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SHRIDEVI INSTITUTE OF ENGINEERING & TECHNOLOGY

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SHRIDEVI
EDUCATION

20 YEARS Academic Excellence

DEPARTMENT OF Mechanical Engineering

ASSIGNMENT BOOK

Name	: Mr. / Ms. VIVEKA . E
Course	: B . E
Course Code	: 18ME54
Semester	: V
USN	: 1 S V 2 0 M E 0 0 9

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ASSIGNMENT MARKS

Date	Assignment No.	Max. Marks	Marks Obtained	Course Instructor Signature
12/11/22	1	10	10	
17/11/22	2	10	10	
23/12/22	3	10	10	
8/1/23	4	10	10	
25/1/22	5	10	10	
	Average	10	10	

CERTIFICATE

This is to certify that Kum/ Sri VIVEKA . E

with USN 1SV20ME009 has satisfactorily completed the

Assignments in the subject Turbo Machines

with Subject Code 18ME54 as prescribed by the

Visvesvaraya Technological University for the V semester

B.E. / M.Tech / MBA degree course in the year 2022-2023

Course Instructor

Head of the Department

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Assignment - 1

(1) Define the following Turbomachines
i) Specific speed
ii) Flow co-efficient
iii) Energy co-efficient
iv) Power co-efficient
v) Speed ratio

Soln. i) Specific speed :- Specific speed of a turbine can be defined as "a speed of a geometrically similar machi which produce 1 KW power under a head of 1m"

ii) Flow co-efficient :- The term $\pi_1 = \frac{Q}{ND^3}$ is Flow co-efficient or capacity co-efficient which signifies the volume flo rate of fluid through a turbomachine of unit runn diameter operating at unit speed.

iii) Energy co-efficient :- The term $\pi_2 = \frac{gH}{N^2D^2}$ is called Head co-efficient. It represents the ratio of kinetic energy of the fluid under the head of H to ~~the~~ kinetic energy of the fluid running at the tangen -tial speed of the rotor. For a given machine with some diameter, the head varies directly as square of the tangential speed of rotor or impeller.

iv) <u>power co-efficient</u>: The term $\pi_3 = \frac{P}{\rho N^3 D^5}$ is called power co-efficient or specific power. It represents the relation b/w the power, fluid density, speed and wheel diameter. For a given ~~the~~ machine, the power is directly proportional to the cube of runner speed.

v) <u>Speed ratio</u>:- Speed ratio is defined as the ratio of Tangential velocity of the runner to Theoretical Jet velocity.

$$\phi = \frac{u}{V}$$

Q. The pressure drop Δp in a pipe depends upon the velocity flow (V), length of pipe [L], dia pipe [D] viscosity (μ), density of pipe [ρ], avg height of roughness projection on side of pipe surface [K] by using dimensional analysis obtain an expression for Δp?

Soln

$$\Delta p = f(K, D, L, V, \mu, \rho) \quad \text{—(1)}$$

$$f_1(K, \Delta p, D, L, V, \mu, \rho) = 0$$

Total No of variables are $= 7 = n$

$\Delta p = ML^{-1}T^{-2}$, $D = L$, $l = L$, $V = LT^{-1}$, $\mu = ML^{-1}T^{-1}$

$\rho = ML^{-3}$, K = dimensionless quantity $(M^0L^0T^0)$

Fundamental dimensions (or) repeating variables are 3 ∴ m=3

∴ They are (D, V, ρ)

No of π terms = n−m = ~~7~~−3 = 4

$f_1(\pi_1, \pi_2, \pi_3, \pi_4) = 0$.

$\pi_1 = D^{a_1} V^{b_1} \rho^{c_1} K$

$M^0L^0T^0 = L^{a_1} [LT^{-1}]^{b_1} [ML^{-3}]^{c_1} [L]$

$M \rightarrow 0 = c_1 + 0 \Rightarrow \boxed{c_1 = 0}$ —(1)

$L \rightarrow 0 = a_1 + b_1 - 3c_1 + 1$, from 1 & (2), $\boxed{a_1 = -1}$

$T \rightarrow 0 = -b_1 + 0 \Rightarrow \boxed{b_1 = 0}$ —(2)

$\pi_1 = D^{-1} V^0 \rho^0 K \Rightarrow \boxed{\pi_1 = K/D}$

$\pi_2 = D^{a_2} V^{b_2} \rho^{c_2} \Delta P$

$M^0L^0T^0 = L^{a_2} [LT^{-1}]^{b_2} [ML^{-3}]^{c_2} [ML^{-1}T^{-2}]$

$M \rightarrow 0 = c_2 + 1 \Rightarrow \boxed{c_2 = -1}$,

$L \rightarrow 0 = a_2 + b_2 - 3c_2 - 1$, ∴ $0 = a_2 - 2 + 3 - 1$, $\boxed{a_2 = 0}$

$T \rightarrow 0 = -b_2 - 2 \Rightarrow \boxed{b_2 = -2}$

$\pi_2 = D^0 V^{-2} \rho^{-1} \Delta P \Rightarrow \boxed{\pi_2 = \frac{\Delta P}{\rho V^2}}$

$$\pi_3 = D^{a_3} V^{b_3} \rho^{c_3} L$$

$$M^0 L^0 T^0 = L^{a_3} [LT^{-1}]^{b_3} [ML^{-3}]^{c_3} [L]$$

$M \rightarrow \boxed{0 = c_3}$

$L \rightarrow 0 = a_3 + b_3 - 3c_3 + 1$, $0 = a_3 + 0 - 3(0) + 1 \Rightarrow \boxed{a_3 = -1}$

$T \Rightarrow \boxed{0 = -b_3}$

$$\therefore \pi_3 = D^{-1} V^0 \rho^0 L \Rightarrow \boxed{\pi_3 = \frac{L}{D}}$$

$$\pi_4 = D^{a_4} V^{b_4} \rho^{c_4} \mu$$

$$M^0 L^0 T^0 = L^{a_4} [LT^{-1}]^{b_4} [ML^{-3}]^{c_4} [ML^{-1}T^{-1}]$$

$M \rightarrow 0 = c_4 + 1 \Rightarrow \boxed{c_4 = -1}$

$L \rightarrow 0 = a_4 + b_4 - 3c_4 - 1$, $0 = a_4 - 1 + 3 - 1$, $\boxed{a_4 = -1}$

$T \rightarrow 0 = -b_4 - 1 \Rightarrow \boxed{b_4 = -1}$

$$\pi_4 = D^{-1} V^{-1} \rho^{-1} \mu \Rightarrow \boxed{\pi_4 = \frac{\mu}{DV\rho}}$$

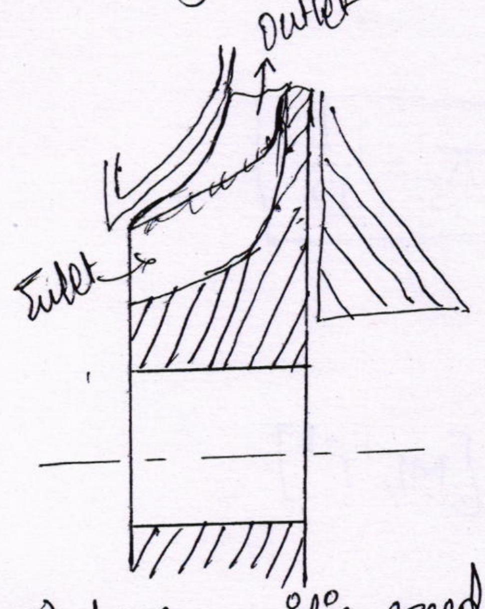
Now, $\pi_2 = f(\pi_1, \pi_3, \pi_4)$

$\pi_2 = \pi_1 f(\pi_3, \pi_4)$

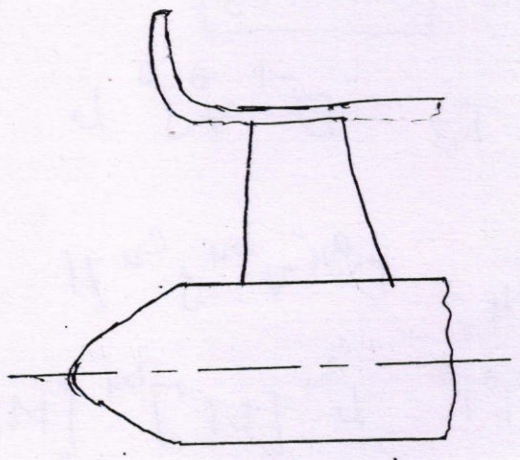
$$\boxed{\Delta p = f_1\left[\frac{K\rho}{D},\ \frac{L}{D},\ \frac{\mu}{DV\rho}\right]}$$

3. Discuss the importance of the Specific Speed in Selection of Turbomachine.

Sol^n:- → It is an important parameter in the design of a turbomachine, because any machine posses maximum efficiency it has high specific speed value



a) Low specific speed



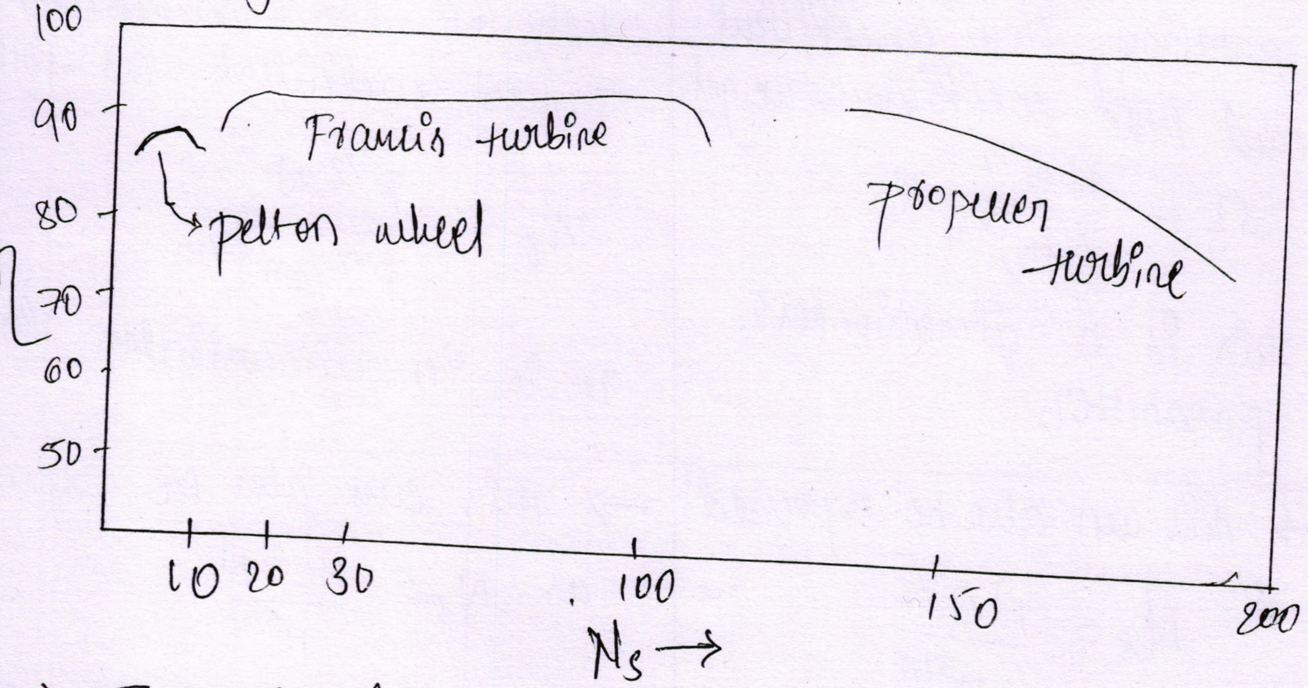
b) High specific speed

For justification, let us consider a centrifugal and axial flow pump as shown in above figure.

