

# Design of Machines and Mechanical Systems (PC-BTM711)

## **Session 28**

Module 7: Design of Centrifugal Pump Adv. Topics

# Session Outcomes

- Perform design calculations for main components of centrifugal pump
  - Suction and Delivery pipe
  - Volute casing
- Check system design for deformation and critical whirling speed
- Discuss axial thrust and design of wear rings

# Design Specification

- A centrifugal pump is to be designed for following specification.
  - Total head = 50 m
  - Discharge = 100 m<sup>3</sup>/hr
  - Liquid = water at 25°C

The pump is directly connected to electric motor. Select suitable motor for pump and design impeller shaft, impeller and casing with volute profile.

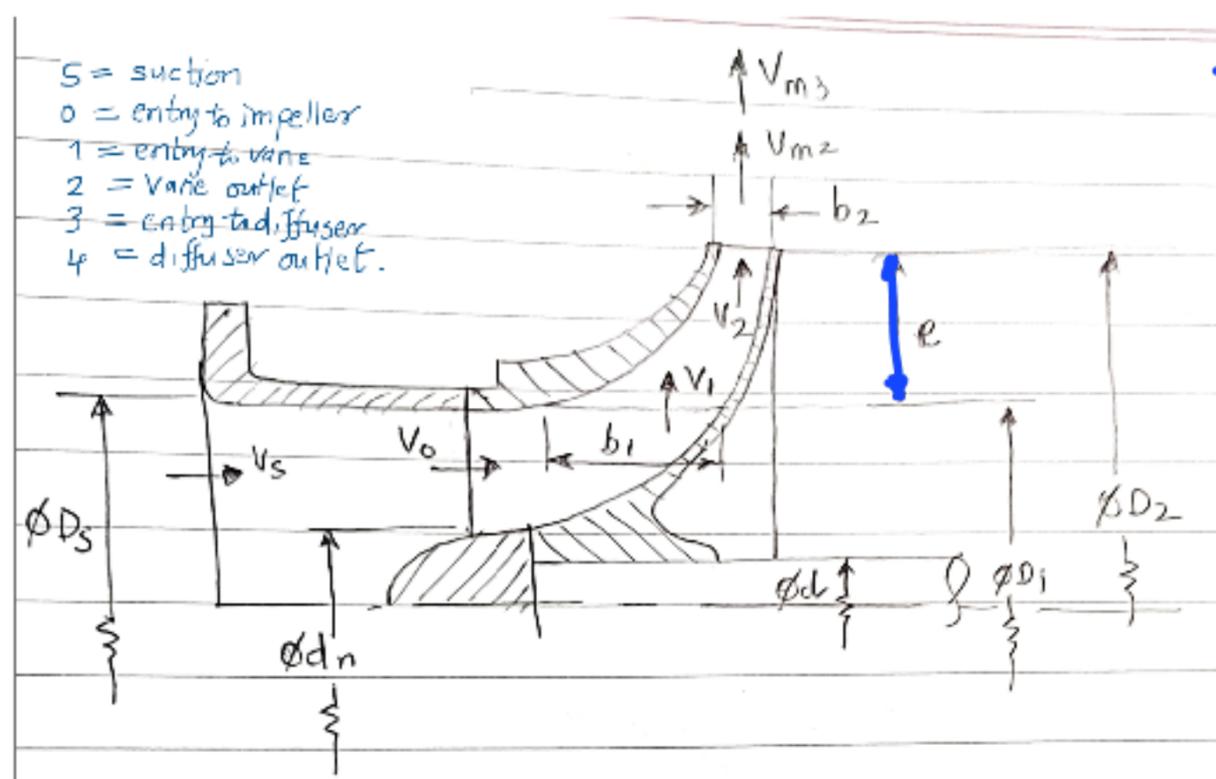
$$z = 13 \frac{\gamma_m}{e} \sin \beta_m$$

$$\beta_m = \frac{\beta_1 + \beta_2}{2}$$

$$\tan \beta_1 = \frac{V_{m1}}{u_1}$$

Absolute inlet vel. at vane  
 =  $V_0 \times 1.4$  for slow speed  
 $\times 1.25$  for high speed

$\beta_2 =$  discharge angle ( $24^\circ - 28^\circ$ )



(D) contd

(vii) Number of vanes (z)

$$\gamma_m = \frac{D_1 + D_2}{4} = \frac{134 + 400}{4} = \boxed{133.5 \text{ mm}}$$

$$V_{m1} = V_0 \times 1.25 \text{ (for high speed)} = 2.625 \times 1.25 = \boxed{3.281 \text{ m/s}}$$

$$u_1 = \left( \frac{2\pi n}{60} \right) \times \frac{D_1}{2} = \left( \frac{2\pi \times 1500}{60} \right) \times \frac{0.134}{2} = \boxed{10.52 \text{ m/s}}$$

