Chapter 11 : Turbomachinary

Turbomachine : a device which adds (↓ pump) or extracts (↓ Turbine) energy from a fluid

Pumps
- → PDP — Viscosity ما بتأثر بال
- → Dynamic (momentum change) — Viscosity بتأثر بال

Centrifugal pumps

$$H = h_p - h_f = \frac{P_2 - P_1}{\rho g} + \frac{V_2^2 - V_1^2}{2g} + z_2 - z_1$$

H: net useful head delivered to the fluid

h_p: pump head
h_f: head loss

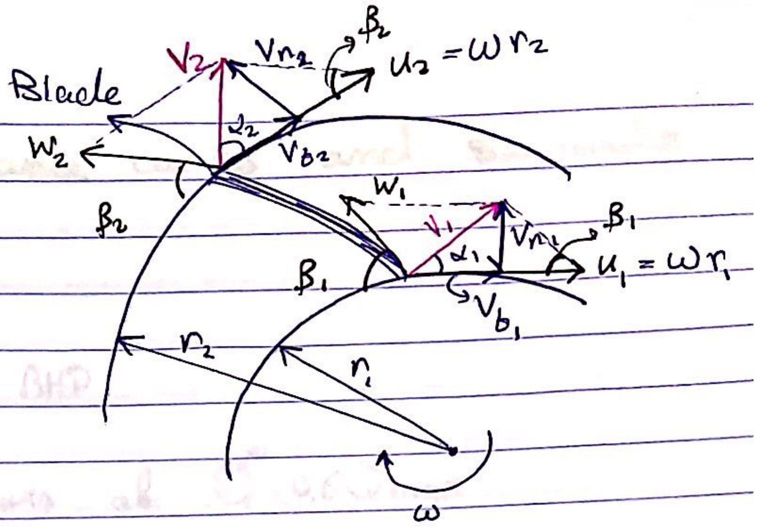
usually: $V_1 \approx V_2$, $\Delta z = 0$

and so $H \simeq \frac{\Delta P}{\rho g}$

Ideal power $= \rho Q g H$

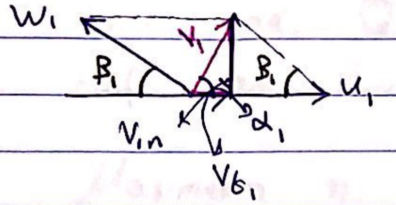
effeciency : $\eta = \frac{P_w}{BHP} = \frac{\rho Q g H}{BHP} = \frac{\rho Q g H}{\omega T}$

where : η: effeciency
P_w: Power to fluid
BHP: shaft power needed to derive the pump
ω: angular speed of shaft
T: Torque delievered to pump shaft



Pump theory

At the inner radius



$$u_1 = r_1 \omega$$
$$V_{n_1} = V_1 \sin\alpha_1 = W_1 \sin\beta_1$$
$$V_{b_1} = V_1 \cos\alpha_1 = u_1 - W_1 \cos\beta_1$$

Ideal pump design
$V_{n_1} = V_1$
$\alpha_1 = 90^\circ$

$$Q = A_1 V_{n_1} = 2\pi r_1 b_1 V_{n_1}$$
(b_1 → inlet width)

for second inlet $V_{n_2} = \dfrac{Q}{2\pi r_2 b_2}$ ← same for first inlet

$$V_{t_2} = V_2 \cos\alpha_2 = u_2 - W_2 \cos\beta_2$$
$$= u_2 - \frac{V_{2n}}{\tan\beta_2}$$

Remember:-
$\tan\beta_2 = \dfrac{V_{2n}}{W_2 \cos\beta_2}$

and $Q = A_1 V_{n_1} = A_2 V_{n_2}$

$$T = \rho Q (r_2 V_{b_2} - r_1 V_{b_1})$$
$$P_w = \rho Q \omega (r_2 V_{b_2} - r_1 V_{b_1})$$

$$BHP = \frac{P_w}{\eta_p}$$

$$H = \frac{u_2 V_{b_2} - u_1 V_{b_1}}{g}$$

$$\text{shut off head} = \frac{u_2^2}{g}$$

11.3: Pump Preformance curves and similarity rules

Ind. var: Q
dep. var: H, η, BHP

Maximum η occurs at $Q^* = 0.6\,Q_{max}$

Best efficiency point, BEP → $Q = Q^*$
$hp = hp^*$
$BHP = BHP^*$

Dimensionless pump parameters:-

$C_Q = \frac{Q}{nD^3}$ (capacity coefficient)

$C_H = \frac{gH}{n^2 D^2}$ (Head coefficient)

$C_P = \frac{bhp}{\rho n^3 D^5}$ (Power coefficient)

If we calculate Q^*, H^*, bhp^* we use

C_Q^*, C_H^*, C_P^* : in the book $C_Q^* = 0.115$
$C_H^* = 5$
$C_P^* = 0.65$

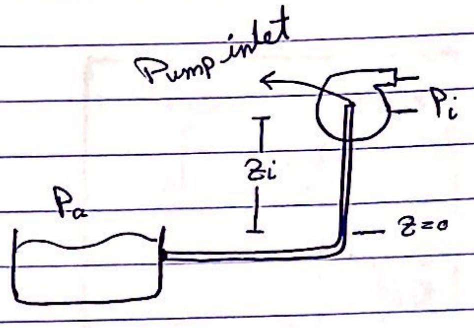
explained next page ←

$C_{HS} = \frac{g\,(NPSH)}{n^2 D^2} = C_{HS}\,C_Q$

Net positive suction head NPSH

hand side of $NPSH = \frac{P_i}{\rho g} + \frac{V_i^2}{2g} - \frac{P_v}{\rho g}$

left side of $NPSH = \frac{P_a}{\rho g} - z_i - h_f - \frac{P_v}{\rho g}$



HS $\geq$ LS to avoid cavitation

Similarity rules: used when two pumps from same geometric design family and are operating at similar operating conditions

$$\frac{Q_2}{Q_1} = \frac{n_2}{n_1}\left(\frac{D_2}{D_1}\right)^3$$

$$\frac{H_2}{H_1} = \left(\frac{n_2}{n_1}\right)^2\left(\frac{D_2}{D_1}\right)^2$$

$$\frac{bhp_2}{bhp_1} = \frac{\rho_2}{\rho_1}\left(\frac{n_2}{n_1}\right)^3\left(\frac{D_2}{D_1}\right)^5$$