→ For power generating machines the specific speed is defined by $N_s = \frac{N P^{1/2}}{H^{5/4}}$.

→ There are three types of hydraulic turbines namely pelton wheel, Francis' turbine and axial flow type of propeller or Kaplan turbine.

→ A pelton wheel employes a high velocity jets and utilizes only a low flow rates but at a high head, i.e. its specific speed range for good efficiency is low.



→ The francis turbine is a mixed flow type and has a wide range of specific speed as it works under a moderate heads and a kaplan or propeller turbine employs very high flow rates with low heads, hence it has a very wide range of specific speed.

• Differentiate b/w the specific speed of pump & turbine.

Specific speed of pump	Specific speed of turbine
→ Specific speed of a pump is defined as a speed of geometrically similar machine discharging $1 m^3/s$ of water under a head of 1m.	→ It can be defined as "a speed of a geometrically similar machine which produce 1 kW power under a head of 1m.

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→ This is obtained by manipulating flow co-efficient and head coefficient we get, $\Omega = \frac{N Q^{1/2}}{(gH)^{3/4}}$ This is a dimensionless parameter.	→ This is obtained with the help of head co-efficient and power coefficient as follows $\pi_6 = \frac{P^{1/2} N}{\rho^{1/2} (gH)^{5/4}}$ It is in dimensionless form
→ This can also be expressed as $N_s = \frac{N Q^{1/2}}{H^{3/4}}$ This is not dimensionless and it has 'N' either in 'rad/s' or 'rpm'	→ This can also be expressed as $N_s = \frac{P^{1/2} N}{H^{5/4}}$ It is not dimensionless and has a dimension of N.

5. Define unit quantities. Explain their uses and Derive the expression to each of them.

Sol. Unit quantities are under consideration of unit head in connection with hydraulic turbines. In other words, the unit quantites are defined for the head of 1m.

Uses:-

→ Unit quantities are used in comparison of the performances of turbines of different output, speeds and different heads.

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1. <u>unit flow</u> :- unit flow is the flow that occurs through the turbomachine while working under an unit head, the speed being the same as at the design point.

Since any given hydraullic machine,

$$\frac{Q}{ND^3} = \text{constant} \quad \& \quad \frac{gH}{N^2D^2} = \text{constant}$$

$$\frac{Q/ND^3}{(gH/N^2D^2)^{1/2}} = \frac{Q}{\sqrt{H}\cdot D^2} = \text{constant}$$

for a turbine, $\frac{Q}{\sqrt{H}} = \text{constant}$

$$Q \propto \sqrt{2gH} \propto \sqrt{H}$$

$Q = K\sqrt{H}$. where K is proportionally constant

but the definition of unit flow is when

$$H = 1m \ , \ Q = Q_u$$

$$\therefore K = Q_u \qquad \therefore \boxed{Q_u = \frac{Q}{\sqrt{H}}}$$

2. <u>unit speed</u> :- It is the speed of a machine when running under a head of 1m.

Since $\frac{gH}{N^2D^2} = \text{constant}$

for any machine and the runner diameter is fixed,

$$N^2 \propto H$$

$$N \propto \sqrt{H}$$

$$N = K\sqrt{H}$$

By the definition of unit speed.

$H = 1m$, $N = N_u$

$N_u = K$

$\therefore \boxed{N_u = \frac{N}{\sqrt{H}}}$

3. <u>unit Power</u>:- It is the power developed by the turbo machine while working under a unit head.

we have power co-efficient $\frac{P}{\rho N^3 D^5}$ = constant

$P \propto N^3 D^5 \propto (N^2 D^2 \times N D^3)$

$P \propto HQ \propto (H \times \sqrt{H})$

$P = K H^{3/2}$ where $H = 1m$, $P = P_u$

hence $K = P_u$

$\boxed{\therefore P_u = \frac{P}{H^{3/2}}}$

6. Discuss the Dimensional analysis and similitude has applied to Turbomachine.

Sol: Dimensional analysis is a mathematical technique that deals with the dimensions of the quantities involved in the process or phenomenon.

~~Performance of a Turbomachines depends on the following variables i.e. discharge~~

Some similitude laws or Dimensionless number's are applied to Turbomachine.

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i. <u>Froude's number</u>:- It is defined as the ratio of inertia force to gravity force. Froude's number has considerable practical significance in free surface flow problems, like flow in orifices, flow over notches, flow over the spillways etc.

The Froude's number is given by $\frac{V^2}{gL}$

ii) <u>Weber's number</u>:- It is defined as the ratio of inertia force to the surface tension force. Weber's number has considerable practical significance in problems influenced by surface tension, like gas-liquid and liquid-liquid interfaces and contact of such interfaces with a solid boundary.

The Weber's number is given by $\frac{\rho L V^2}{\sigma}$

iii) <u>Mach's number</u>:- It is defined as the ratio of inertia force to elastice force. Mach's number has considerable practical significance in compressible flow problems, like shells, bullets, missiles and rockets fired into air.

The Mach's number is given by $\frac{V}{\sqrt{K/\rho}}$

iv) <u>Euler's number</u>:- It is defined as the ratio of pressure force to inertia force. Euler's number has considerable practical significance in modelling of hydraulic turbines and pumps.

The Euler's number is given by $\frac{P}{\rho V^2}$

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v) Reynold's number:- It is the ratio of inertial force to viscous forces within a fluid that is subjected to relative internal movement due to different fluid velocities.

$$Re = \frac{\rho u L}{\mu}$$

Assignment-2

1. Define utilization factor and Degree of reaction. Also derive an expression for Degree of reaction and utilization factor.

Soln:-

→ Due to finite exit velocity, for an ideal fluid also, all the energy supplied at inlet can not be converted into useful work. Therefore the ratio of ideal work to the energy supplied is called as the diagram efficiency (or) utilization factor (ε).

→ Degree of reaction is defined as "the ratio of static energy transfer due to the static pressure change to the total energy transfer due to the total pressure change in a rotor".

Expression

General eqn for degree of reaction for any turbine is given by the eqn:

$$R = \frac{(U_1^2 - U_2^2) + (V_{r_2}^2 - V_{r_1}^2)}{(V_1^2 - V_2^2) + (U_1^2 - U_2^2) + (V_{r_2}^2 - V_{r_1}^2)}$$

$$\frac{1}{R} = \frac{(V_1^2 - V_2^2)}{(U_1^2 - U_2^2) + (V_{r_2}^2 - V_{r_1}^2)} + \frac{(U_1^2 - U_2^2) + (V_{r_2}^2 - V_{r_1}^2)}{(U_1^2 - U_2^2) + (V_{r_2}^2 - V_{r_1}^2)}$$

$$\therefore \frac{V_1^2 - V_2^2}{(U_1^2 - U_2^2) + (V_{r_2}^2 - V_{r_1}^2)} = \frac{1}{R} - 1 = \frac{1 - R}{R} \quad \text{--- (1)}$$

Also, utilization factor, $\varepsilon = \dfrac{(V_1^2-V_2^2)+(U_1^2-U_2^2)+(V_{r2}^2-V_{r1}^2)}{V_1^2+(U_1^2-U_2^2)+(V_{r2}^2-V_{r1}^2)}$

from eqn (1)

$$\varepsilon = \frac{(V_1^2-V_2^2)+\frac{R}{(1-R)}(V_1^2-V_2^2)}{V_1^2+\frac{R}{(1-R)}(V_1^2-V_2^2)}$$

$$= \frac{(V_1^2-V_2^2)(1-R)+R(V_1^2-V_2^2)}{V_1^2(1-R)+R(V_1^2-V_2^2)}$$

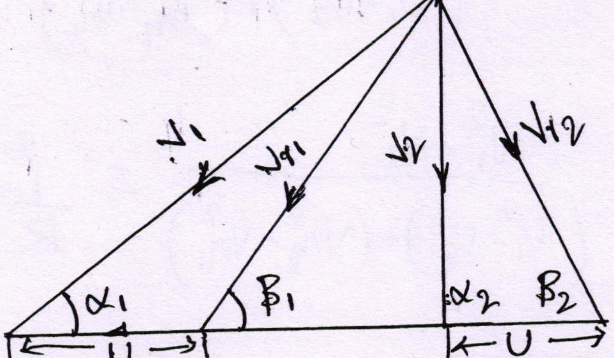
$$\varepsilon = \frac{V_1^2-V_2^2-\cancel{RV_1^2}+\cancel{RV_2^2}+\cancel{RV_1^2}-\cancel{RV_2^2}}{V_1^2-\cancel{RV_1^2}+\cancel{RV_1^2}-RV_2^2}$$

$$\boxed{\varepsilon = \frac{V_1^2-V_2^2}{V_1^2-RV_2^2}}$$

The above eqn is the general utilization ~~factor~~ irrespective of any type of turbines whether it is axial or radial in the range of $0<R<1$

Q. Show that for maximum utilization of axial flow turbine with reaction $= 1/4$. The speed ratio is given by, $\frac{U}{V_1} = \frac{2}{3}\cos\alpha_1$, where U = Blade speed, V_1 = Inlet absolute velocity α_1 = Inlet nozzle angle.

Soln.



For axial flow turbine, degree of reaction is,

$$R = \frac{(V_{r_2}^2 - V_{r_1}^2)}{[(V_1^2 - V_2^2) + (V_{r_2}^2 - V_{r_1}^2)]} = \frac{1}{4}$$

(or), $$(V_1^2 - V_2^2) + (V_{r_2}^2 - V_{r_1}^2) = 4(V_{r_2}^2 - V_{r_1}^2)$$

$$(V_1^2 - V_2^2) = 3(V_{r_2}^2 - V_{r_1}^2) \quad \text{—— (1)}$$

From ΔOAC, $\sin\alpha_1 = \frac{OC}{OA} = \frac{V_2}{V_1} \Rightarrow V_2 = V_1 \sin\alpha_1$

(or)

$$V_2^2 = V_1^2 \sin^2\alpha_1$$

From ΔOCD, $V_{r_2}^2 = V_2^2 + U^2$

(or)

$$V_{r_2}^2 = V_1^2 \sin^2\alpha_1 + U^2$$

By applying cosine rule to ΔOAB,

$$V_{r_1}^2 = V_1^2 + U^2 - 2UV_1\cos\alpha_1$$

Substitute the values V_2^2; $V_{r_2}^2$ & $V_{r_1}^2$ in eq^n (1)

$$V_1^2 - V_1^2\sin^2\alpha_1 = 3\left[V_1^2\sin^2\alpha_1 + U^2 - (V_1^2 + U^2 - 2UV_1\cos\alpha_1)\right]$$

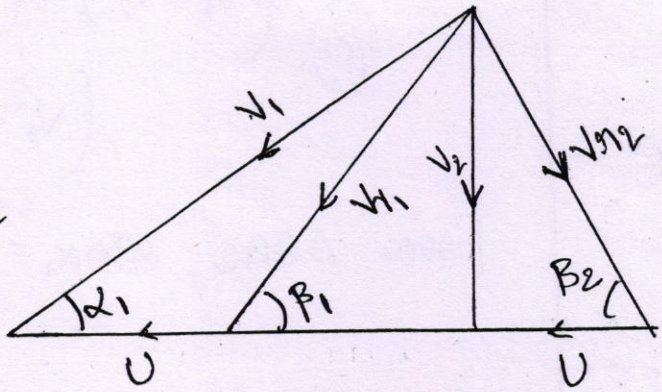
$$4(V_1^2 - V_1^2\sin^2\alpha_1) = 6UV_1\cos\alpha_1$$

$$\therefore \boxed{\psi = \frac{U}{V_1} = \frac{2}{3}\cos\alpha_1}$$

4. Draw the velocity Δ^{les}. at inlet and outlet of an axial flow turbine when i) R is negative ii) R = 0, iii) R = 0.5, iv) R = 1. Discuss the energy transfer in these cases.