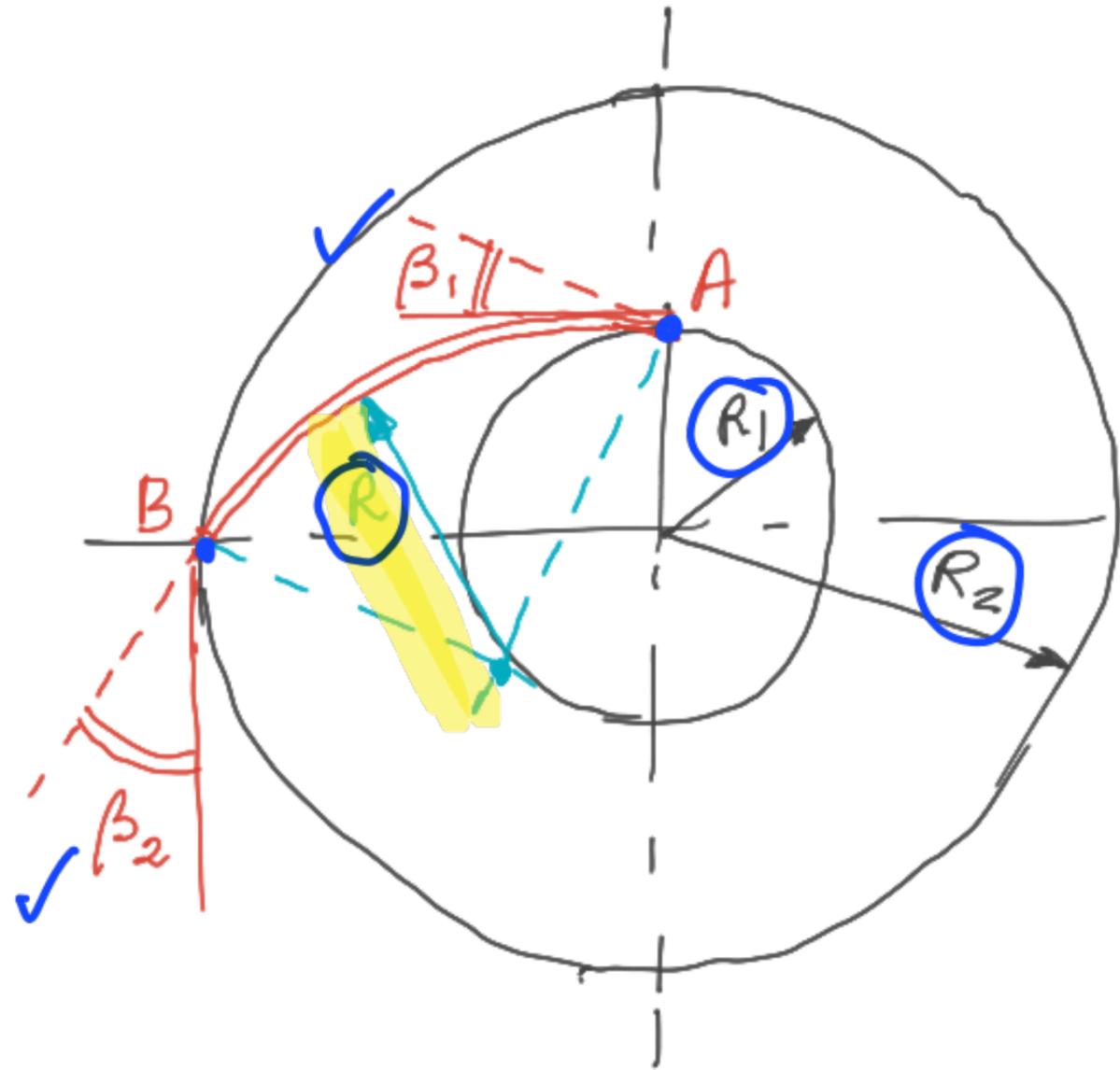
$$\therefore \tan \beta_1 = \frac{3.281}{10.52} \Rightarrow \beta_1 = \boxed{17.32^\circ}$$

$$\therefore \beta_m = \frac{17.32 + 25}{2} = \boxed{21.16^\circ}$$

$$e = \frac{D_2 - D_1}{2} = \frac{400 - 134}{2} = \boxed{133 \text{ mm}}$$

$$\therefore z = 13 \times \frac{133.5}{133} \sin 21.16^\circ = \boxed{4.71} \Rightarrow \boxed{z = 5}$$

(E) Design of plane vane profile (approx. method)



$$R_1 = \frac{134}{2} = 67 \text{ mm}$$

$$R_2 = \frac{400}{2} = 200 \text{ mm}$$

$$\beta_1 = 17.32^\circ \checkmark$$

$$\beta_2 = 25^\circ \checkmark$$

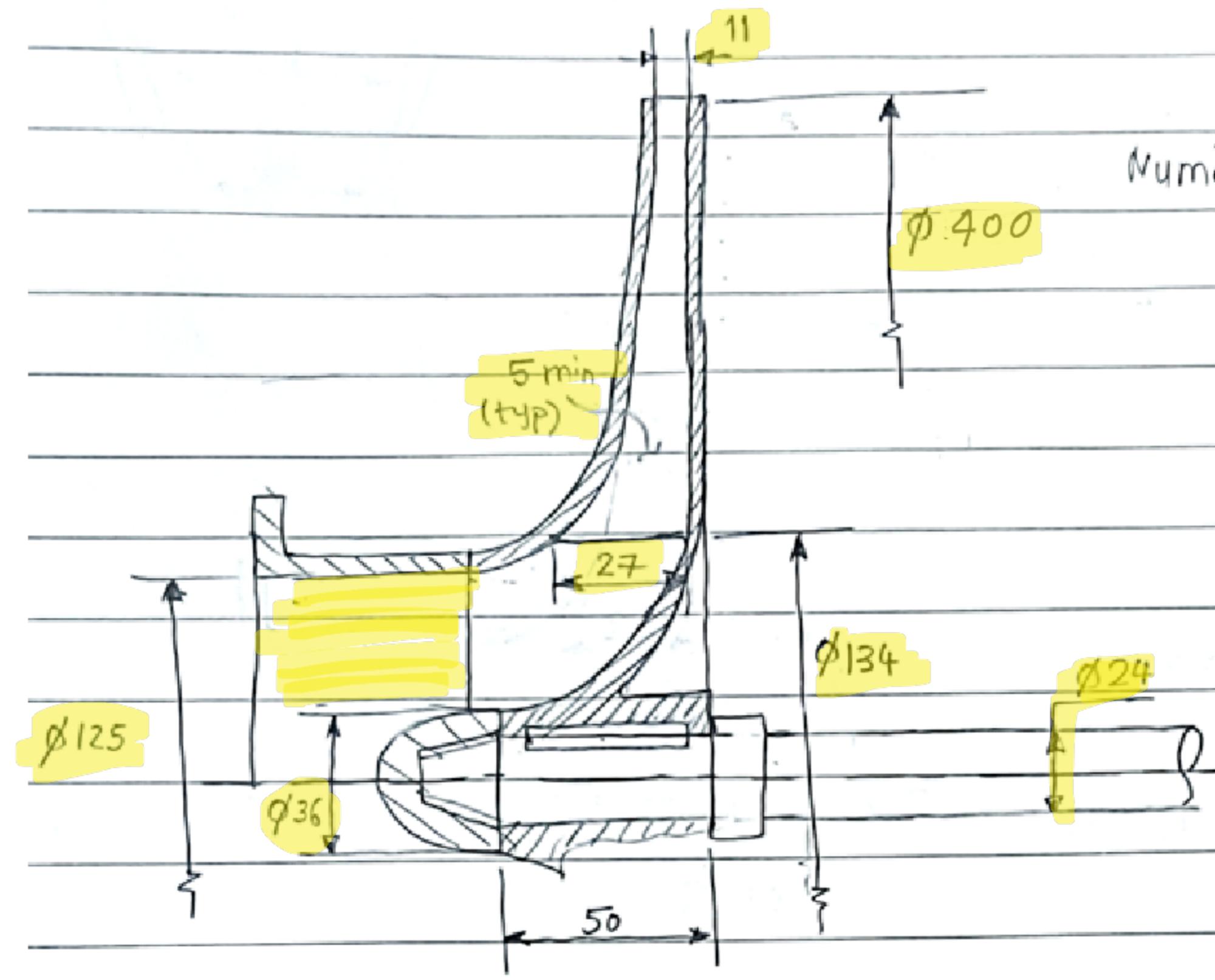
$$R = \frac{R_2^2 - R_1^2}{2(R_2 \cos \beta_2 - R_1 \cos \beta_1)}$$

