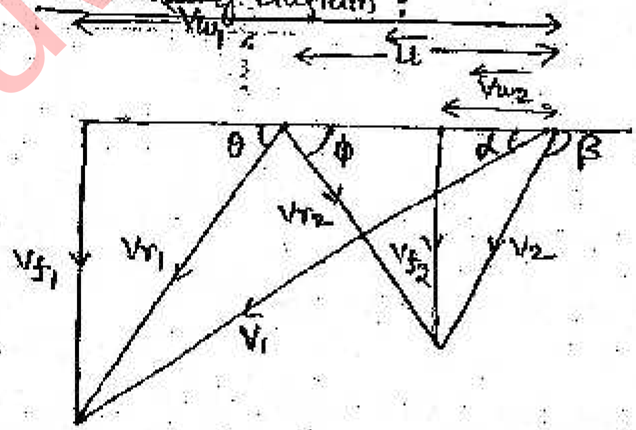
② $\sin\theta = \frac{V_{f_1}}{V_{r_1}} \Rightarrow V_{r_1} = 126.16$ m/s

$V_{r_2} = K V_{r_1} = 114.73$ m/s

$V_{w_2} = V_{r_2}\cos\phi - u$

$V_{w_2} = -0.92$ m/s [∵ $V_{w_2}$ is -ve]

∴ New velocity diagram:




③ $F_a = \dot{m}(V_{f_1} - V_{f_2})$

$\sin\phi = \frac{V_{f_2}}{V_{r_2}}$

$V_{f_2} = 65.73$ m/s

$F_a = 10(72.23 - 65.73)$

$\boxed{F_a = 65\ N}$

$V_{w_2} = u - V_{r_2}\cos\phi = 0.92$ m/s

$P = 10(198.45 - 0.92) \times 95.03$

$\boxed{P = 187.5\ kW}$

## Blade or Diagram efficiency :-

It is the ratio of workdone by the blade to the actual power at the inlet of blade

$$\eta_b = \frac{\text{Blade power}}{\text{K.E at inlet of Blade}} = \frac{\dot m (V_{w_1}+V_{w_2})u}{\dot m \frac{V_1^2}{2}}$$

$$\boxed{\eta_b = \frac{2(V_{w_1}+V_{w_2})u}{V_1^2}}$$

## Condition for maximum blade efficiency :-

Anything you want to be proof convert it in $(V_1, u, \alpha)$.

$$V_{w_1} + V_{w_2} = V_{r_1}\cos\theta + V_{r_2}\cos\phi$$

$$= V_{r_1}\cos\theta \left[1 + \frac{V_{r_2}}{V_{r_1}}\frac{\cos\phi}{\cos\theta}\right]$$

$\boxed{\frac{V_{r_2}}{V_{r_1}} = K}$ & let $\boxed{x = \frac{\cos\phi}{\cos\theta}}$

$$(V_{w_1}+V_{w_2}) = V_{r_1}\cos\theta\,[1+Kx]$$

$\rightarrow$

$$V_{r_1}\cos\theta = V_{w_1} - u$$

$$V_{r_1}\cos\theta = (V_1\cos\alpha - u)$$

$\therefore$

$$(V_{w_1}+V_{w_2}) = (V_1\cos\alpha - u)(1+Kx)$$

$$\eta_b = \frac{2u(V_1\cos\alpha - u)(1+Kx)}{V_1^2}$$

$$\eta_b = \frac{2(V_1 u\cos\alpha - u^2)(1+Kx)}{V_1^2}$$

$\boxed{\rho = \frac{u}{V_1}}$ (speed ratio) $\Rightarrow$ $\boxed{u = \rho V_1}$

$$\eta_b = 2(\rho\cos\alpha - \rho^2)(1+Kx)$$

For $\max^m$ $\eta_b$, $\frac{d\eta_b}{d\rho} = 0$

$$\cos\alpha - 2\rho = 0$$

$$\boxed{\rho_{opt} = \frac{\cos\alpha}{2} = \frac{u}{V_1}}$$

### Maximum efficiency

$$\boxed{(\eta_b)_{max} = \frac{\cos^2\alpha}{2}(1+Kx)}$$

(*) For Symmetrical Blade

$$\theta = \phi \Rightarrow x = 1$$

& for frictionless $V_{r_1} = V_{r_2}$

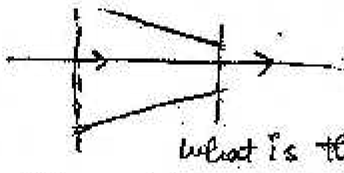
$$K = 1$$

So $\boxed{(\eta_b)_{max} = \cos^2\alpha}$

$\alpha \simeq 15^\circ$ to $20^\circ$ ($18^\circ$)