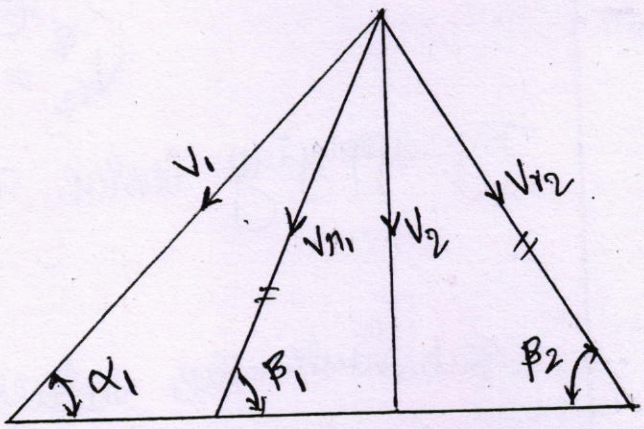
Sol

i) when R is negative



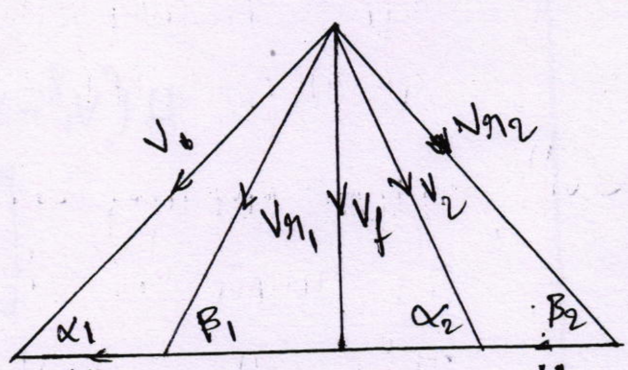
R will be negative if V_{r1} is greater than V_{r2} i.e $V_{r1} > V_{r2}$ even though the R is −ve, the energy transfer E is +ve,

ii) when R = 0



R = 0, when $V_{r1} = V_{r2}$ and hence $\beta_1 = \beta_2$. This is the characteristic of impulse turbine. In this case E is +ve

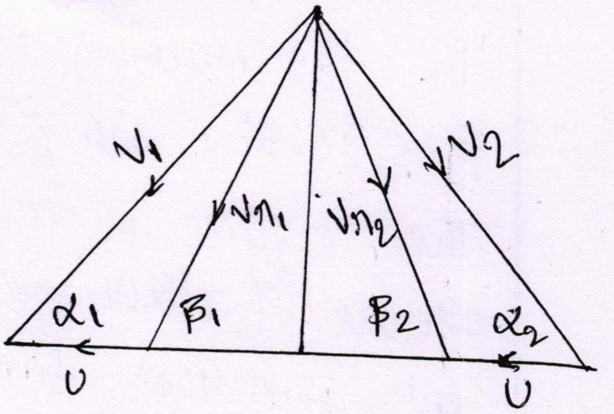
iii) R = 0.5



~~when~~ R = 0.5, when $V_{r1} = V_{r2}$ and $V_2 = V_1$. In this case energy transfer occur initially by impulse action & then by reaction.

iv) when R = 1 (Full reaction)

R=1, when $V_1 = V_2$. In this case energy transfer takes place purely due to change in relative kinetic energy of fluid.



Define the static and stagnation state?

A:- → Static pressure is the pressure at a point in a fluid. It is the actual thermodynamic pressure of the fluid. It doesn't take into account the flow of fluid.

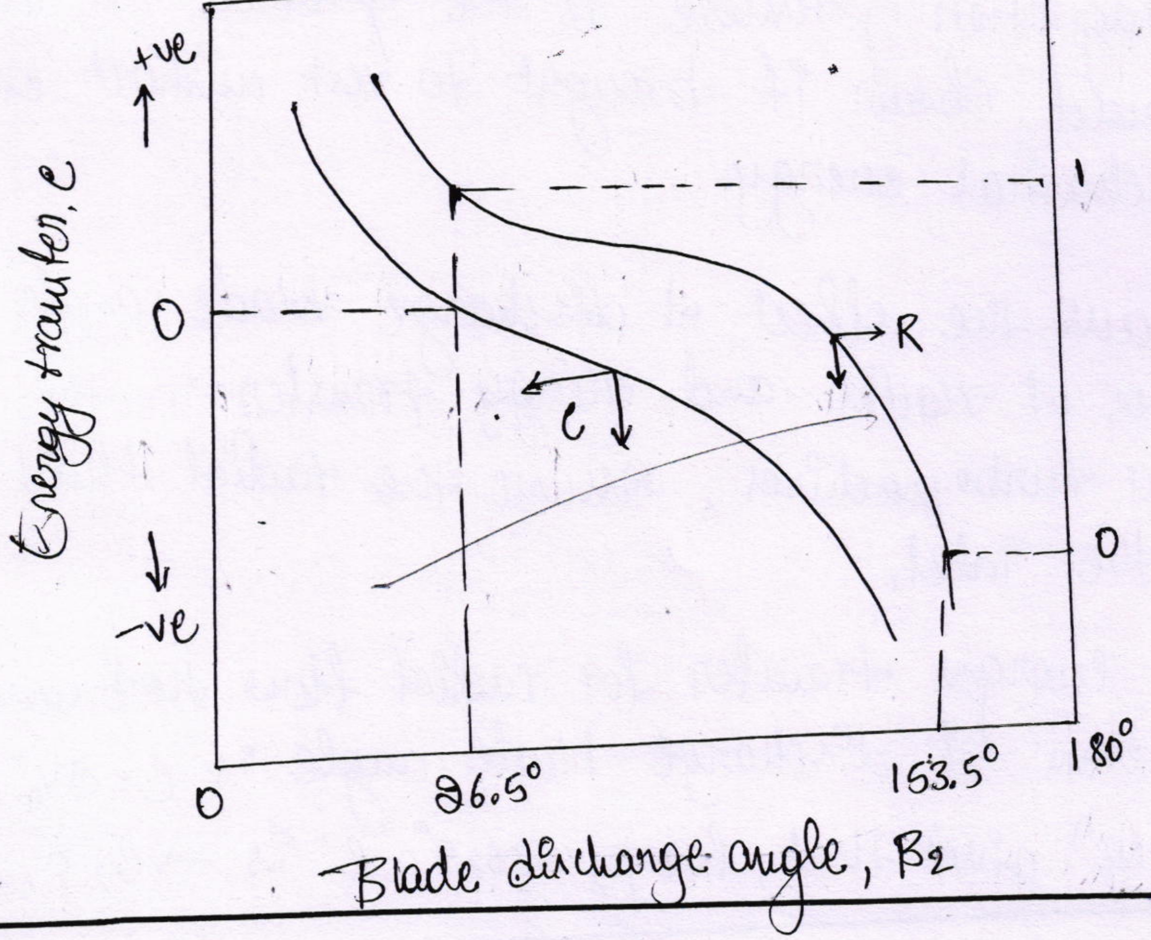
→ Stagnation pressure is the pressure the fluid would obtain if brought to rest without loss of mechanical energy.

Discuss the effect of discharge blade angle on degree of reaction and energy transfer in the radial flow turbomachines. Assume the radial fluid entry at the inlet.

The energy transfer for radial flow turbomachines in terms of discharge blade angle is $e = 2V_m^2(\cot\beta_2 - 2)$. This eq^n gives that, for $\beta_2 > 26.5°$, 'e' is -ve) & continuou increases with β_2. As 'e' negative for these values of β_2; the machines will acts as pump or compressor. For $\beta_2 < 26.5°$ 'e' is positive & machines will act as a turbine.

The degree of reaction for radial flow turbomachines in terms of discharge blade angle is $R = \frac{2 + \cot\beta_2}{4}$. This eq^n gives that, for β_2 in the range of $26.5°$ to $153.5°$ the value of R decreases linearly from near unity to very small positive value. For $\beta_2 = 153.5°$, $R = 0$ & hence machine will act as impulse turbine.

The effect of discharge blade angle on energy transfer and degree of reaction of turbomachine is shown in fig.



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Assignment -3

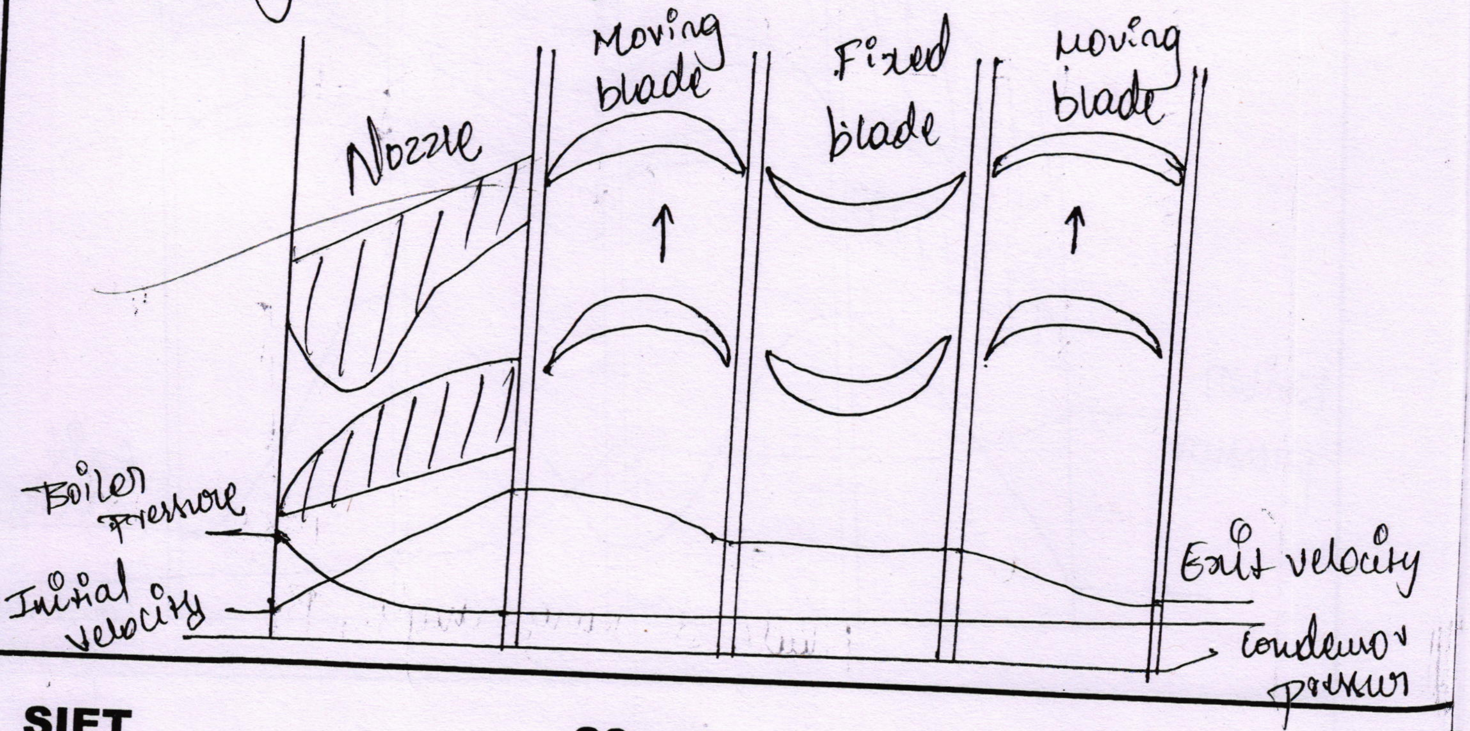
Q.
3. What is compounding of steam turbine? Explain the method of compounding of steam turbine with a neat sketch?