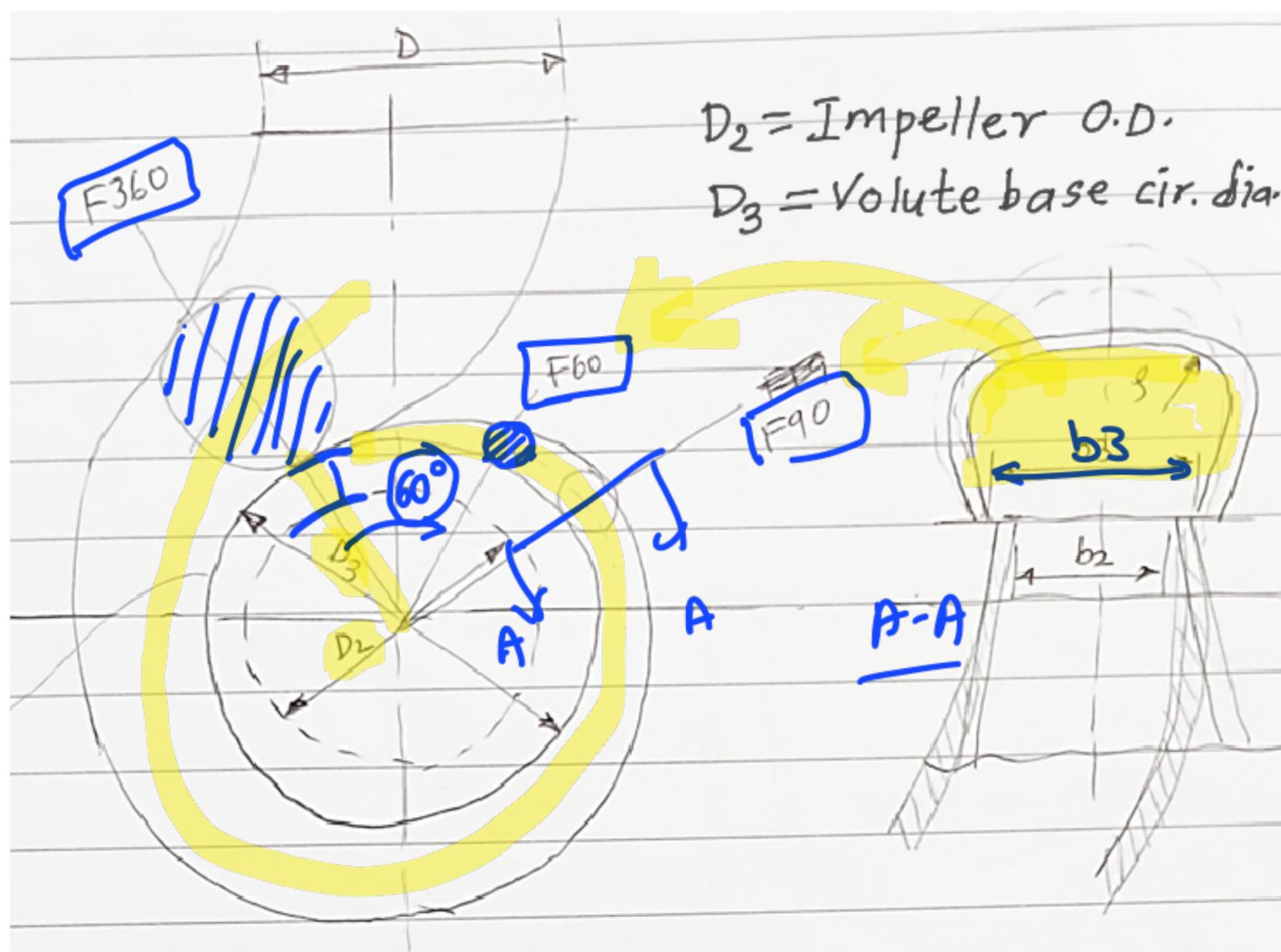
$$= \frac{200^2 - 67^2}{2(200 \cos 25^\circ - 67 \cos 17.32^\circ)}$$

$$= 151.4 \text{ mm}$$

Vane thickness = 3 to 10 mm  
(5 mm selected)

Number of vanes = 5





## (F) Design of Volute Casing

(i) Volute width ( $b_3$ )

$$\underline{b_3} = \boxed{2 b_2} \text{ when } \underline{n_g = 20}$$

$$= 1.75 b_2 \text{ when } n_g > 20$$

$$b_3 = 2 \times 11 = \boxed{22 \text{ mm}}$$

(ii) Volute base cir. dia. ( $D_3$ )

$$D_3 = \underline{D_2} + 2 \frac{D_2}{60}$$

$$= 0.4 + 2 \times \frac{0.4}{60}$$

$$= \underline{0.413 \text{ m}} = \boxed{415 \text{ mm}}$$

$$\underline{r_3} = D_3/2 = \boxed{207.5 \text{ mm}}$$

(F) contd

(iii) volute areas

$$F_{\theta} = \frac{\pi}{4} (2 \times \rho_{\theta})^2$$

$$\rho_{\theta} = \left( \frac{\theta}{C} \right) + \sqrt{2r_3 \left( \frac{\theta}{C} \right)}$$