## Gross stage efficiency :-

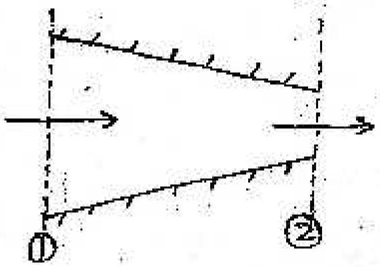
## Nozzle :-



what is this?

Your answer will be nozzle. But this is wrong. converging Section को देख कर यह नहीं कह सकते की यह nozzle है। Always increase in K.E with decrease in pressure is called as nozzle.

### (a) Converging passage ($dA = -ve$)




① Subsonic ($M < 1$)

$(M^2 - 1) = -ve$

$\boxed{dV = +ve}$

$V\uparrow, P\downarrow, T\downarrow, \rho\downarrow, M\uparrow$

(work as nozzle)

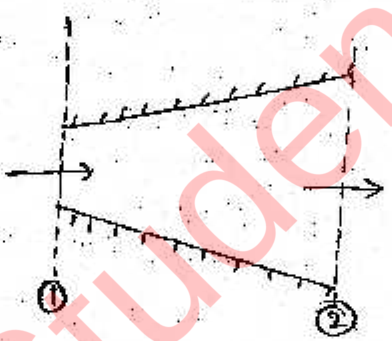
### Mach Number :-

$$M = \frac{\text{Actual velocity}}{\text{Sonic velocity}} = \frac{V}{C}$$

$$\boxed{M = \frac{V}{\sqrt{\gamma RT}}} \qquad \boxed{M = \frac{V_1}{\sqrt{\gamma RT}}}$$

$$\boxed{\frac{dA}{A} = \frac{dV}{V}(M^2 - 1)}$$

### (b) Diverging passage :- ($dA = +ve$)




$\boxed{dV = -ve}$

$V\downarrow, P\uparrow, \rho\uparrow, T\uparrow, \rho, M\downarrow$

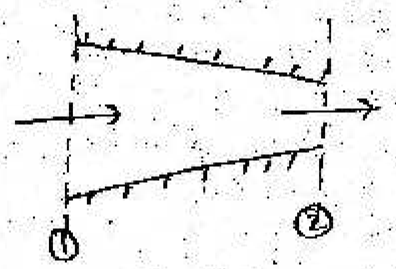
(work as diffuser)

For subsonic compressible flow converging passage act as always nozzle and diverging passage always act as diffuser.

(ii) Supersonic (M > 1)

$(M^2-1) = +ve$

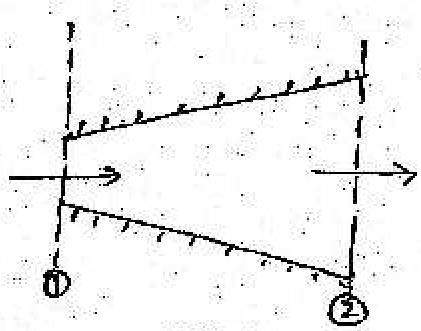
ⓐ Converging passage




$\boxed{dV = -ve}$

V↓ P↑ ρ↑ T↑ M↓

ⓑ Diverging passage




$dV = +ve$

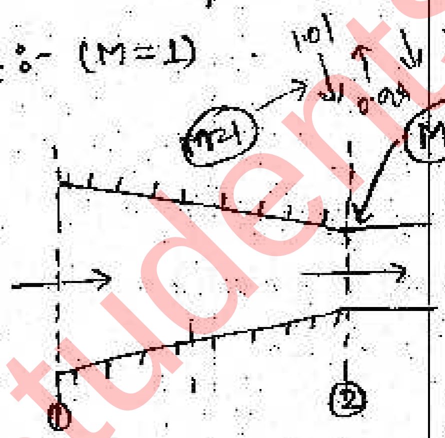
V↑, P↓, ρ↓, T↓, M↑

For supersonic compressible flow converging passage always act as diffuser and diverging passage act as nozzle.

NOTE :- for incompressible fluid converging passage always act as nozzle and diverging passage always work as diffuser.

③ Sonic :- (M=1)

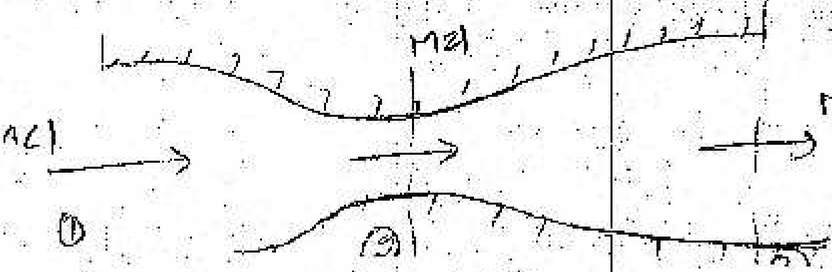
(dA=0)




यहीं पर मिलेगा | और कहीं M=1 नहीं मिलेगा |

कभी भी converging passage से sonic से ज्यादा velocity नहीं मिल सकती है क्योंकि तो ही supersonic velocity होगी यह work करेगा diffuser की तरह | और velocity घट जायेगी |

Convergent Divergent nozzle

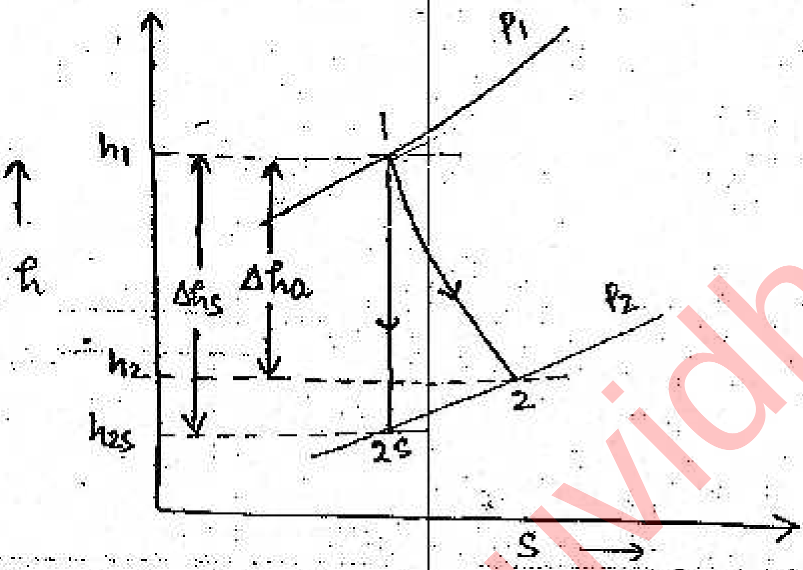



For getting supersonic velocity.

For $M = 1$, $dA = 0$ → this condition correspond to minimum cross-sectional area of the nozzle known as throat.

* At this point mass passing through the nozzle is maximum and is termed as choked nozzle

**Nozzle efficiency:-**




In actual working there is always friction in the nozzle passage due to which actual velocity obtained is less. Nozzle efficiency is defined as the ratio of actual enthalpy drop to the isentropic enthalpy drop possible in a nozzle.

$$\eta_n = \frac{\text{Actual enthalpy drop}}{\text{Isentropic enthalpy drop}}$$

$$\boxed{\eta_n = \frac{\Delta h_a}{\Delta h_s} = \frac{h_1 - h_2}{h_1 - h_{2s}}}$$

$$\eta_n = \frac{\frac{V_2^2 - V_1^2}{2}}{\frac{V_{2s}^2 - V_1^2}{2}}$$

if $V_1 << V_2$

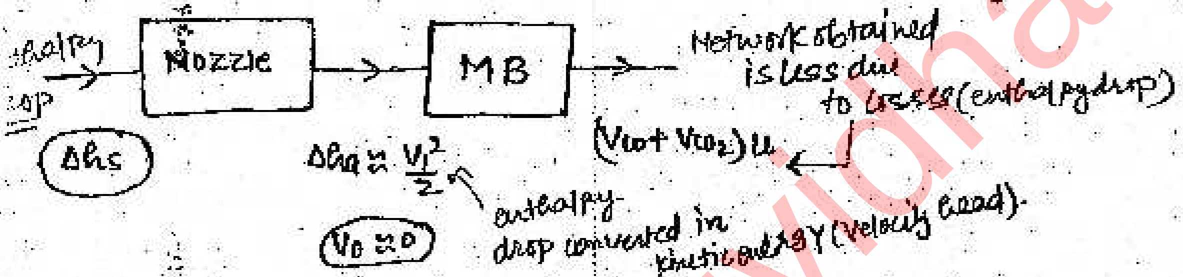
$$\boxed{\eta_n = \frac{V_2^2}{V_{2s}^2}}$$

$V_{2s} > V_2$

## Effects of nozzle friction :-

- Reduction in actual enthalpy drop. $\downarrow\downarrow \dot{m} = \downarrow\rho A V\downarrow = \frac{A \cdot V\downarrow}{v\uparrow}$
- Reduction in exit velocity of fluid.
- Increase in dryness fraction.
- Increase in specific volume ($\uparrow$ density decreases)
- Decrease in mass flow rate.
- Increase in entropy.

## Gross stage efficiency :- ($\eta_{gs}$)




→ It is the ratio of actual workdone by the blade in a stage to the total isentropic enthalpy drop possible in a stage.

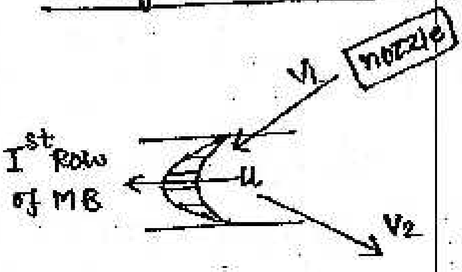
$$\eta_{gs} = \frac{\dot{m}(V_{w1} + V_{w2})u}{\dot{m}\,\Delta h_s}$$

$$\eta_{gs} = \frac{(V_{w1} + V_{w2})u}{\Delta h_s}$$

$$\eta_{gs} = \frac{V_1^2/2}{\Delta h_s} \times \frac{(V_{w1} + V_{w2})u}{V_1^2/2}$$

$$\boxed{\eta_{gs} = \eta_n \times \eta_b}$$

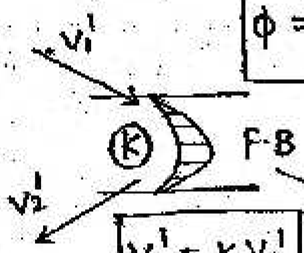
## Carry over coefficient ($\phi$) :- 2 Row curtis (velocity compounded)




$$\phi = \frac{V_1'^2/2}{V_2^2/2}$$

$$\boxed{\phi = \frac{V_1'^2}{V_2^2}}$$

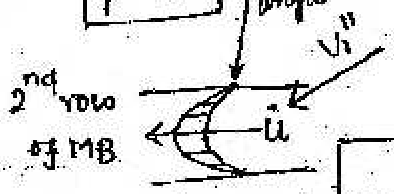
$\boxed{V_1' < V_2}$




$\boxed{V_2' = K V_1'}$

$\phi'$ = outlet blade angle of this fixed blade.

$\boxed{\phi' = \alpha''}$ nozzle angle




$$\boxed{\phi = \frac{V_1''^2}{V_2'^2}}$$

$\boxed{\phi = 0.9 \text{ to } 0.95}$

(*) It takes into account the amount of kinetic energy lost b/w the stages. It is the fraction of kinetic energy which will available for the utilisation in the succeeding stage compare to preceeding stage.

$$\boxed{P = \dot{m}\,(V_{w_1} + V_{w_2} + V''_{w_1} + V''_{w_2})\,u}$$

$$\boxed{\eta_b = \frac{P}{\frac{\dot{m} V_1^2}{2}}}$$

(*) Blade speed remain same for both the row of moving blade and the fixed blade outlet angle becomes the nozzle for the $2^{nd}$ row of moving blade.