Multi Stage:

A Three stage centrifugal pump has impellers 40 cm in diameter and 2 cm wide at outlet. The vanes are curved back at the outlet at 45° and reduce the circumferential area by 10%. The manometric efficiency is 90% and the overall efficiency is 80%. Determine the head generated by the pump when running at 1000 rpm delivering 50 litre per second. What would be the shaft horse power?

Given:

Number of stages $n = 3$

Dia of impeller at o/l $D_2 = 40\,cm = 0.40\,m$

Width at outlet $B_2 = 2\,cm = 0.02\,m$

Vane angle at o/l $\phi = 45^\circ$

Reduction in area at outlet $= 10\% = 0.1$

Area of flow at outlet $= 0.9 \times \pi D_2 \times B_2$

$= 0.9 \times \pi \times 0.4 \times 0.02$

$= 0.02262\,m^2$

Manometric efficiency $\eta_{man} = 90\% = 0.90$

Overall efficiency $\eta_o = 80\% = 0.80$

Speed $N = 1000$ rpm.

Discharge $Q = 50$ litres/second $= 0.05\,m^3/s$

Determine:

(i) Head generated by the pump

(ii) Shaft power

Velocity of flow at outlet $V_{f_2} = \frac{\text{Discharge}}{\text{Area of flow}}$

$= \frac{0.05}{0.02262}$

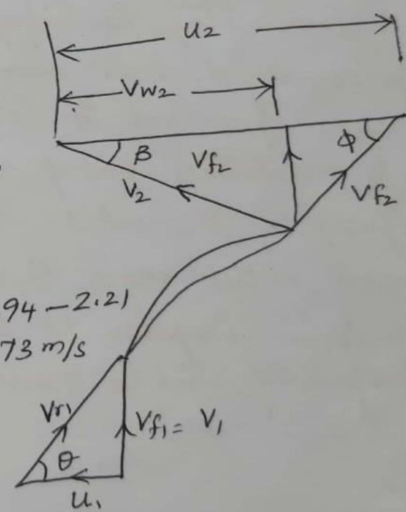
$= 2.21 \text{ m/s}$

Tangential velocity of impeller at outlet

$u_2 = \frac{\pi D_2 N}{60}$

$u_2 = \frac{\pi \times 0.4 \times 1000}{60}$

$u_2 = 20.94 \text{ m/s}$



$\tan\phi = \frac{V_{f_2}}{u_2 - V_{w_2}}$

$u_2 - V_{w_2} = \frac{V_{f_2}}{\tan\phi} = \frac{2.21}{\tan 45^\circ}$

$u_2 - V_{w_2} = 2.21 \text{ m/s}$

$V_{w_2} = u_2 - 2.21 = 20.94 - 2.21$

$= 18.73 \text{ m/s}$

using the equation

$\eta_{man} = \frac{g H_m}{V_{w_2} u_2}$

$0.90 = \frac{9.81 \times H_m}{18.73 \times 20.94}$

$H_m = \frac{0.90 \times 18.73 \times 20.94}{9.81} = 35.98 \text{ m}$

using equation Total head $= n \times H_m = 3 \times 35.98 = 107.94 \text{ m}$

Power o/p of the pump $= \frac{\text{weight of water lifted} \times \text{Total head}}{1000}$

$= \frac{\rho g \times Q \times 107.94}{1000} = \frac{1000 \times 9.81 \times 0.05 \times 107.94}{1000}$

$= 52.94$ KW

Using equation $\eta_o = \dfrac{\text{Power o/p of pump}}{\text{Power i/p of pump}}$

$= \dfrac{52.94}{\text{Shaft power}}$

$\text{Shaft power} = \dfrac{52.94}{\eta_o}$

$= \dfrac{52.94}{0.80}$

Shaft Power = 66.175 KW

For practice

A four-stage centrifugal pump has four identical impellers, keyed to the same shaft. The shaft is running at 400 rpm and the total manometric head developed by the multistage pump is 40 m. The discharge through the pump is 0.2 m^3/s. The vanes of each impeller are having outlet angle as 45°. If the width and diameter of each impeller at outlet is 5 cm and 60 cm respectively, find the manometric efficiency.