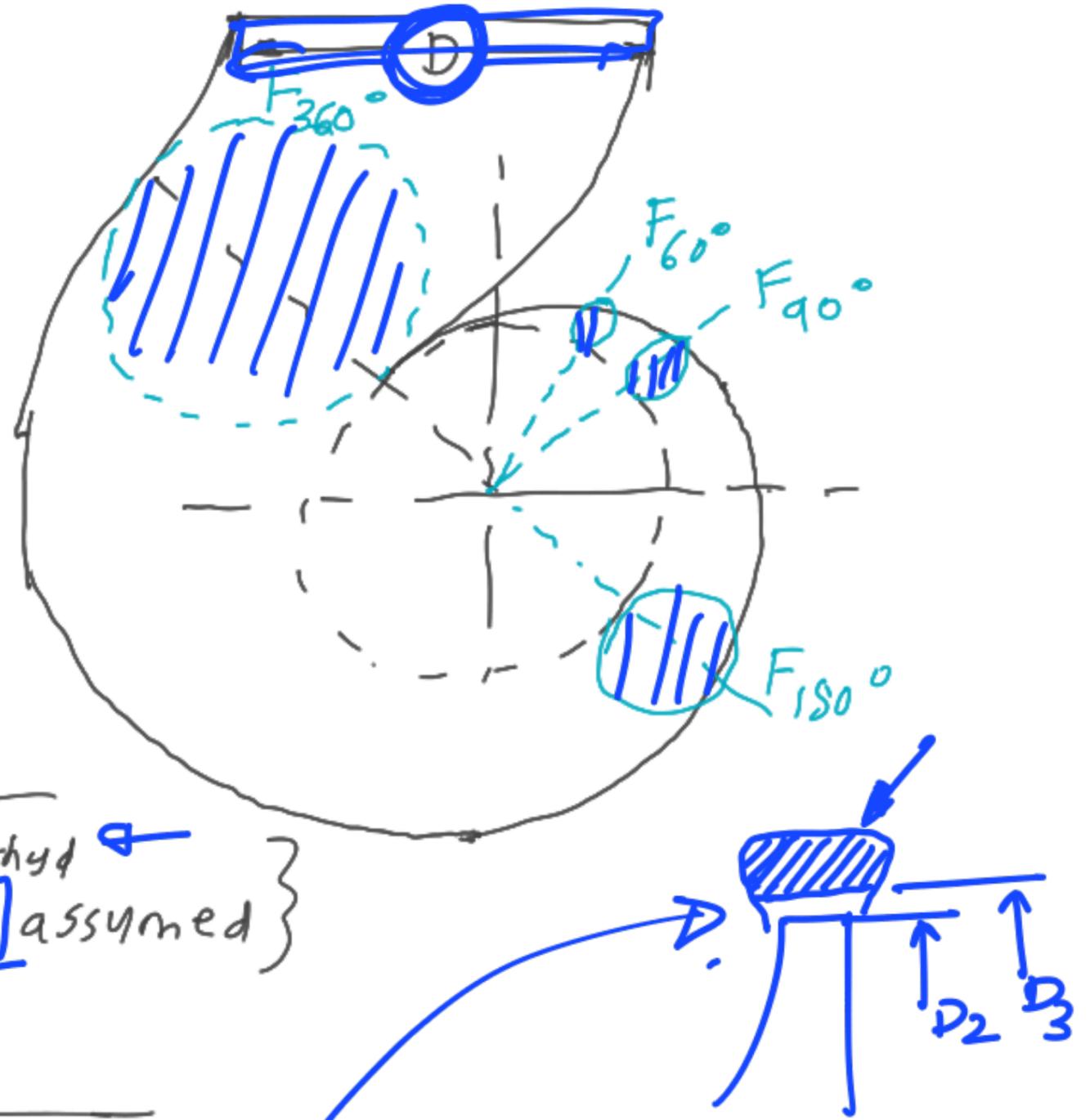
$$C = \frac{2 \times 360^{\circ} \times \pi \times g \times H_{th}}{WQ'}$$

$$\therefore C = \frac{2 \times 360^{\circ} \times \pi \times 9.806 \times (50/0.9)}{\left( \frac{2\pi \times 1500}{60} \right) \times (0.02944)} \left\{ \begin{array}{l} H_{th} = \frac{H}{\eta_{hyd}} \\ \eta = 0.9 \text{ assumed} \end{array} \right.$$
  
$$= 266,467.4$$

$$\therefore \rho_{360^{\circ}} = \frac{\sqrt{360}}{266,467.4} + \sqrt{\frac{2 \times 0.2075 \times 360}{266467.4}} = 0.025 \text{ m} = 25 \text{ mm}$$

$$\therefore F_{360^{\circ}} = \frac{\pi}{4} \times (2 \times 25)^2 = 1963.5 \text{ mm}^2$$

Similarly volute areas at other angular locations can be calculated.



(F) contd

(iv) Pipe diameter at delivery end of volute casing (D)

$$\boxed{Q'} = \frac{\pi}{4} D^2 \times \underline{V_d} \quad \left\{ \underline{V_d} = \underline{V_{m_2}} = \underline{2.6772 \frac{m}{s}}, \text{ from D(vi)} \right\}$$

$$\therefore 0.02944 = \frac{\pi}{4} \times D^2 \times 2.6772$$

$$\therefore D = \boxed{0.1183 \text{ m}} \approx \boxed{120 \text{ mm}}$$

(v) Thickness of delivery pipe

$$\begin{aligned} \underline{t} &= \frac{PD}{2\sigma} \\ &= \frac{0.49 \times 120}{2 \times 50} \\ &= \boxed{0.59 \text{ mm}} \end{aligned}$$

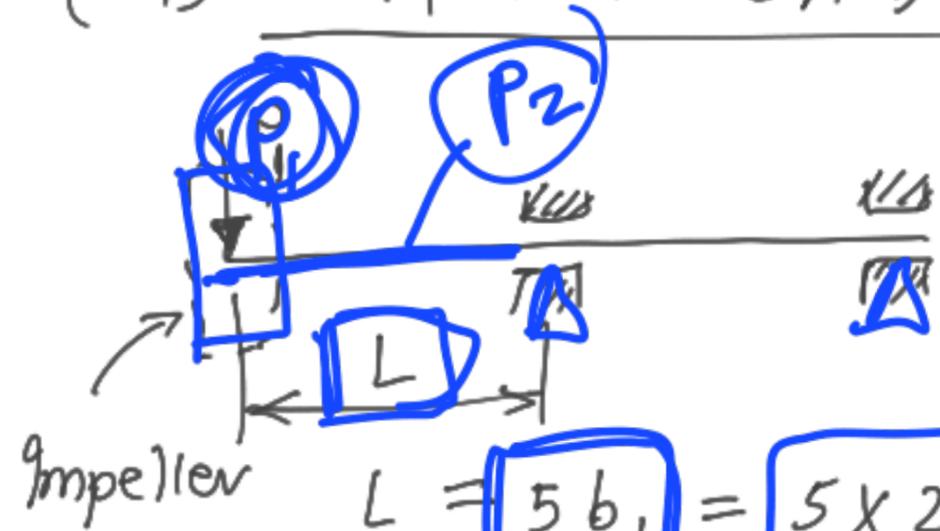
$$t > \boxed{10 \text{ mm}}$$

$$t_{\text{provided}} = \boxed{10 \text{ mm}}$$

density of fluid

$$\left. \begin{aligned} P &= \rho g H \times 10^{-6} \text{ MPa} \\ &= 1000 \times 9.806 \times 50 \times 10^{-6} = \boxed{0.49 \text{ MPa}} \\ \sigma &= \frac{\sigma_Y}{FOS} = \frac{\boxed{200}}{\boxed{4}} = \boxed{50 \text{ MPa}} \end{aligned} \right\}$$