Sol?:
Compounding is the method of reducing blade speed for a given overall pressure drop.

Methods of compounding of steam turbines

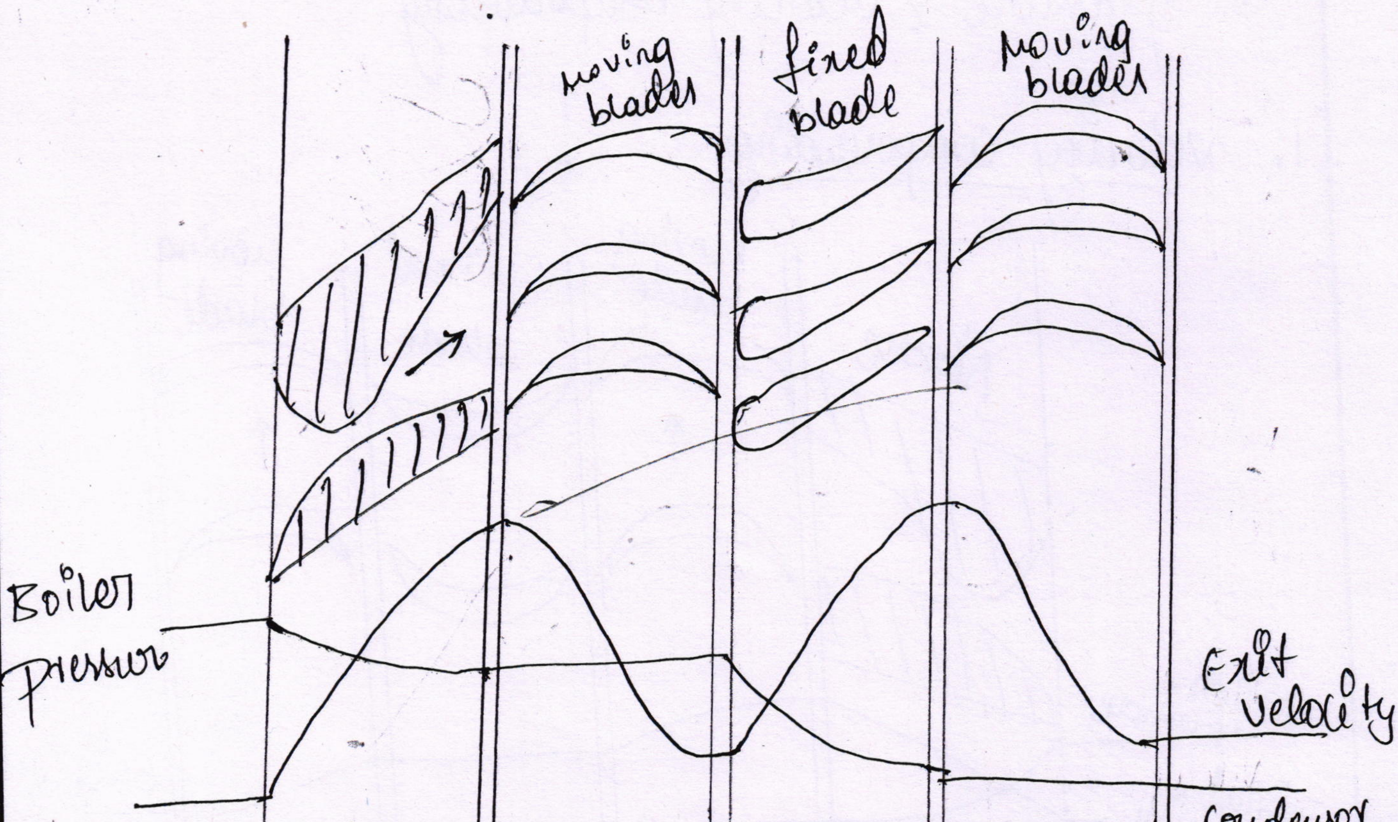
1. Velocity compounding
2. Pressure compounding
3. Pressure & velocity compounding

1. Velocity compounding



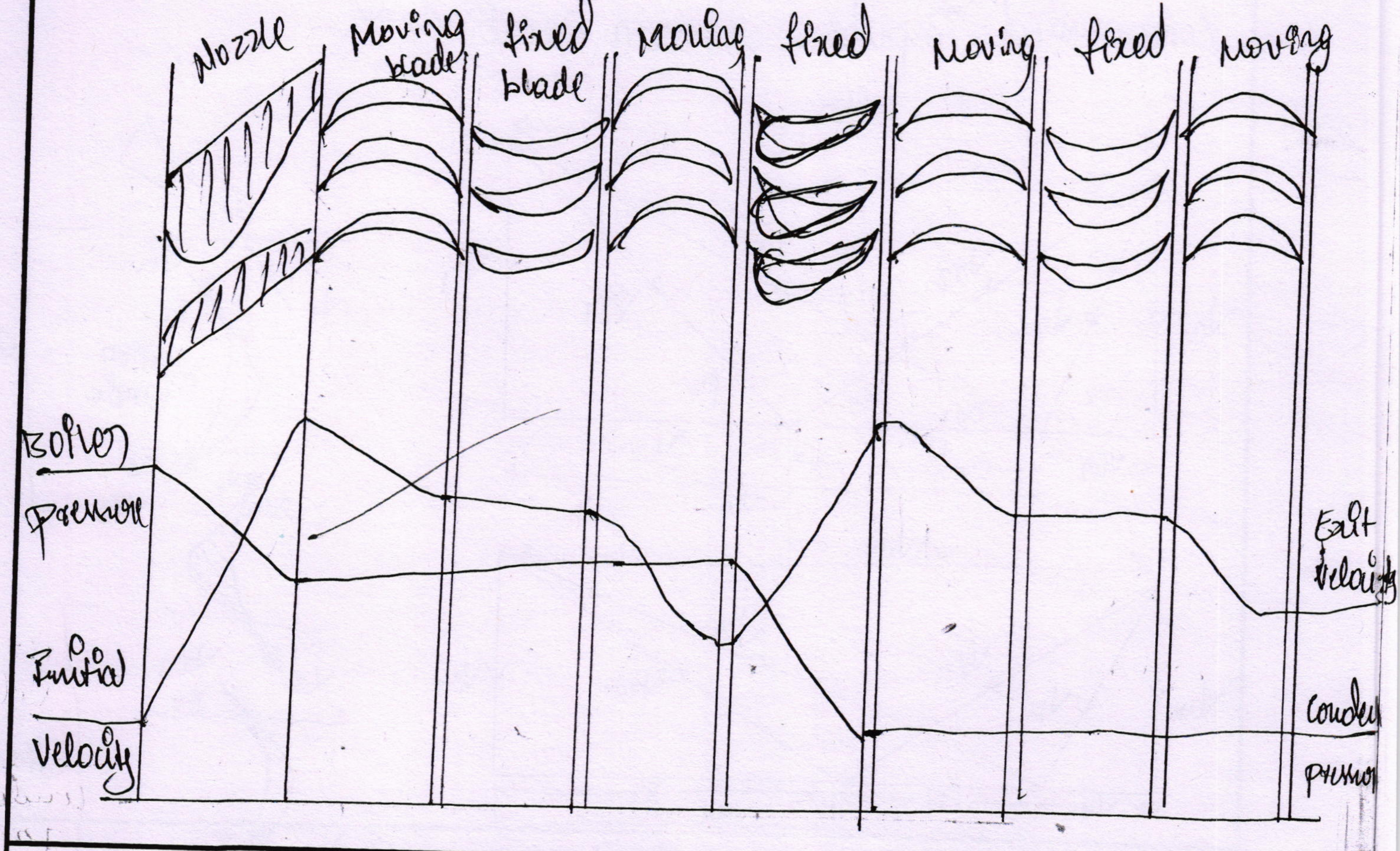
Nozzle is fitted to the stationary casing. Each fixed blade row is fitted b/w the moving blades. The function of the fixed blade is to direct the steam coming from the first moving blade row to the next moving row without appreciable change in velocity. The pressure drop occurs in one set of stationary nozzles. The Kinetic energy of steam gained in the nozzle is successively absorbed by moving row & the steam is exited from the last row with very low velocity. Due to this, the rotor speed decreases considerably. The turbine working on this principle is called the velocity compounded impulse turbine. Ex:- Curtis turbine.

2. Pressure compounding



A pressure compoundeded impulse turbine is simply a number of simple impulse stages arranged in series. Here the turbine is provided with rows of fixed blad which acts as nozzles at the entry of each row of moving blades. The total pressure drop of the steam does not tak place in the first row of nozzles but is divided among all the rows of fixed blades which acts as nozzles. Each of the simple impulse turbine is named "stage" of the turbine. This arrangement is equivalen to splitting up the whole pressure drop into a series of smaller pressure drop into a series of smaller pressure drops, hence the term "pressure compounded".

3. Pressure - velocity compounding



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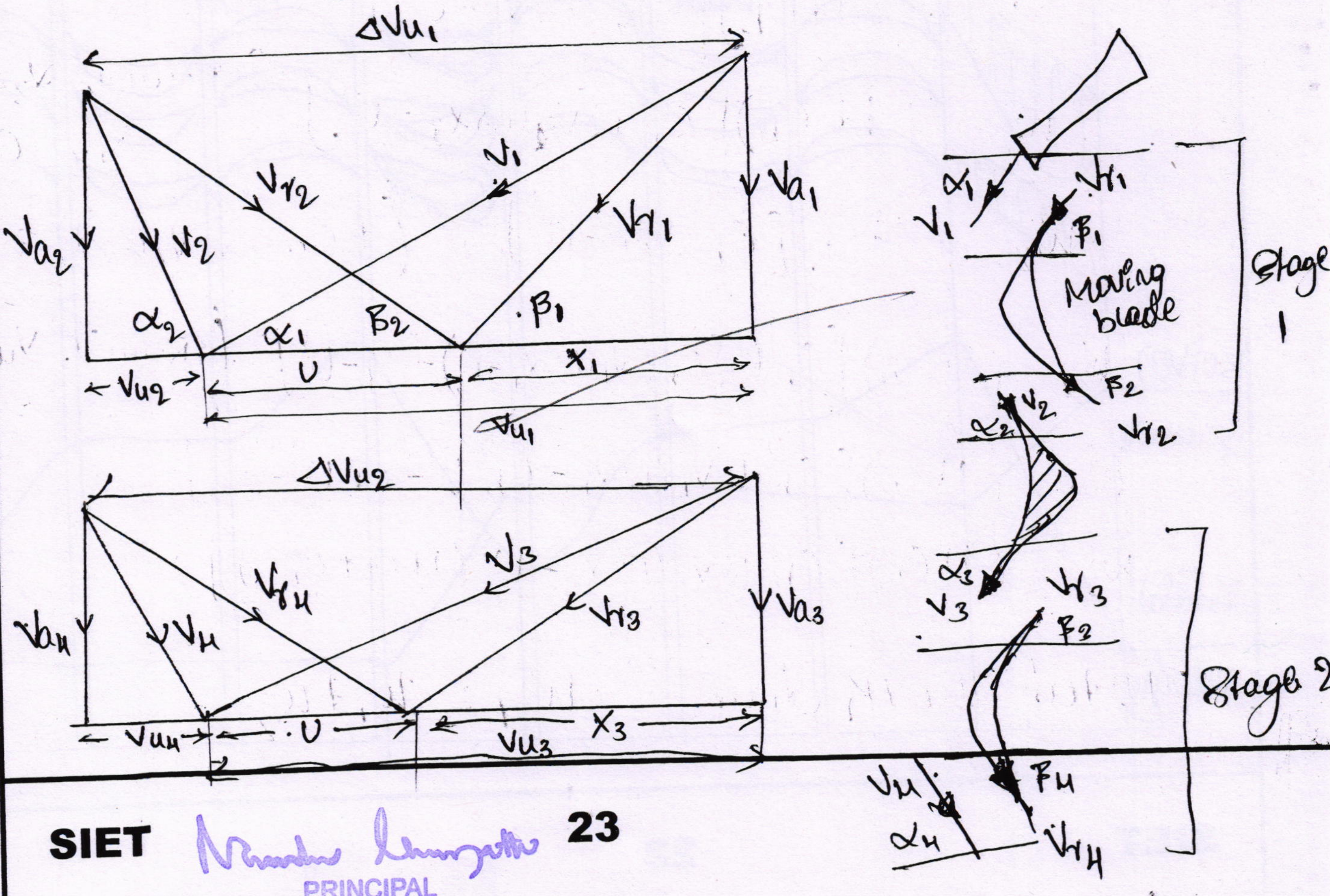
This arrangement is in two stages. Each stage has a two stage velocity compounded turbine. Steam leaving the boiler with high pressure enters a set of nozzles of the first stage. The pressure drops partially in the nozzles and steam enters the first set of rotates of first stage with very high velocity. In the first set of rotates, kinetic energy is absorbed partially with no change in pressure energy. Then, steam leaves the rotor & enters the stator. Here, theoretically, pressure energy & kinetic energy will remain constant. Then, steam with comparatively high K.E enters the second set of rotors of first stage. Here, the remaining K.E is absorbed. This completes expansion in one stage.