G.D

$n = 4$

$N = 400$ rpm

$H_m = 40$ m

H_m for each stage $= \dfrac{40}{4} = 10$ m

$Q = 0.2\ m^3/s$

o/l vane angle $\phi = 45°$

width of outlet $B_2 = 5\text{ cm} = 0.05$ m

Diameter at outlet $D_2 = 60\text{ cm} = 0.6$ m

Tangential velocity of impeller at outlet $u_2 = \dfrac{\pi D_2 N}{60}$

$= \dfrac{\pi \times 0.6 \times 400}{60}$

$u_2 = 12.56$ m/s

velocity of flow at outlet

$V_{f_2} = \dfrac{\text{Discharge}}{\text{Area of flow}} = \dfrac{0.20}{\pi D_2 B_2}$

$V_{f_2} = \dfrac{0.20}{\pi \times 0.6 \times 0.5} = 2.122$ m/s

W.K.T velocity triangle at outlet

$$\tan\phi = \frac{V_{f_2}}{u_2 - V_{w_2}}$$

$$u_2 - V_{w_2} = \frac{V_{f_2}}{\tan\phi} = \frac{2.122}{\tan 45^\circ} = 2.122 \text{ m/s}$$

$$V_{w_2} = u_2 - 2.122 = 12.56 - 2.122$$

$$V_{w_2} = 10.438$$

$$\eta_{man} = \frac{g H_m}{V_{w_2} u_2} = \frac{9.81 \times 10.0}{10.438 \times 12.56} = 0.7482 = 74.82\%$$

Problem on minimum speed ✓

The diameter of an impeller of a Centrifugal pump at inlet and outlet are 30 cm and 60 cm respectively. The velocity of flow at outlet is 2 m/s and the vanes are set back at an angle of 45° at the outlet. Determine the minimum starting speed of the pump if the manometric efficiency is 70%.

Given:

$D_i = 30\text{cm} = 0.30\text{m}$, $D_o = 60\text{cm} = 0.60\text{m}$, $\eta_{man} = 70\% = 0.70$

velocity of flow at outlet $V_{f_2} = 2 \text{ m/s}$

Vane angle at outlet $\phi = 45^\circ$

Let the minimum starting speed $= N$.

Solution:

W.K.T velocity triangle at o/l $\tan\phi = \frac{V_{f_2}}{(u_2 - V_{w_2})}$ (or) $u_2 - V_{w_2} = \frac{V_{f_2}}{\tan\phi}$

$$u_2 - V_{w_2} = \frac{2}{\tan 45^\circ} = 2.$$

$V_{w2} = u_2 - 2$

$u_2 = \frac{\pi D_2 N}{60} = \frac{\pi \times 0.60 \times N}{60} = 0.03141 N$

$V_{w2} = (0.03141 N - 2)$

W.K.T Equation for Minimum Starting speed.

$N = \frac{120 \times \eta_{man} \times V_{w2} \times D_2}{\pi (D_2^2 - D_1^2)} = \frac{120 \times 0.70 \times (0.03141N - 2) \times 0.6}{\pi (0.6^2 - 0.3^2)}$

$N = \frac{50.4 (0.03141N - 2.0)}{\pi (0.36 - 0.09)} = 59.417 (0.03141N - 2.0)$

$N = 1.866N - 118.834$

$1.866N - N = 118.834$ (or) $0.886N = 118.834$

$N = \frac{118.834}{0.866}$

$\boxed{N = 137.22 \text{ rpm}}$

Model Testing of Centrifugal pump:

Two geometrically similar pumps are running at the same speed of 1000 rpm one pump has an impeller diameter of 0.30 metre and lifts water at the rate of 20 litres per second against a head of 15 metre. Determine the head and impeller diameter of the other pump to deliver half the discharge.

Given

For pump No. 1

$N_1 = 1000$ rpm

$D_1 = 0.30$ m

$Q_1 = 20$ litres/second

$Q_1 = 0.02\ m^3/s$

Head $H_{m_1} = 15$ m

For pump No. 2

$N_2 = 1000$ rpm

Discharge $Q_2 = \frac{Q_1}{2} = \frac{20}{2} = 10$ lit/s

$Q_2 = 0.01\ m^3/s$

D_2 = Diameter of impeller

H_{m_2} = Head developed.