# (G) Impeller shaft deflection check



$$L = 5b_1 = 5 \times 27 = 135 \text{ mm}$$

$$\text{deflection, } \gamma = \frac{L^3}{EI} \left( \frac{P_1}{3} + \frac{P_2}{8} \right)$$

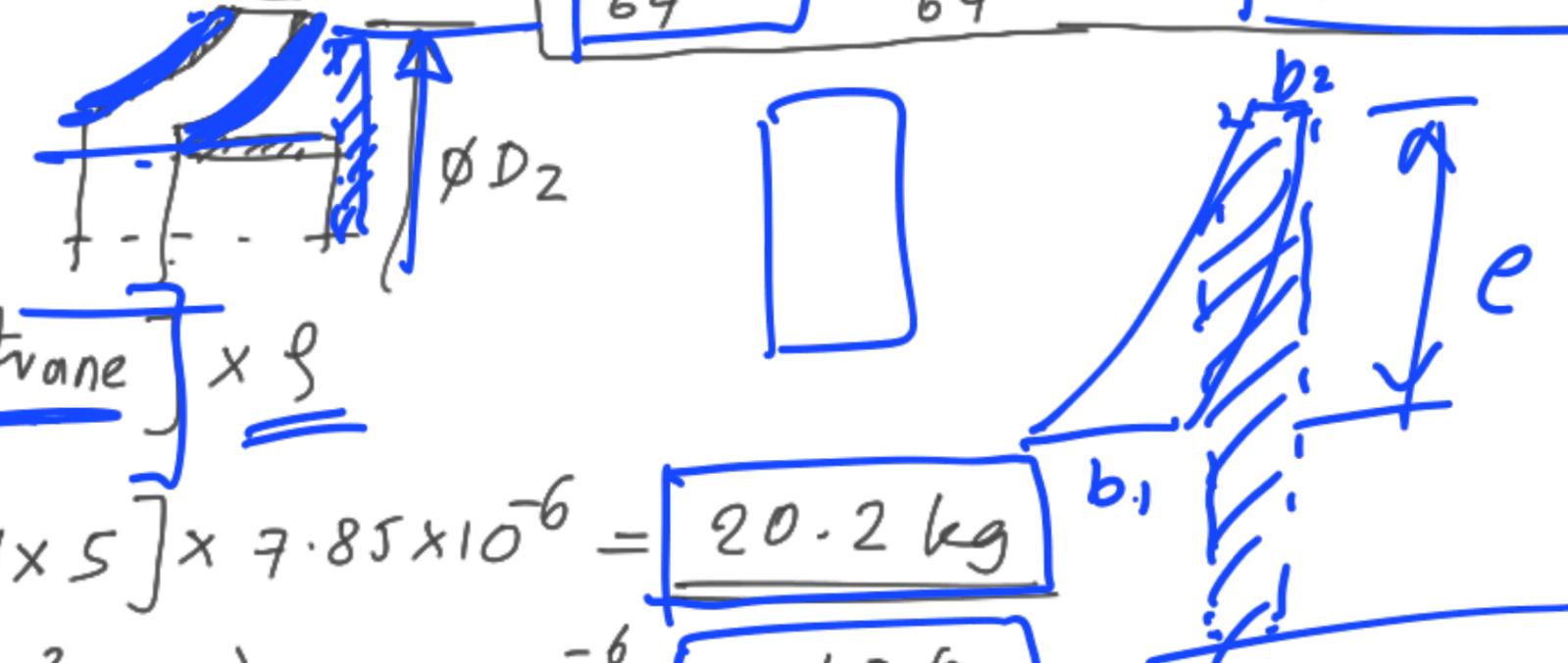
$$E = 200,000 \text{ MPa}$$

$$I = \frac{\pi}{64} d^4 = \frac{\pi}{64} \times 24^4 = 16,286 \text{ mm}^4$$

$P_1 =$  Weight of impeller

$$\approx \left[ \left( \frac{\pi}{4} D_2^2 t_i \right) \times 2 + z \times \left[ \frac{D_2}{2} \times b_2 \times t_{\text{vane}} \right] \right] \times \rho$$

front & back



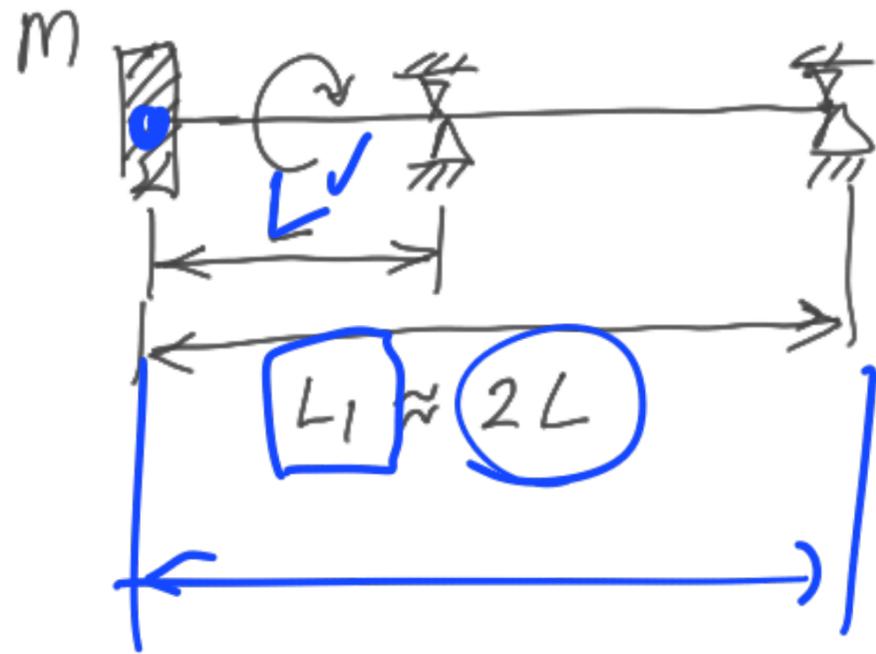
$$= \left[ \left( \frac{\pi}{4} \times 400^2 \times 10 \right) \times 2 + 5 \times \frac{400}{2} \times 11 \times 5 \right] \times 7.85 \times 10^{-6} = 20.2 \text{ kg}$$

$$P_2 = \text{Weight of shaft} = \left( \frac{\pi}{4} \times 24^2 \times 135 \right) \times 7.85 \times 10^{-6} = 0.48 \text{ kg}$$

$$\therefore \gamma = \frac{\sqrt{135^3}}{200,000 \times 16,286} \times \left( \frac{20.2 \times 9.806}{3} + \frac{0.48 \times 9.806}{8} \right) = 0.0503 \text{ mm}$$

$\gamma <$  wear ring clearance.