Q. Derive the maximum blade efficiency eqn. for velocity compounded impulse ~~steam~~ turbine.

Soln.



The work done by first row moving blades is

$$W_1 = \cancel{\phi} U\Delta V_{u_1} = U[V_{u_1} + V_{u_2}]$$

from 1st stage velocity diagram, $V_{u_1} = V_1\cos\alpha_1$

& also,

$$V_{u_2} = x_2 - U = V_{r_2}\cos\beta_2 - U$$

$$V_{u_2} = C_b V_{r_1}\cos\beta_1 - U \quad \text{(Because } V_{r_2} = C_b \text{...}$$

$$V_{u_2} = C_b x_1 - U = C_b(V_{u_1} - U) - U$$

(Because $V_{r_1}\cos\beta_1 = x_1 = V_{u_1} - U$)

$$V_{u_2} = C_b(V_1\cos\alpha_1 - U) - U \quad \text{(Because } V_{u_1} = V_1\cos\alpha_1\text{)}$$

Then, $W_1 = U[V_1\cos\alpha_1 + C_b(V_1\cos\alpha_1 - U) - U]$

$$W_1 = (1 + C_b)UV_1\cos\alpha_1 - (1 + C_b)U^2$$

$$W_1 = (1 + C_b)[UV_1\cos\alpha_1 - U^2]$$

|||ly

$$W_2 = (1 + C_b)[UV_3\cos\alpha_3 - U^2]$$

$$W_2 = (1 + C_b)[C_b U V_2\cos\alpha_3 - U^2] \quad \left\{\text{Because } \alpha_3 = \alpha_2,\ V_3 = C_b V_2\right\}$$

$$W_2 = (1 + C_b)[C_b U V_{u_2} - U^2] \quad \{\text{Because } V_2\cos\alpha_2 = V_{u_2}\}$$

$$W_2 = (1 + C_b)[C_b U\{C_b(V_1\cos\alpha_1 - U) - U\} - U^2] \quad \text{(Because } V_{u_2} = C_b(V_1\cos\alpha_1 - U) - U$$

$$W_2 = (1 + C_b)[C_b^2 U V_1\cos\alpha_1 - C_b^2 U^2 - C_b U^2 - U^2]$$

$$W_2 = (1 + C_b)[C_b^2 U V_1\cos\alpha_1 - U^2(1 + C_b + C_b^2)]$$

Total work done, $W_T = W_1 + W_2$

$$W_T = (1+C_b)\left[UV_1\cos\alpha_1 - U^2\right] + (1+C_b)\left[C_b^2 UV_1\cos\alpha_1 - U^2(1+C_b+C_b^2)\right]$$

$$W_T = (1+C_b)\left[(1+C_b^2)UV_1\cos\alpha_1 - U^2(2+C_b+C_b^2)\right]$$

Let $C_b' = (1+C_b)(1+C_b^2)$ & $C_b'' = (1+C_b)(2+C_b+C_b^2)$

Then, $W_T = C_b' UV_1\cos\alpha_1 - C_b'' U^2$

Blade (or) rotor η, $\eta_b = \dfrac{W_T}{e_a} = \dfrac{C_b' UV_1\cos\alpha_1 - C_b'' U^2}{\frac{1}{2}V_1^2}$

$$\eta_b = 2\left[C_b'\left(\frac{U}{V_1}\right)\cos\alpha_1 - C_b''\left(\frac{U}{V_1}\right)^2\right]$$

$$\therefore \eta_b = 2\left[C_b'\psi\cos\alpha_1 - C_b''\psi^2\right]$$

The slope of max blade efficiency.

$$\frac{d\eta_b}{d\psi} = 0 \Rightarrow \frac{d}{d\psi}\left\{2(C_b'\psi\cos\alpha_1 - C_b''\psi^2)\right\} = 0$$

$$2(C_b'\cos\alpha_1 - 2C_b''\psi) = 0$$

$$\psi_{opt} = \left(\frac{C_b'}{C_b''}\right)\frac{\cos\alpha_1}{2}$$

The max blade efficiency is,

$$\eta_{bmax} = 2\left[C_b'\left(\left(\frac{C_b'}{C_b''}\right)\frac{\cos\alpha_1}{2}\right)\cos\alpha_1 - C_b''\left[\left(\frac{C_b'}{C_b''}\right)\frac{\cos\alpha_1}{2}\right]^2\right]$$

$$= 2\left(\frac{(C_b')^2}{C_b''}\left(\frac{\cos^2\alpha_1}{2}\right) - \frac{(C_b')^2}{C_b''}\left(\frac{\cos^2\alpha_1}{4}\right)\right]$$

$$\therefore \boxed{\eta_{bmax} = \frac{(C_b')^2}{C_b''}\frac{\cos^2\alpha_1}{2}}$$

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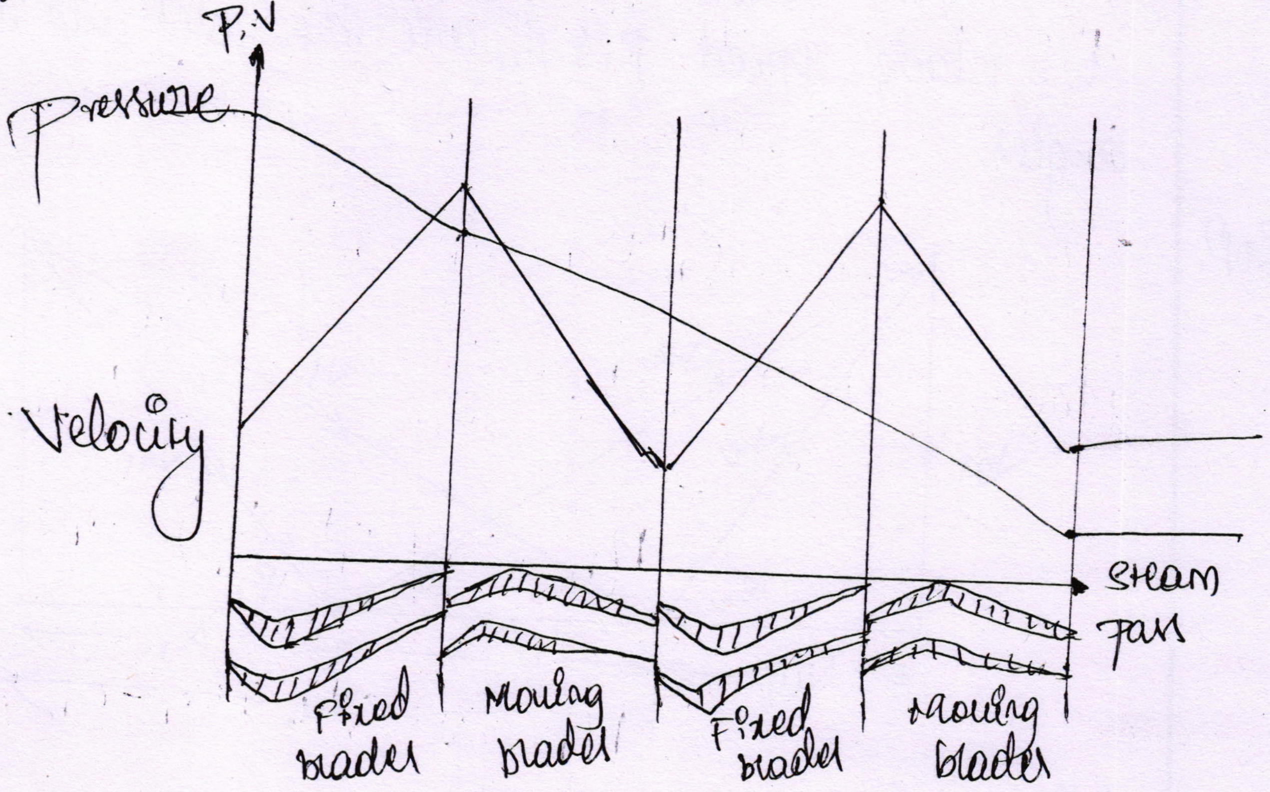
4. Explain with neat diagram the operations of a reaction turbine.

Soln.



In the impulse reaction turbine, power is generated by the combination of impulse action & reaction by expanding the steam in both fixed blades (act as nozzles) & moving blades as shown. Here the pressure of the steam drops partially in fixed blades & partially in moving blades. Steam enters the fixed row of blades, undergoes a small drop in pressure and increases in velocity. Then steam enters the moving row of blades, undergoes a change in direction and momentum (impulse action), and a small drop in pressure too (reaction), giving rise to increase in kinetic energy. Hence, such a turbine is termed as impulse reaction turbine. Ex:- Parson, Ljungstrom etc.

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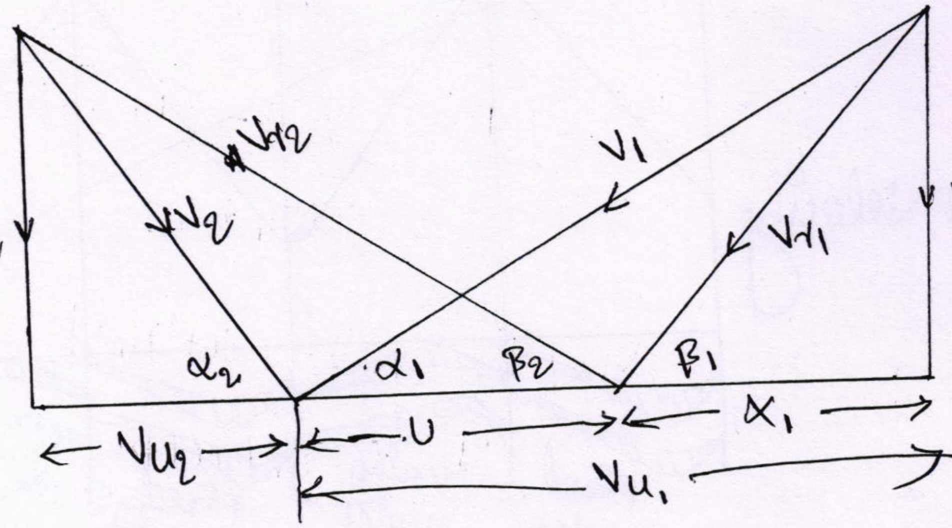
5. Prove that the degree of reaction of a reaction turbine is given by $R = \frac{V_a}{2U}(\cot\beta_2 - \cot\beta_1)$ where V_a = axial velocity, U = Blade speed, β_1 & β_2 are the inlet and outlet blade angles.