Using equation $\frac{N_1\sqrt{Q_1}}{H_{m_1}^{3/4}} = \frac{N_2\sqrt{Q_2}}{H_{m_2}^{3/4}}$

$$\frac{1000 \times \sqrt{0.02}}{15^{3/4}} = \frac{1000 \times \sqrt{0.01}}{H_{m_2}^{3/4}}$$

$$H_{m_2}^{3/4} = \frac{1000 \times \sqrt{0.01} \times 15^{3/4}}{1000 \times \sqrt{0.02}}$$

$$= \sqrt{\frac{0.01}{0.02}} \times 7.622$$

$$= 5.389 = (5.389)^{4/3}$$

$$H_{m_2} = 9.44\ m$$

Using the equation $\left(\frac{\sqrt{H_m}}{DN}\right)_1 = \left(\frac{\sqrt{H_m}}{DN}\right)_2$

(or)

$$\frac{\sqrt{H_{m1}}}{D_1 N_1} = \frac{\sqrt{H_{m2}}}{D_2 N_2}$$

$$\frac{\sqrt{15}}{0.3 \times 1000} = \frac{\sqrt{9.44}}{D_2 \times 1000}$$

$$D_2 = \frac{\sqrt{9.44} \times 0.3}{\sqrt{15}}$$

$$D_2 = 0.238\,m$$

$$\boxed{D_2 = 238\,mm}$$

Problem on Cavitation ✓

A Centrifugal pump rotating at 1000 rpm delivers 160 lit/sec of water against a head of 30m. The pump is installed at a place where atmosphere Pressure is 1×10^5 Pa (abs) and Vapour Pressure of water is 3 Kpa (abs). The head loss in Suction pipe is equivalent to 0.2m of water. Calculate (i) Minimum NPSH (ii) Maximum allowable height of the pump from free surface of water in the Sump.

Given:

$N = 1000$ rpm $Q = 160$ lit/second $= 0.16\ m^3/s$

$H_m = 30m$, $P_a = 1 \times 10^5 Pa\,(abs) = 1 \times 10^5 N/m^2\,(abs)$

$P_v = 3\,K\,Pa\,(abs) = 3 \times 10^3 N/m^2\,(abs)$

$h_{fs} = 0.2m.$

(i) Minimum NPSH

Using the equation $\sigma = \frac{NPSH}{H_m}$

From the above equation, it is clear that NPSH is directly proportional to Thoma's Cavitation factor σ.

NPSH will be minimum when σ is minimum. But the minimum value of σ for no cavitation is σ_c

Hence when $\sigma = \sigma_c$ then NPSH will be minimum

$$\sigma_c = \frac{(NPSH)_{min}}{H_m}$$

$$\text{or } (NPSH)_{min} = H_m \times \sigma_c \quad \text{——— (1)}$$

Now the critical value of σ i.e σ_c is given by equation

$$\sigma_c = 1.03 \times 10^{-3} \times N_s^{4/3} \quad \text{——— (2)}$$

where N_s = Specific speed of pump

$$N_s = \frac{N\sqrt{Q}}{H_m^{3/4}}$$

$$N_s = 1000 \times \frac{\sqrt{0.16}}{30^{3/4}}$$

[$\because N = 1000$ rpm $Q = 0.16\ m^3/s$ $H_m = 30m$)

Substituting the value of N_s in equation (2) we get

$$\sigma_c = 1.03 \times 10^{-3} \times \left[\frac{1000 \times \sqrt{0.16}}{30^{3/4}}\right]^{4/3}$$

$$= 1.03 \times 10^{-3} \times \frac{1000^{4/3} \times 0.16^{2/3}}{30}$$

$$\sigma_c = \frac{1.03 \times 10^{-3} \times 10^4 \times 0.2947}{30}$$

$= 0.1012$

Substituting the value of σ_c in eqn (1) we get

$(NPSH)_{min} = H_m \times 0.1012$

$= 30 \times 0.1012$

$(NPSH)_{min} = 3.036m$

(ii) Maximum allowable height of the pump from free surface of water in the sump i.e h_s

Let $(h_s)_{max}$ = Max. allowable height of pump from free surface of water

using the equation

$NPSH = H_a - H_v - h_s - h_{fs}$ —— (3)

From the above equation, it is clear that for a given value of atmospheric pressure head $\left[H_a = \frac{P_a}{\rho g}\right]$

From the above equation, it is clear that for a given value of atmospheric pressure head $\left(H_a = \frac{P_a}{\rho g}\right)$ given vapour pressure head $\left(H_v = \frac{P_s}{\rho g}\right)$ given loss of head due to friction (h_{fs}) the value of suction head h_s will be maximum if NPSH is minimum

$NPSH_{min} = H_a - H_v - (h_s)_{max} - h_{fs}$

$(h_s)_{max} = H_a - H_v - h_{fs} - (NPSH)_{min}$

$H_a = \frac{P_a}{\rho g} = \frac{1 \times 10^5}{1000 \times 9.81} = 10.193m$ of water

$H_v = \frac{P_v}{\rho g} = \frac{3 \times 10^3}{1000 \times 9.81} = 0.305$ m of water

$h_{fs} = 0.2$ m and $(NPSH)_{min}$

$h_{fs} = 3.036$ m

Substituting the value of H_a, H_v, h_{fs} and $(NPSH)_{min}$ in equation (13) we get

$(h_s)_{max} = 10.193 - 0.305 - 0.2 - 3.036$

$$(h_s)_{max} = 6.652 \text{ m}$$

①

1. ①

UNIT-V PUMPS – IG.