# (H) Critical speed of shaft



$$\begin{aligned} \underline{\underline{\omega_{cr}}} &= \sqrt{\frac{3EI}{mL^2L_1}} \\ &= \sqrt{\frac{3 \times (200 \times 10^9) \times (16,286 \times 10^{-12})}{20.2 \times (0.135)^2 \times (0.270)}} \end{aligned}$$

$$= 313.5 \text{ rad/s}$$

$$= 2993 \text{ rpm}$$

For smooth operation,

$\omega < (15 \text{ to } 25\%) \text{ of } \omega_{cr}$

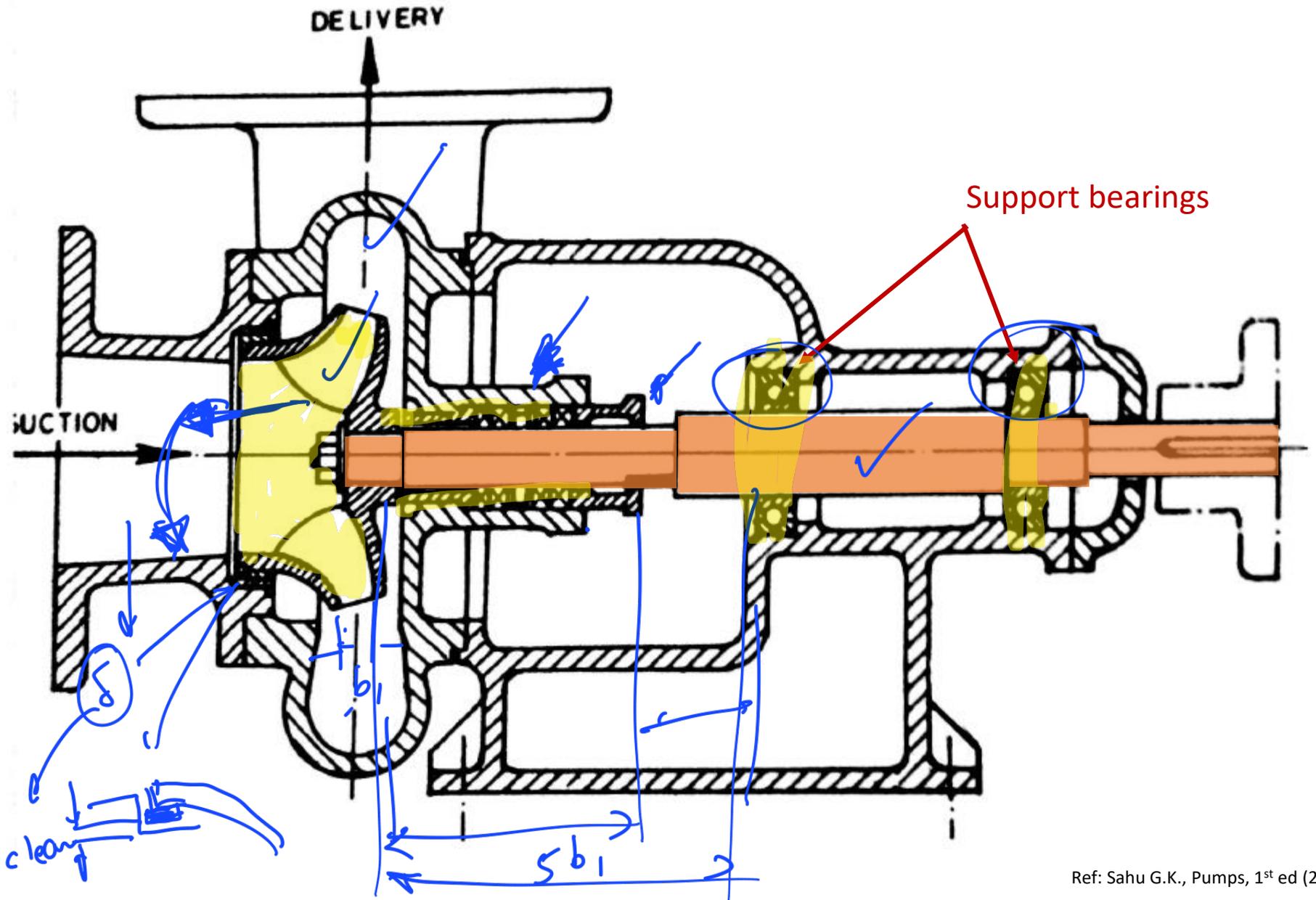
$$1500 \text{ rpm}$$

$$0.25 \times 2993 = 748.25 \text{ rpm}$$

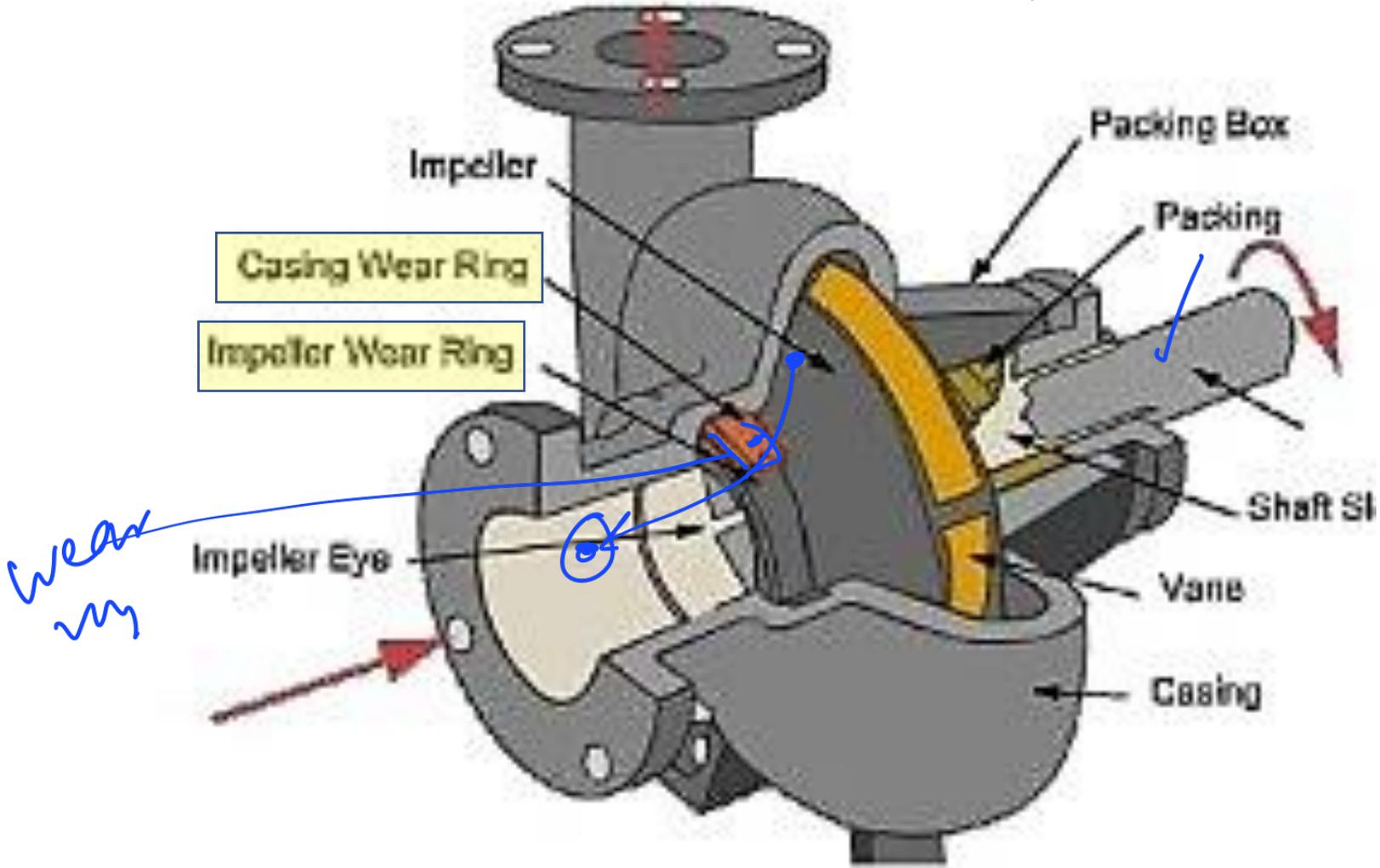
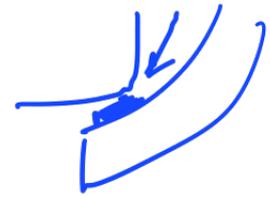
Since  $\omega > \omega_{reqd}$

⇒ Bearing location, impeller overhang need modification

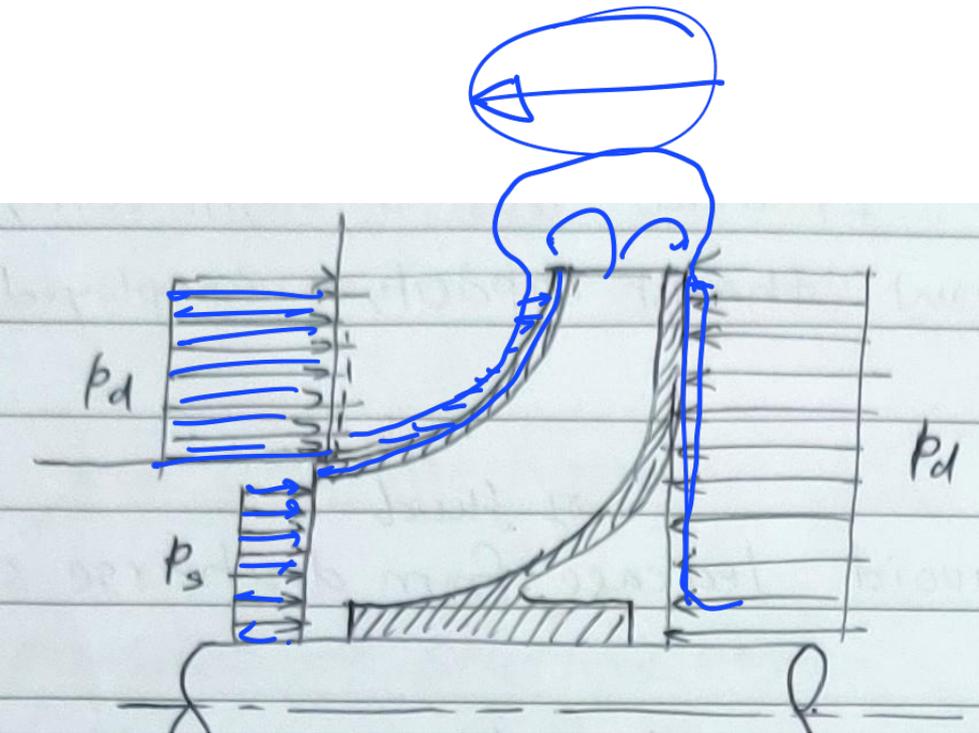
# Shaft Support



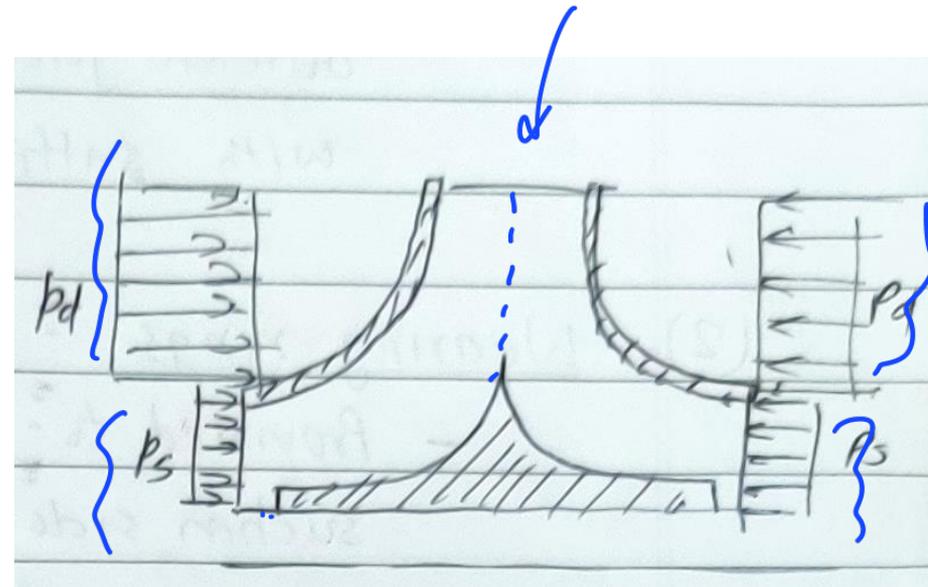
# Wear ring



# Axial Thrust in Centrifugal Pumps

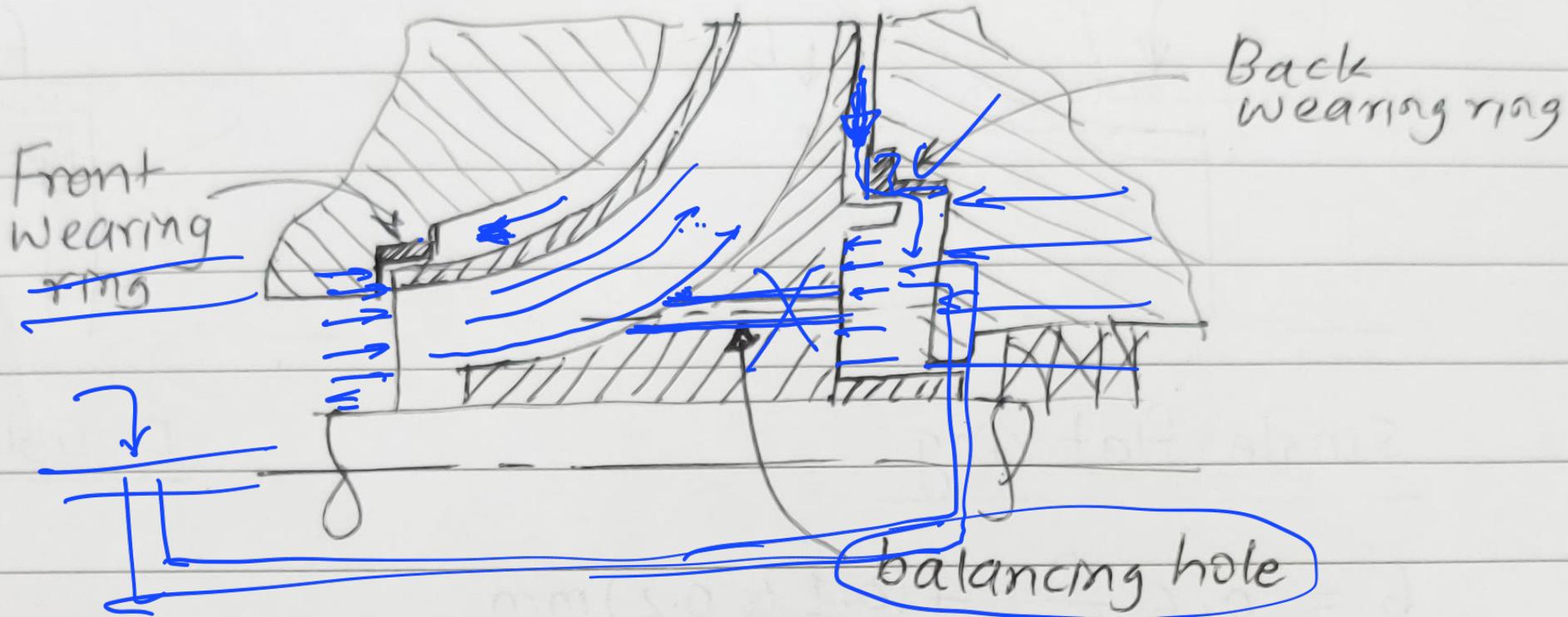


Single-suction  
Axial Thrust present

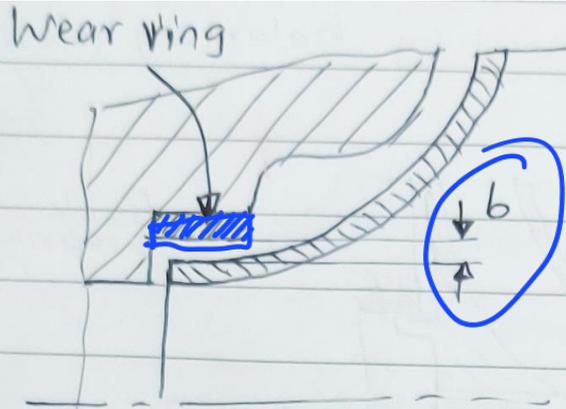


Double-suction  
Axial Thrust reduced

# Axial Thrust in Centrifugal Pumps



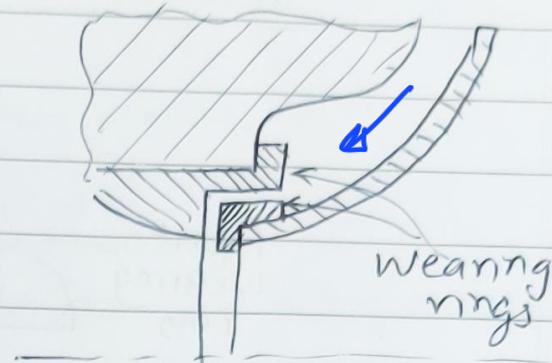
# Wear Rings



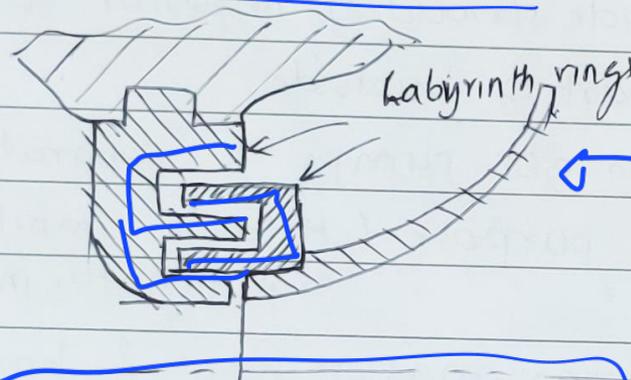
Single flat ring

$$b = 0.6 \frac{D}{1000} + (0.1 \text{ to } 0.2) \text{ mm}$$

D = impeller eye diameter



Double L-type rings



More complex to design

Double labyrinth rings