Sol.



from given data, $V_{a1} = V_{a2} = V_a$

$$R = \frac{\frac{1}{2}(V_{r2}^2 - V_{r1}^2)}{e} = \frac{V_{r2}^2 - V_{r1}^2}{2e}$$

from velocity diagram, $(V_{u1}+V_{u2}) = (x_1 + U + x_2 - U)$

$$= (x_1 + x_2) = (V_{a1}\cot\beta_1 + V_a\cot\beta_2)$$

or, $(V_{u1}+V_{u2}) = V_a(\cot\beta_1 + \cot\beta_2)$

from velocity diagram, $\sin\beta_2 = \frac{V_{a2}}{V_{r2}} \Rightarrow V_{r2} = \frac{V_{a2}}{\sin\beta_2}$

$$V_{r2} = V_a \operatorname{cosec}\beta_2$$

lly $\sin\beta_1 = \frac{V_{a1}}{V_{r1}} \Rightarrow V_{r1} = \frac{V_{a1}}{\sin\beta_1}$

$$\therefore V_{r1} = V_a \operatorname{cosec}\beta_1$$

Then $e = U(V_{u1}+V_{u2}) \Rightarrow e = UV_a(\cot\beta_1 + \cot\beta_2)$

and, $(V_{r_2}^2 - V_{r_1}^2) = (V_a^2 \operatorname{cosec}^2 \beta_2 - V_a^2 \operatorname{cosec}^2 \beta_1)$

$$V_{r_2}^2 - V_{r_1}^2 = V_a^2 (\operatorname{cosec}^2 \beta_2 - \operatorname{cosec}^2 \beta_1)$$

$$\therefore \quad R = \frac{V_a^2 (\operatorname{cosec}^2 \beta_2 - \operatorname{cosec}^2 \beta_1)}{2 U V_a (\cot \beta_1 + \cot \beta_2)}$$

$$R = \frac{V_a [(1 + \cot^2 \beta_2) - (1 + \cot^2 \beta_1)]}{2 U (\cot \beta_1 + \cot \beta_2)}$$

$$R = \frac{V_a [(\cot^2 \beta_2) - (\cot^2 \beta_1)]}{2 U (\cot \beta_1 + \cot \beta_2)}$$

$$R = \frac{V_a [(\cot \beta_2 - \cot \beta_1)(\cot \beta_2 + \cot \beta_1)]}{2 U (\cot \beta_1 + \cot \beta_2)}$$

$$\boxed{\therefore R = \left(\frac{V_a}{2U}\right) [\cot \beta_2 - \cot \beta_1]}$$

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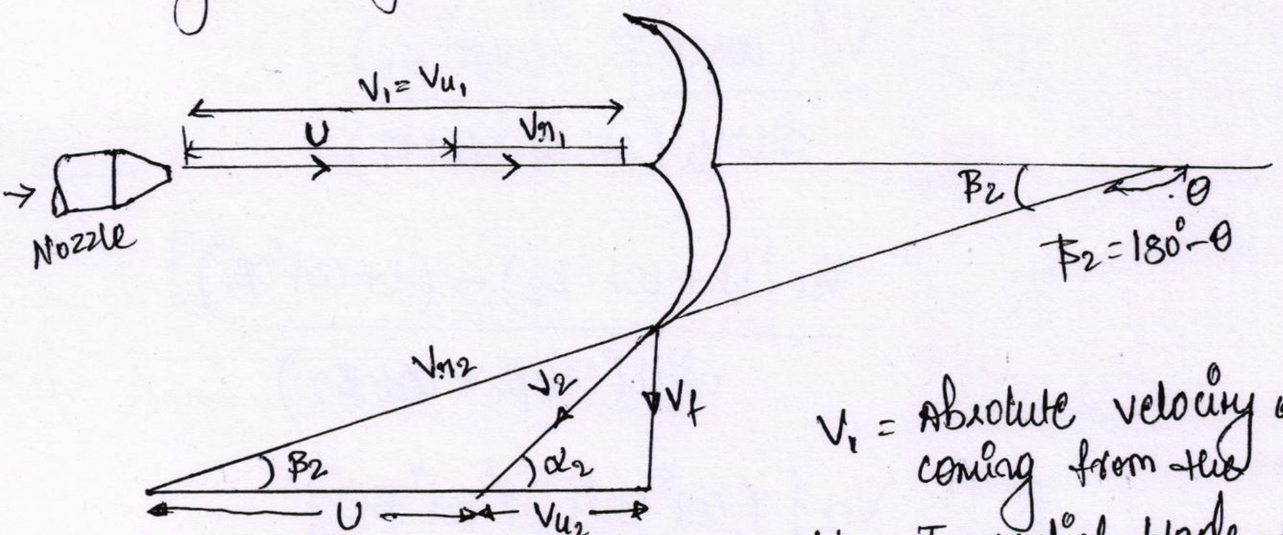
1. Derive an expression for work done by a pelton wheel with necessary velocity triangles.

Sol^n



V_1 = Absolute velocity of water coming from the nozzle

U = Tangential blade speed

V_{r_1} = Relative velocity at inlet

V_{u_1} = Tangential component of absolute velocity at inlet

θ = Angle of turn

β_2 = Blade angle at outlet $= 180° - \theta$

V_2, V_{r_2}, V_{u_2} are corresponding velocity terms at outlet.

Let θ be the angle through which the jet gets deflected by the bucket, then $\beta_2 = 180° - \theta$

from the inlet velocity triangle.

$\alpha_1 = 0$, $\beta_1 = 0$

$V_1 = V_{u_1}$ and $V_{r_1} = V_1 - U$

From the outlet velocity triangle,

$V_{u_2} = V_{r_2} \cos\beta_2 - U$

$= V_{r_1} \cos\beta_2 - U$ $\quad [\because V_{r_1} = V_{r_2}$, no losses$]$

$V_{u_2} = (V_1 - U)\cos\beta_2 - U$

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work done per kg of water,

$$W = U[V_{u_1} \pm V_{u_2}]$$

$$W = U(V_{u_1} + V_{u_2})$$

$$= U\left[V_{u_1} + (V_1 - U)\cos\beta_2 - U\right]$$

$$= U\left[(V_1 - U) + (V_1 - U)\cos\beta_2\right]$$

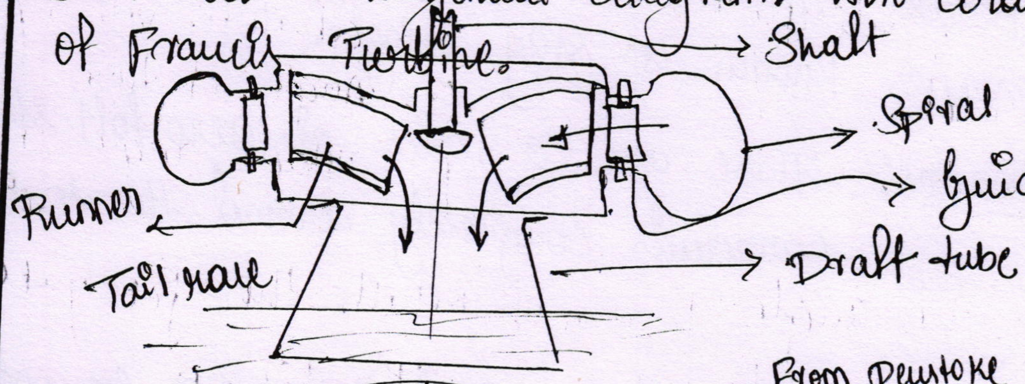
$$W = U(V_1 - U)(1 + \cos\beta_2)$$

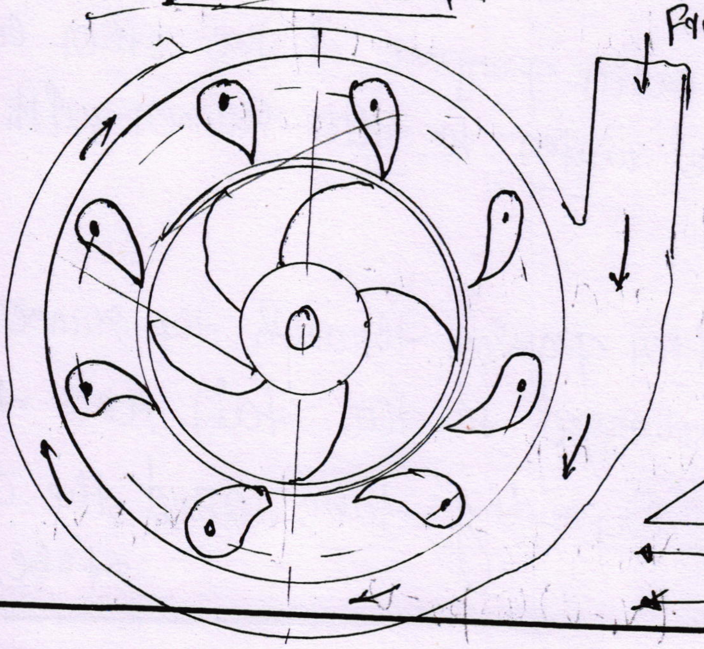
Note: + if both are in opposite direction
− if both are in same direction.

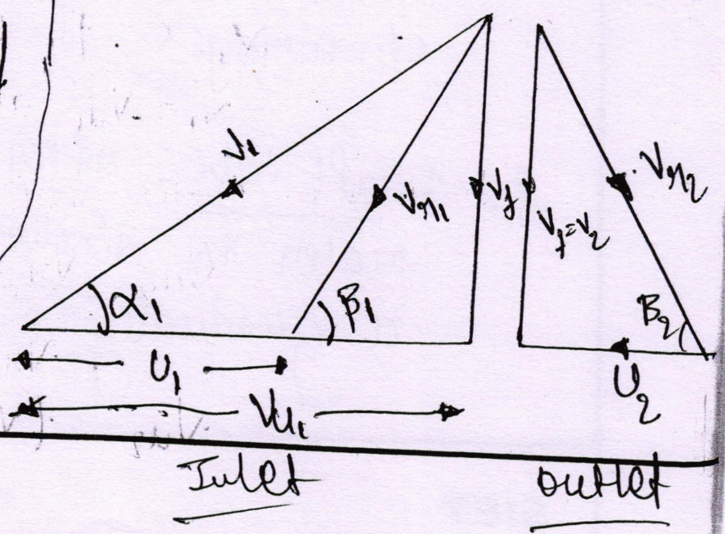
$$\boxed{W = U(V_1 - U)(1 + C_b\cos\beta_2)}$$ if C_b is considered.

(2) Explain the working of Francis turbine with the help of sectional arrangement diagram. Also draw the velocity △le of Francis Turbine.

Sol?







Francis turbine is an inward flow, medium head reaction turbine. Molecular Francis turbines are mixed flow type, in which water enters the runner radially & leaves axially at the center.

Components

a. Penstock:- It is a large sized conduit which conveys water from the upstream of the dam to the turbine runner.

b. Scroll casing:- The water from the penstock enters the scroll casing (spiral casing) which completely covers the runner.

c. Stay ring:- The water from scroll casing enters the fixed blades, which are usually half in number of guide vanes known as stay rings.

d. Guide vanes:- These are a series of aero foil shaped blades that surrounds completely around the turbine runner.

e. Runner:- The main purpose of the other components is to lead the water to the runner with min loss of energy.

f. Draft tube:- After passing through the runner, the water is discharged to the tail race through a gradually expanding tube called the draft tube.