Problems:

A single acting reciprocating pump has a stroke length of 170mm. Suction pipe is 10m long and the ratio of suction pipe diameter to the piston diameter is 3/4. The water level is the sump is 3.5m below the axis of the pump cylinder and the pipe connecting the sump and pump cylinder is 70mm in diameter. If the crank is running at 60 rpm; determine the pressure head on the piston at the beginning middle and end of the suction stroke. Take friction co-efficient f = 0.01.

Given data:

Stroke $L = 170mm = 0.17m$

Crank radius $r = \frac{L}{2} = \frac{0.17}{2} = 0.085m$

Length of Suction pipe $L_s = 10m$

$$\frac{d_s}{D} = \frac{3}{4}$$

Head of Suction $h_s = 3.5m$

Diameter of Suction pipe $d_s = 70mm = 0.07m$

UNIT-V PUMPS – IG.

Problems:

A single acting reciprocating pump has a stroke length of 170mm. Suction pipe is 10m long and the ratio of Suction pipe diameter to the piston diameter is 3/4. The water level is the sump is 3.5m below the axis of the pump cylinder and the pipe connecting the pump and pump cylinder is 70mm in diameter. If the crank is running at 60 rpm, determine the pressure head on the piston at the beginning middle and end of the suction stroke, Take friction co-efficient $f = 0.01$.

Given data:

Stroke $L = 170mm = 0.17m$

Crank radius $r = \frac{L}{2} = \frac{0.17}{2} = 0.085m$

Length of Suction pipe $L_s = 10m$

$$\frac{d_s}{D} = \frac{3}{4}$$

Head of Suction $h_s = 3.5m$

Diameter of Suction pipe $d_s = 70mm = 0.07m$

Speed of the Crank $N = 60$ rpm

Friction Co-efficient $f = 0.01$

Solution

$$\frac{A}{a_s} = \frac{\text{Area of piston}}{\text{Area of Suction pipe}} = \frac{\frac{\pi}{4} D^2}{\frac{\pi}{4} d_s^2}$$

$$= \left(\frac{D}{d_s}\right)^2 = \left(\frac{4}{3}\right)^2 = \frac{16}{9}$$

(i) Pressure head at the beginning of stroke.

At the beginning $\theta = 0°$

The pressure head $= h_s + h_{as} + h_{fs}$

$$h_{as} = \frac{l_s}{g} \frac{A}{a_s} \omega^2 r \quad [\because \cos 0° = 1]$$

$$h_{fs} = 0 \quad [\because \sin 0° = 0]$$

$$\therefore \text{The Pressure head} = 3.5 + \frac{10}{9.81}\left(\frac{16}{9}\right) \times \left(\frac{2\pi\ 60}{60}\right)^2 \times 0.085$$

$$= 9.58 \text{ m of water}$$

(ii) At the middle of stroke

$\theta = 90°$ $\quad \because \cos 90° = 0$

$h_{as} = 0$

$$h_{fs} = \frac{4 f l_s}{2 g d_s}\left(\frac{A}{a_s} \omega r\right)^2 \quad \because \sin 90° = 1.$$

$$= \frac{4 \times 0.01 \times 10}{2 \times 9.81 \times 0.07}\left[\frac{16}{9} \times \frac{2\pi \times 60}{60} \times 0.085\right]^2$$

$$= 0.263 \text{ m of water}$$

∴ The Pressure head $= h_s + h_{fs}$

$= 3.5 + 0.263$

$= 3.763$ m of water

(iii) At the end of stroke.

$\theta = 180°$

$h_{as} = \frac{-l_s}{g} \frac{A}{a_s} w^2 r$ [∵ $\cos 180° = -1$]

$= \frac{-10}{9.81} \left(\frac{16}{9}\right) \times \left(\frac{2\pi 60}{60}\right)^2 \times 0.085$

(∵ $\sin 180° = 1$)

$= -6.08$ m of water

$h_{fs} = 0$

∴ The Pressure head $= h_s + h_{as}$

$= 3.5 - 6.08$

$= -2.58$ m of water