AXIAL FLOW TURBINE

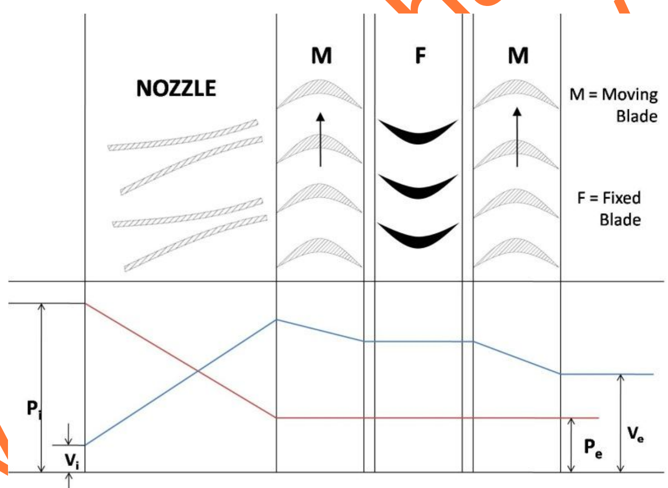
WORKING PRINCIPLE:

Turbine operates on principle of momentum. The high temperature and high pressure gases at the turbine entry are first allowed to accelerate in the nozzle and this high velocity jet is then allowed to impinge on the rotor blade. Hence there occurs momentum transfer from hot .jet to rotor blades and blades will starts rotating.

In stator (nozzle) only energy transfer motion $(\Delta K.E)$ takes place but in rotor both energy transfer and energy transformation at the rotor is possible.

However turbine in which only transfer takes place is known as impulse turbine. The stage in which at the rotor, both transformation and transfer takes place is known as reaction stage.

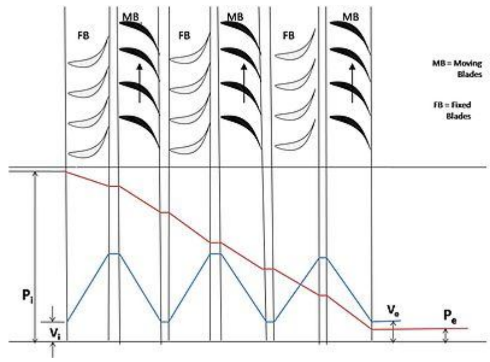
AN IMPULSE STAGE:



The impulse turbine is the turbine in which only energy transfer takes place in the rotor. Thus the absolute velocity in the rotor decreases while static pressure almost remains constant.

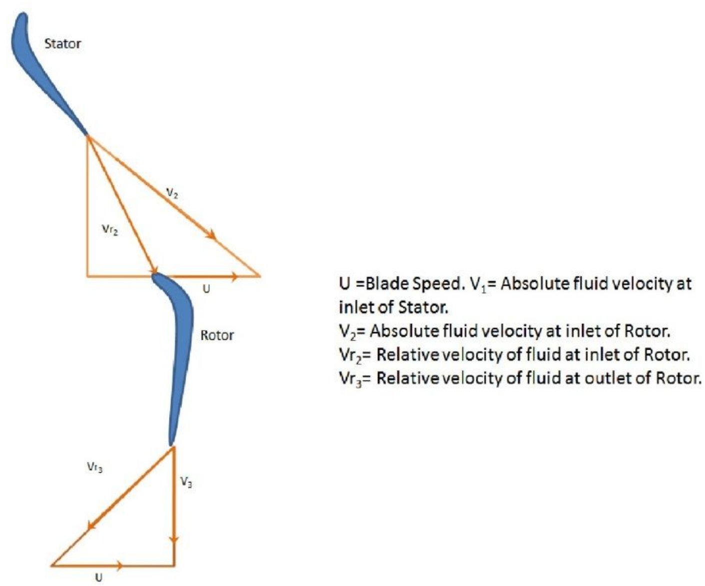
Also as in rotor there is no acceleration adverse pressure gradient will be developed in the rotor which will lead to flow separation hence in impulse turbine separation as well as losses will be more as compare to reaction turbine.

REACTION TURBINE:



In reaction turbine energy transfer as well as energy transformation takes place in the rotor. Hence static pressure also decreases in the rotor part.