3. Explain the functions of Draft tube?

Sol

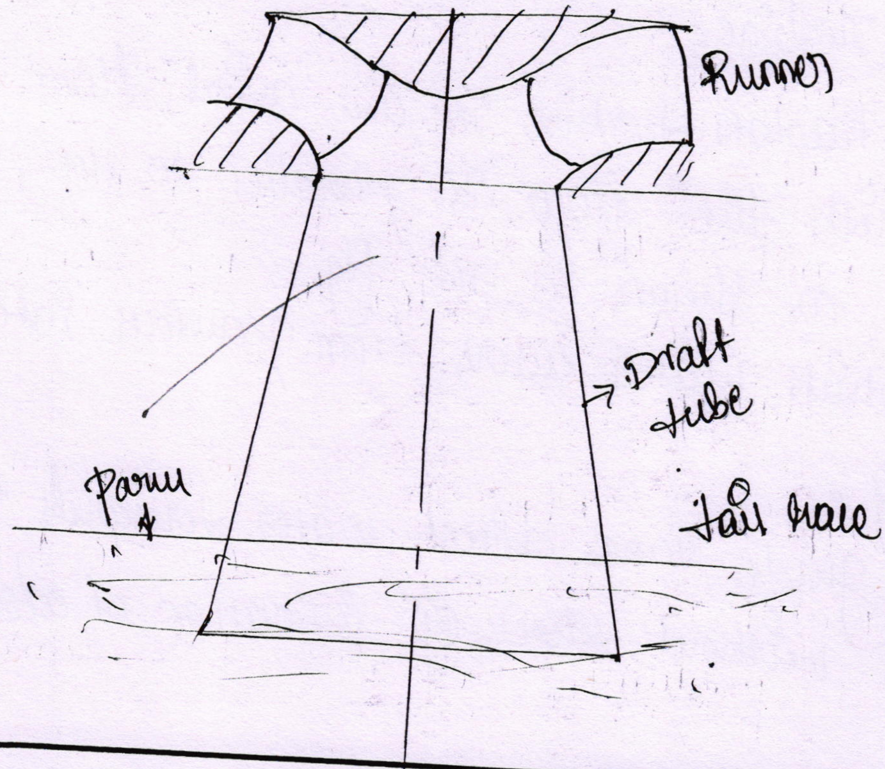
Soln. → A reaction turbine is required to be installed above the tail race level for easy of maintenance work. hence some head is lost. The draft tube recovers this head by reducing the pressure head at the outlet to below the atmosphere level.

→ Exit K.E of water is a necessary loss in the case of turbine. A draft tube recovers part of the exit K.E.

→ The turbine can be installed at the tail race level, above the tail race level or below the tail race level.

4. With a neat sketch, Explain the application of Draft tubes.

Soln.



→ A draft tube is a simple, slightly divergent conduit that is connected to the outlet of the runner of the reaction turbine at its smaller end. Its larger end is submerged below the tail race level. A draft tube runs full, just like the casing and runner.

→ The main purpose of the draft tube is to recover the head. Because of the draft tube, the pressure at the exit of the runner is lower than the atmospheric pressure.

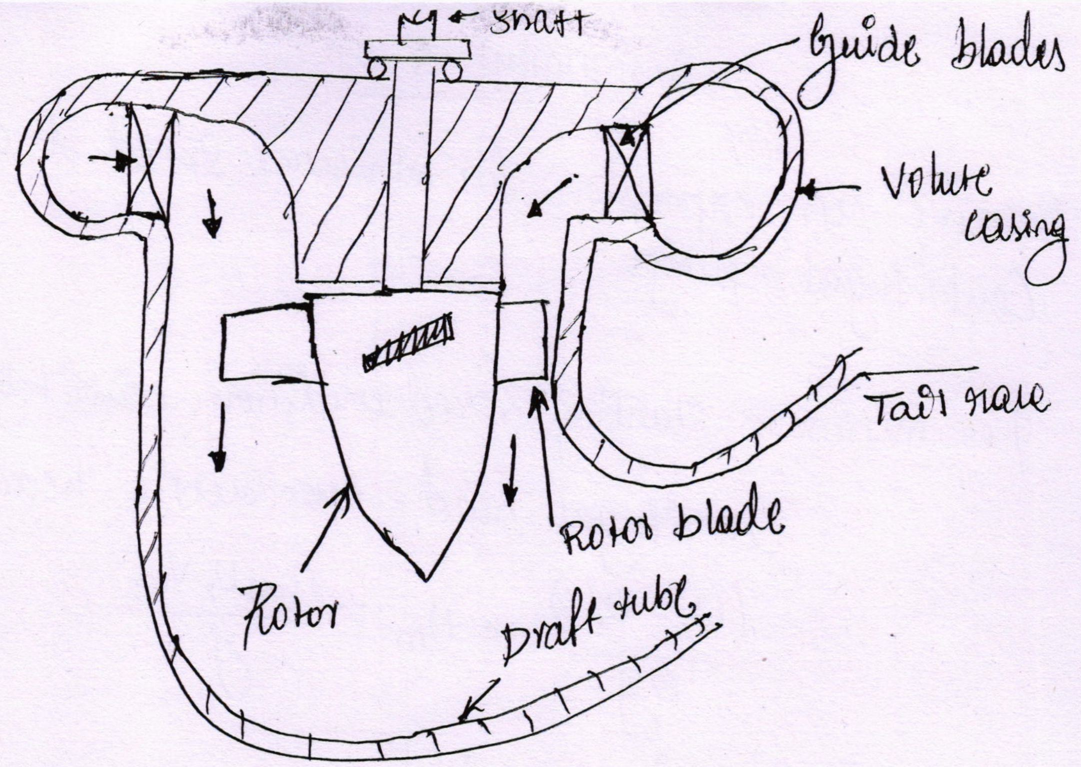
→ The second purpose of the draft tube is accomplish-ed by making the draft tube a little divergent. At the exit of the runner, there is the exit loss, $V_2^2/2g$, but due to divergent shape, this loss is reduced to $V_4^2/2g$ where V_4 is the velocity at the exit of the draft tube. V_4 is less than V_2.

5. With a neat sketch, show the sectional arrangement of Kaplan Turbine.

Sol? → The Kaplan turbine is an axial flow reaction turbine in which the flow is parallel to the axis of the shaft as shown in the fig.

→ In which water enters from penstock into the spiral casing.

→ The guide vanes direct water towards the runner vanes without shock or formation of eddies.



Kaplan turbine

→ B/w the guide vanes and the runner, the fluid gets deflected by 90°. So that flow is parallel to the axis of rotation of the runner which is known as axial flow.

→ The guide vanes impart whirl component to flow and runner vanes nullify this effect making flow purely axial. As compared to Francis turbine runner blades (16 to 24 numbers) kaplan turbine uses only 3 to 8 blades. Due to this, the contact surface with water is less which reduces frictional resistance and losses.

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Assignment -5

1. Derive an expression for minimum speed of starting a Centrifugal pump.

Sol: For minimum starting speed condition, ~~centrifugal hea~~

Centrifugal head = manometric head

$$\frac{(U_2^2 - U_1^2)}{2g} = H_m = \frac{\eta_{ma} U_2 V_{u2}}{g}$$

$$\frac{\left[\left(\frac{\pi D_2 N}{60}\right)^2 - \left(\frac{\pi D_1 N}{60}\right)^2\right]}{2} = \eta_{ma}\left(\frac{\pi D_2 N}{60}\right) V_{u2}$$

$$\frac{\left(\frac{\pi N}{60}\right)^2 \left[D_2^2 - D_1^2\right]}{2} = \eta_{ma}\left(\frac{\pi N}{60}\right) D_2 V_{u2}$$

$$\frac{\pi N D_2^2 \left[1 - \frac{D_1^2}{D_2^2}\right]}{120} = \eta_{ma} D_2 V_{u2}$$

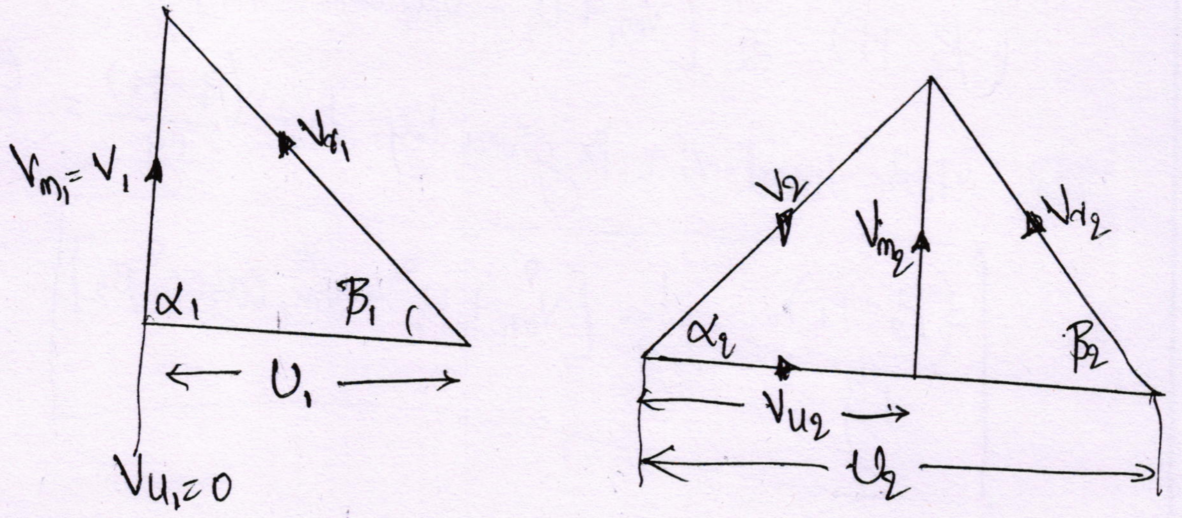
$$\frac{\pi N D_2 \left[1 - \frac{D_1^2}{D_2^2}\right]}{120} = \eta_{ma} V_{u2}$$

Then minimum starting speed in rpm is,

$$\therefore \boxed{N_{min} = \frac{120\, \eta_{ma} V_{u2}}{\pi D_2 \left[1 - \frac{D_1^2}{D_2^2}\right]}}$$

1 g Q. Derive the expression for pressure rise in the centrifugal pump.

Sol:



Energy transfer due to static pressure change is given by,

$$e_{static} = \frac{(U_2^2 - U_1^2)}{2} - \frac{(V_{r_2}^2 - V_{r_1}^2)}{2}$$

from inlet velocity Δles $V_{r_1}^2 = U_1^2 + V_{m_1}^2$

from outlet velocity Δles, $V_{r_2}^2 = V_{m_2}^2 + x_2^2$

But $\cot\beta_2 = \frac{x_2}{V_{m_2}} \Rightarrow x_2 = V_{m_2}\cot\beta_2$

Then, $V_{r_2}^2 = V_{m_2}^2 + V_{m_2}^2 \cot^2\beta_2$

$$e_{static} = \frac{(U_2^2 - U_1^2)}{2} - \frac{\left[V_{m_2}^2 + V_{m_2}^2\cot^2\beta_2 - U_1^2 - V_{m_1}^2\right)}{2}$$

$$e_{static} = \frac{1}{2}\left[V_{m_1}^2 + U_2^2 - V_{m_2}^2\left[1+\cot^2\beta_2\right)\right]$$

$\therefore\ e_{static} = \frac{1}{2}\left[V_{m_1}^2 + U_2^2 - V_{m_2}^2 \operatorname{cosec}^2\beta_2\right]$

The static pressure rise is given by, $(P_2 - P_1) = \rho\, e_{static}$

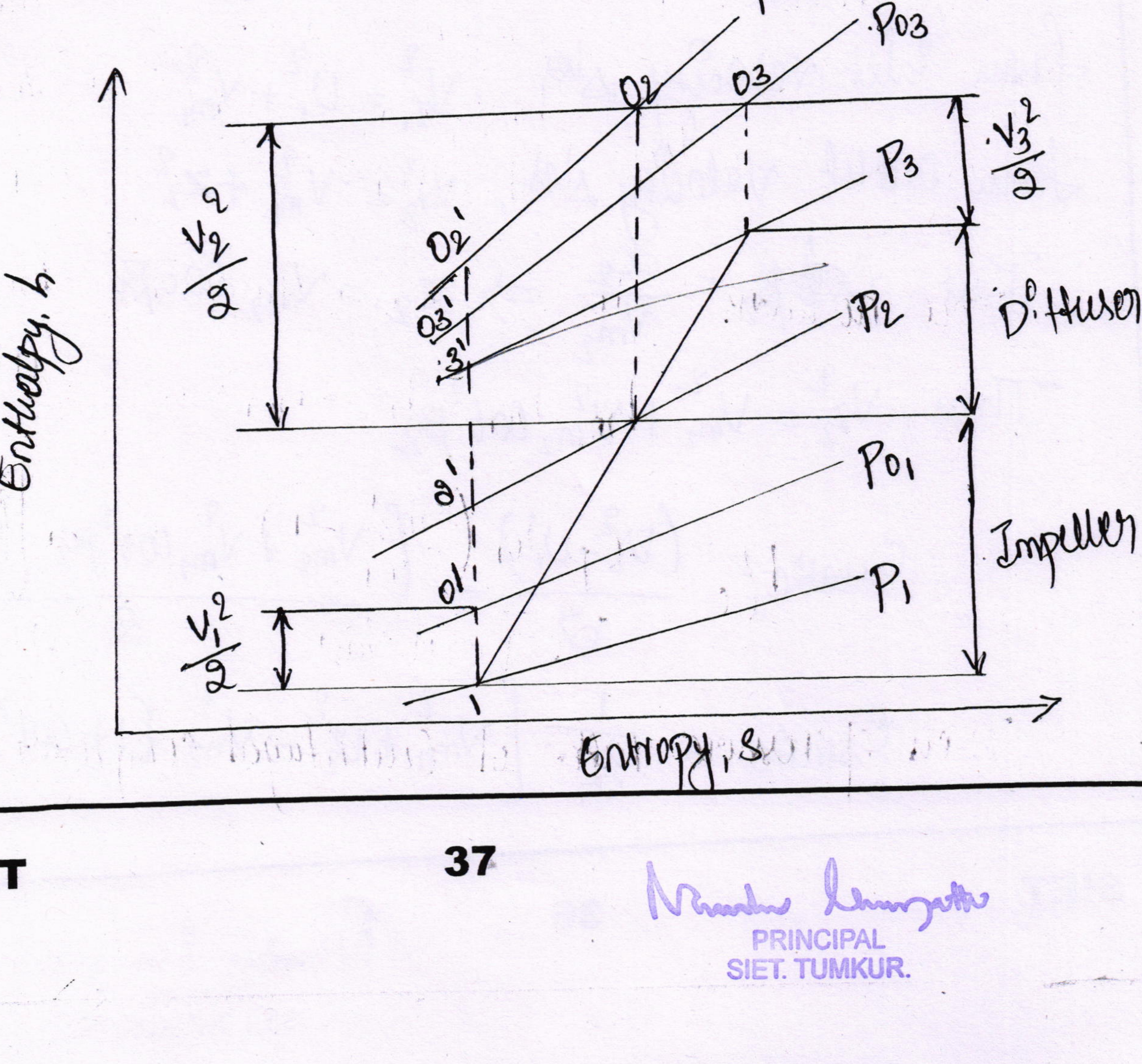
$$(P_2 - P_1) = \frac{\rho}{2}\left[V_{m_1}^2 + U_2^2 - V_{m_2}^2 \operatorname{cosec}^2\beta_2\right]$$

The static head rise is given by, $h = \frac{(P_2 - P_1)}{\rho g} = \frac{e_{static}}{g}$

$$\boxed{\frac{(P_2 - P_1)}{\rho g} = \frac{1}{2g}\left[V_{m_1}^2 + U_2^2 - V_{m_2}^2 \operatorname{cosec}^2\beta_2\right]}$$

5. Derive an expression of overall pressure ratio of a centrifugal compressor in terms of impeller tie up speed, slip, power input factor and isentropic efficiency of compressor.

Sol



Euler's work done, $e = U_2 V_{u2}'$ (Because $V_{u1} = 0$)

For backward curved vanes,

$$V_{u2}' = U_2 - V_{m2} \cot\beta_2$$

Then, $e = U_2(U_2 - V_{m2} \cot\beta_2)$

For forward curved vanes,

$$V_{u2}' = U_2 + V_{m2} \cot(180° - \beta_2) = U_2 - V_{m2} \cot\beta_2$$

Then, $e = U_2(U_2 - V_{m2} \cot\beta_2)$

For radial vanes, $V_{u2}' = U_2$

$$e = U_2^2$$

Stage efficiency, $\eta_c = \dfrac{\text{Total isentropic enthalpy rise b/w inlet \& outlet}}{\text{Actual enthalpy rise b/w same total pressure limits}}$

$$\eta_c = \frac{h_{03}' - h_{01}}{h_{03} - h_{01}} = \frac{C_p(T_{03}' - T_{01})}{h_{03} - h_{01}}$$

Since, no work is done in the diffuser, $h_{02} = h_{03}$.

$$h_{03} - h_{01} = h_{02} - h_{01} = W = \Omega \mu U_2 V_{u2}'$$

$$\eta_c = \frac{C_p T_{01}\left(\frac{T_{03}'}{T_{01}} - 1\right)}{\Omega \mu U_2 V_{u2}'} = \frac{C_p T_{01}\left[\left(\frac{P_{03}}{P_{01}}\right)^{\frac{\gamma-1}{\gamma}} - 1\right]}{\Omega \mu U_2 V_{u2}'}$$

Then pressure ratio of centrifugal compressor is,

$$P_{r0} = \frac{P_{03}}{P_{01}} = \left[1 + \frac{\eta_c \Omega \mu U_2 V_{u2}}{C_p T_{01}}\right]^{\frac{\gamma}{\gamma-1}}$$

For backward curved vanes.

$$P_{r0} = \left[1 + \frac{\eta_c \Omega \mu U_2 \left[U_2 - V_{m2} \cot \beta_2\right)}{C_p T_{01}}\right]^{\frac{\gamma}{\gamma-1}}$$

For forward curved vanes.

$$P_{r0} = \left[1 + \frac{\eta_c \Omega \mu U_2 \left[U_2 - V_{m2} \cot \beta_2\right)}{C_p T_{01}}\right]^{\frac{\gamma}{\gamma-1}}$$

For radial vanes,

$$\boxed{P_{r0} = \left[1 + \frac{\eta_c \Omega \mu U_2^2}{C_p T_{01}}\right]^{\frac{\gamma}{\gamma-1}}}$$

6. What is cavitation in a centrifugal pump? what are the effects of cavitation?

Sol? If the pressure at any point in a suction side of centrifugal pump falls below the vapour pressure, then the water starts boiling forming saturated vapour bubbles. Thus, formed bubbles moves at very high velocity to the more pressure side of the impeller blade & strikes the surface of the blade & collapse there. In this way, as the pressure further decreases, more bubbles will be formed and collapses on the surfaces of the blades, physically enables to erosion and pitting. This process takes place forming a cavities on blades.

many thousand times in a second & damages the blade of a centrifugal pump. This phenomenon is known as cavitation.

Effects

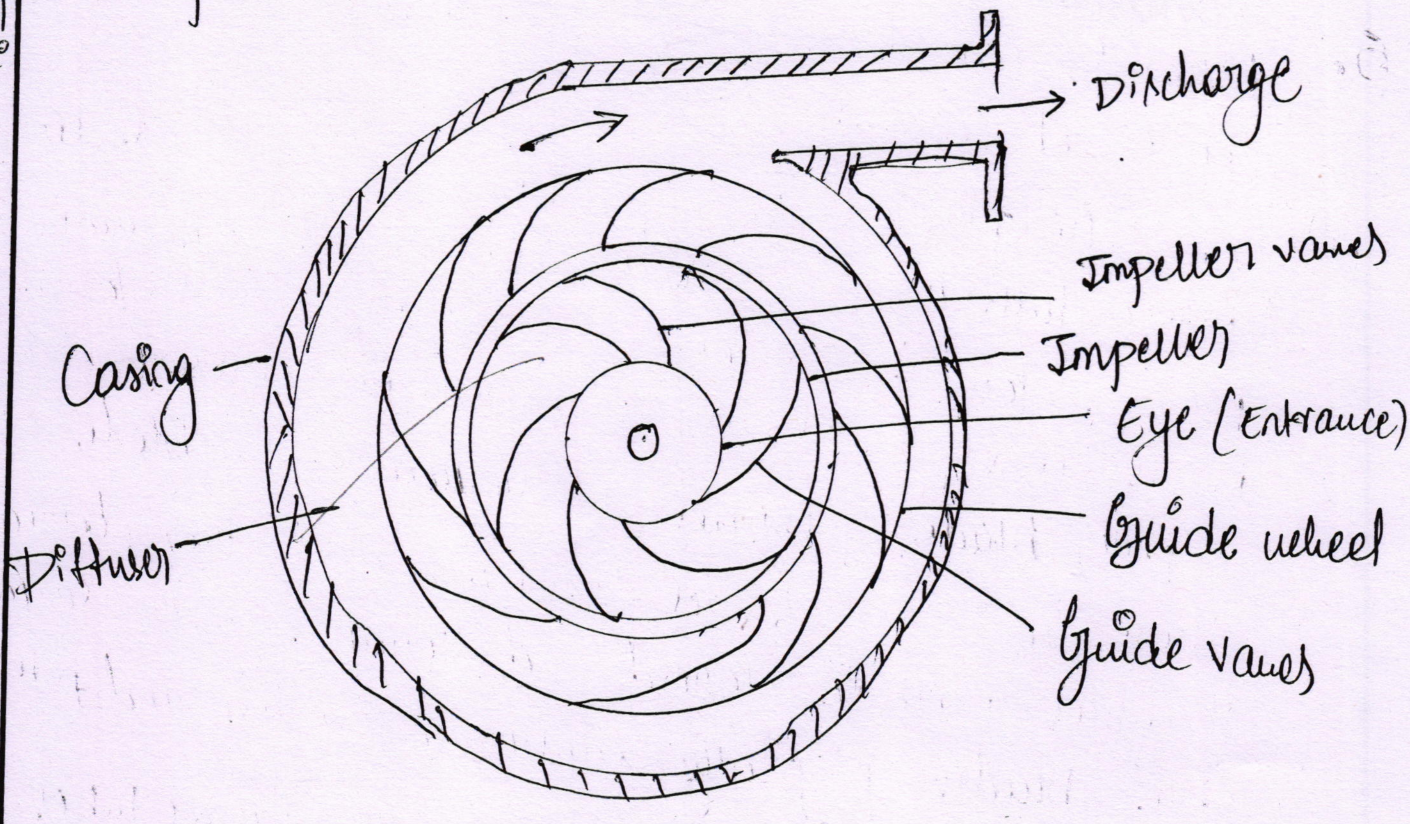
→ The metallic surfaces damaged & cavities are formed on the impeller surface.

→ Considerable noise and vibration are produced due to the sudden collapse of vapour bubble.

→ The efficiency of the machine reduces.

3. Explain the working principle of centrifugal compressor with a neat sketch.

5M



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→ The principal components are the impeller and the diffuser when the impeller is rotating at high speed, air is drawn in through the eye of the impeller.

→ The absolute velocity of the inflow air is axial.

→ The air then flows radially through the impeller passages due to centrifugal force.

→ The total mechanical energy driving the compressor is transmitted to the fluid stream in the impeller where it is converted into kinetic energy, pressure & heat due to friction.

→ The air leaving the diffuser is collected in a spiral casing from which it is discharged from compressor.

→ The pressure & velocity variation across the centrifugal compressor is shown in fig.

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