VELOCITY TRIANGLES FOR SINGLE STAGE:



As we know from Euler's equation of turbo machines

$$\vec{c} = \vec{u} + \vec{w}$$

By following assumptions of constant peripheral velocity & axial velocity we can write from above diagram

$$c_{a2} = c_2 \cos \propto_2 = w_2 \sin \beta_2$$

$$c_{t2} = c_2 \sin \beta_2 = w_{t2} + u_2$$

$$= w_2 \sin \beta_2 + u_2$$

$$\frac{u}{\sin(\alpha_2 - \beta_2)} = \frac{c_2}{\sin(90 + \beta_2)} = \frac{c_2}{\cos\beta_2}$$

$$\frac{u}{c_2} = \frac{\sin(\alpha_2 - \beta_2)}{\cos\beta_2}$$

$$c_{a3} = w_3 \cos\beta 3 = c_3 \cos \propto_3$$

By using all these equations we can write

$$\boldsymbol{c_{t2} + c_{t3} = w_{t2} + w_{t3}}$$

Hence we can write $\quad \boldsymbol{\tan\alpha_2 + \tan\alpha_3 = \tan\beta_2 + \tan\beta_3}$

This is very important relation for numerical analysis of AFT.

BLADE EFFICIENCY OR UTILIZATION FACTOR:

It is defined as the ratio of work done by the rotor to the work input to the rotor.

Also called as 'Utilization factor'.

$$\varepsilon = \frac{work\ output\ to\ rotor}{work\ input\ to\ rotor}$$

$$Work\ output = u_2 c_{t2} - u_3 c_{t3}$$

For constant u and from orientation of the Ct3 we can say

$$\boldsymbol{Work\ output = u\,(c_{t2} + c_{t3})}$$

MAXIMUM UTILIZATION FOR SINGLE IMPULSE STAGE:

Turbine blade efficiency is also called as utilization factor

It can be defined as

$$\eta_b = \varepsilon = \frac{Rotar\ blade\ work}{Energy\ supplied\ to\ the\ rotor\ blades} = \frac{W}{Erb}$$

As we know from expression of turbine work output is $\boldsymbol{Work\ output = u\,(c_{t2} + c_{t3})}$

& also from Euler's equation we know that

$$\boldsymbol{W = E = \frac{1}{2}\left[\underbrace{\left(C_2{}^2 - C_3{}^2\right)}_{I} + \underbrace{\left(U_2{}^2 - U_3{}^2\right)}_{II} + \underbrace{\left(W_2{}^2 - W_3{}^2\right)}_{III}\right]}$$

But blade energy input is

$$\boldsymbol{E_{rb} = \frac{1}{2}\left[\underbrace{\left(C_2{}^2\right)}_{I} + \underbrace{\left(U_2{}^2 - U_3{}^2\right)}_{II} + \underbrace{\left(W_2{}^2 - W_3{}^2\right)}_{III}\right]}$$

Hence we can say

$$\varepsilon = \frac{\frac{1}{2}\left[\underbrace{\left(C_2{}^2 - C_3{}^2\right)}_{I} + \underbrace{\left(U_2{}^2 - U_3{}^2\right)}_{II} + \underbrace{\left(W_2{}^2 - W_3{}^2\right)}_{III}\right]}{\frac{1}{2}\left[\underbrace{\left(C_2{}^2\right)}_{I} + \underbrace{\left(U_2{}^2 - U_3{}^2\right)}_{II} + \underbrace{\left(W_2{}^2 - W_3{}^2\right)}_{III}\right]}$$

for asumption of

$w_2 = w_2$&u=c

We get $\varepsilon = \frac{u\,(c_{t2}+c_{t3})}{\frac{1}{2}\left[\underbrace{\left(C_2{}^2\right)}_{I}\right]}$

By principle of calculus we can say condition for max. Utilization factor

Is $\sigma_{opt}(speed\ ratio = \frac{u}{c_2})$

MULTISTAGE IMPULSE TURBINE:

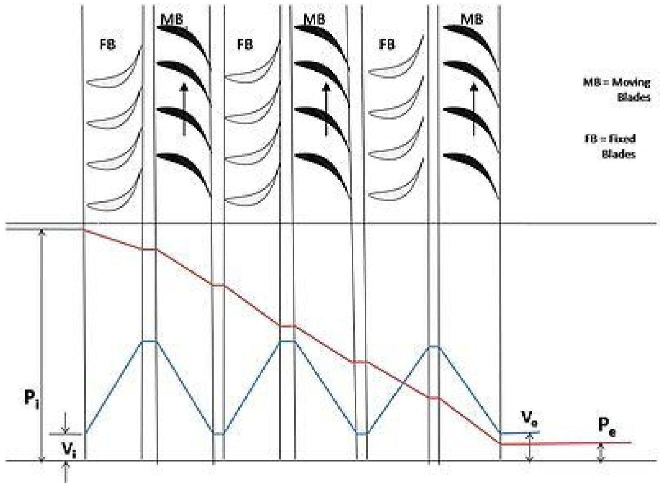
To achieve high pressure drop multi-staging of turbine is done. To do so there are two methods

a. Velocity compounding.
b. Pressure compounding.

VELOCITY COMPOUNDING:

In velocity compounding initially velocity of gases is increased by expanding them through large passage of nozzle blades. This will obviously cause static pressure drop.

There onward energy of the gases transferred through number of rotor and nozzle (stator) stages gradually. Also as turbine is of impulse type after first nozzle (C.N) static pressure remains constant.



OBSERVATION:

1. Velocity drop in rotor blades signifies energy transfer.
2. Velocity drop in stator blades is due to the loss.
3. Such stages are referred to velocity or ……………..stage.

DIFFICULTIES IN VELOCITY COMPOUNDING:

1. Nozzles have to be of convergent divergent type to generate high velocity. This leads to more expensive design of nozzle blade rows.
2. High velocity at the nozzle exit causes higher cascade losses.
3. Shock waves are generated if the flow is supersonic which will further increases the losses.

DIFFICULTIES IN VELOCITY COMPAUNDING:

1. The nozzles have to be convergent-divergent type in order to generate high velocity. This results in a more expensive and difficult design of nozzle blade rows.
2. High velocity at the nozzle exit leads to higher cascade losses.
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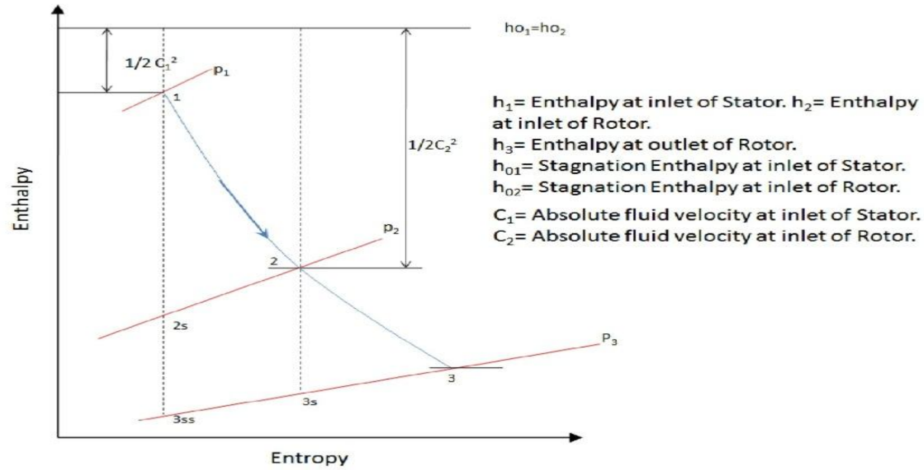
REACTION TURBINE:

Enthalpy-Entropy diagram:



DEGREE OF REACTION:

1. Incompressible fluid:

$$R = \frac{Drag\ in\ static\ pressure\ in\ Rotor}{Drag\ in\ static\ pressure\ in\ stage} = \frac{P_2 - P_3}{P_1 - P_3}$$

2. Compressible fluid:

$$R = \frac{Drag\ in\ static\ enthalpy\ in\ Rotor}{Drag\ in\ static\ enthalpy\ in\ stage} = \frac{h_2 - h_3}{h_1 - h_3}$$

$$R = \frac{C_a}{2u}(\tan\beta_3 - \tan\beta_2)$$

$$R = \frac{1}{2} + \frac{C_a}{2u}(\tan\beta_3 - \tan\alpha_2)$$

$$\boldsymbol{R = 1 + \frac{C_a}{2u}(\tan\alpha_3 - \tan\alpha_2)}$$

THREE DIMENSIONAL FLOWS:

1. Continuity flow (in cylindrical co-ordinates):

$$\frac{\partial\rho}{\partial t} + \frac{1}{r}\frac{\partial(r\rho u_r)}{\partial r} + \frac{1}{r\sin\theta}\frac{\partial(\rho u_z)}{\partial z} = 0$$

2. Momentum equation (radial for cylinder):

$$\rho\left[\frac{\partial u_r}{\partial t} + u_r\frac{\partial u_r}{\partial r} + u_\theta\frac{\partial u_r}{r\partial\theta} - \frac{{u_\theta}^2}{r} + u_z\frac{\partial u_r}{\partial z}\right]$$

$$= -\frac{\partial p}{\partial r} + \mu\left[\frac{\partial}{\partial r}\left\{\frac{1}{r}\frac{\partial(ru_r)}{\partial r}\right\} + \frac{\partial^2 u_r}{r^2\partial\theta^2} + \frac{\partial^2 u_z}{\partial z^2} - \frac{2}{r^2}\frac{\partial u_\theta}{\partial r}\right] + f_x$$

3. Tangential direction:

$$\rho\left[\frac{\partial u_\theta}{\partial t} + u_r\frac{\partial u_\theta}{\partial r} + u_\theta\frac{\partial u_\theta}{\partial \theta} + \frac{u_\theta u_r}{r} + u_z\frac{\partial u_\theta}{\partial z}\right] = -\frac{\partial p}{r\partial\theta} + \mu\left[\frac{\partial}{\partial r}\left\{\frac{1}{r}\frac{\partial(ru_\theta)}{\partial r}\right\} + \frac{\partial^2 u_\theta}{r^2\partial\theta^2} + \frac{\partial^2 u_\theta}{\partial z^2} + \frac{2}{r^2}\frac{\partial u_r}{\partial r}\right] + f_y$$

4. Axial direction:

$$\rho\left[\frac{\partial u_z}{\partial t} + u_r\frac{\partial u_z}{\partial r} + u_\theta\frac{\partial u_z}{\partial \theta} + u_z\frac{\partial u_z}{\partial z}\right] = -\frac{\partial p}{\partial z} + \mu\left[\frac{\partial^2 u_z}{\partial r^2} + \frac{1}{r}\frac{\partial u_z}{\partial r} + \frac{\partial^2 u_z}{r^2\partial\theta^2} + \frac{\partial^2 u_z}{\partial z^2}\right] + f_z$$

ASSUMPTION:

1. Steady.
2. Axis symmetric (w.r.to θ term is zero)
3. Inviscid fluid (μ term are zero)
4. No body forces ($f_x = f_y = f_z = 0$)

∴ Radial direction:

$$\left[u_r\frac{\partial u_r}{\partial r} - \frac{u_\theta^2}{r} + u_z\frac{\partial u_r}{\partial z}\right] = \frac{-1}{\rho}\frac{\partial p}{\partial r}$$

Tangential direction:

$$\left[u_r\frac{\partial u_\theta}{\partial r} + \frac{u_\theta u_r}{r} + u_z\frac{\partial u_\theta}{\partial z}\right] = 0$$

Axial direction:

$$\left[u_r\frac{\partial u_z}{\partial r} + u_z\frac{\partial u_z}{\partial z}\right] = \frac{-1}{\rho}\frac{\partial p}{\partial z}$$

SIMPLIFIED RADIAL EQUILLIBIUM EQUATION:

It is assumed that all the radial motion of the particle takes within the blade raw passage, while in the axial spacing between the successive blade rows radial equilibrium is assumed. Thus the radial component of the velocity is neglected in the spaces between blade rows.

$u_r << u_z \qquad (u_r \approx 0)$

$$\frac{u_\theta^2}{r} = \frac{1}{\rho}\frac{\partial p}{\partial r}$$

Radial equilibrium equation:

$$h_0 = h + \frac{V^2}{2}$$

$$h_0 = h + \frac{u_\theta^2}{2} + \frac{u_z^2}{2}$$

PRESSURE COMPOUNDING: