Design of Machines and Mechanical Systems (PC-BTM711)

Session 14

Module 3: Hydrodynamic Bearing Design – Other Topics

Mechanical Seals

Session Outcomes

- Discuss bearing constructions, materials and lubricating oils
- Describe failure mechanisms of hydrodynamic bearings
- Compare Sliding-contact and Rolling-contact bearings
- Explain different types of mechanical seals
    - Static
    - Dynamic

Bearing Design – Selection of Parameters DDB T16.11

Table 16.11 *Bearing parameters*

Length to diameter ratio

The length-to-diameter ratio (l/d) affects the performance of the bearing. A long bearing has more load carrying capacity compared with a short bearing. A short bearing, on the other hand, has greater side flow, which improves heat dissipation. The long bearings are more susceptible to metal-to-metal contact at the two edges, when the shaft is deflected under load. The longer the bearing, more difficult it is to get sufficient oil flow through the passage between the journal and the bearing. Therefore, the design trend is to use (l/d) ratio as 1 or less than 1. When the shaft and the bearing are precisely aligned, the shaft deflection is within the limit and cooling of lubricant and bearing does not present a serious problem, the (l/d) ratio can be taken as more than 1. In practice, the (l/d) ratio varies from 0.5 to 2.0, but in the majority of applications, it is taken as 1 or less than 1.

Unit bearing pressure

The unit bearing pressure ($p = W/ld$) is the load per unit of projected area of the bearing in running condition. It depends upon number of factors, such as bearing material, operating temperature, the nature and frequency of load and service conditions.

Permissible unit bearing pressures

Application	Unit bearing pressure (p) (MPa or N/mm^2)
(i) Diesel engines:	
Main bearing	5–10
Crank pin	7–14
Gudgeon pin	13–14
(ii) Automotive engines:	
Main bearing	3–4
Crank pin	10–14
(iii) Air compressors:	
Main bearing	1–1.5
Crank pin	1.5–3.0
(iv) Centrifugal pumps:	
Main bearing	0.5–0.7
(v) Electric motors:	
Main bearing	0.7–1.5
(vi) Transmission shafting:	
Light duty	0.15
Heavy duty	1.00
(vii) Machine tools:	
Main bearing	2

Start-up load

The unit bearing pressure for starting conditions should not exceed 2 MPa. The start-up load is static load when the shaft is stationary. It mainly consists of the dead weight of shaft and its attachments. The start-up load can be used to determine the minimum length of the bearing on the basis of starting conditions.

(Contd.)

Bearing Design – Selection of Parameters DDB T16.11

(*Contd.*)

Radial clearance

The radial clearance (c) should be small to provide the necessary velocity gradient. However, this requires costly finishing operations, rigid mountings of the bearing assembly and clean lubricating oil without any foreign particles. This increases the initial and maintenance costs. The practical value of radial clearance is 0.001 mm per mm of the journal radius or

$$c = (0.001)\,r$$

The practical values of radial clearances for commonly used bearing materials are as follows:

Material	Radial clearance (c)
Babbitts	$(0.001)\,r$ to $(0.00167)\,r$
Copper-lead	$(0.001)\,r$ to $(0.01)\,r$
Aluminium-alloy	$(0.002)\,r$ to $(0.0025)\,r$

Minimum oil film thickness

The surface finish of the journal and the bearing is governed by the value of the minimum oil film thickness (h_o) selected by the designer and vice versa. There is a lower limit for the minimum oil film thickness, below which metal-to-metal contact occurs and hydrodynamic film breaks. This lower limit is given by,

$$h_0 = (0.0002)r$$

Maximum oil film temperature

The lubricating oil tends to oxidise when the operating temperature exceeds 120°C. Also, the surface of babbitt bearing tends to soften at 125° C (for bearing pressure of 7 N/mm^2) and at 190° C (for bearing pressure of 1.4 N/mm^2). Therefore, the operating temperature should be kept within these limits. In general, the limiting temperature is 90° C for bearings made of babbitts.

Numerical Problem

A full hydrodynamic bearing operates under following conditions:

- Radial load = 50 kN
- Journal diameter = 150 mm
- Bearing length = 150 mm
- Radial clearance = 0.15 mm
- Minimum film thickness = 0.03 mm
- Viscosity of lubricant = 8 cP

What is the minimum speed of operation for journal to work under hydrodynamic conditions?

$P = 50\ kN$

$D = 150\ mm$

$l = 150\ mm$

$c = 0.15\ mm$

$h_o = 0.03\ mm$

$\mu = 8\ cP = 8 \times 10^{-9}\ N.s/m^2$

$n_s = ?$

$$S = \left(\frac{r}{c}\right)^2 \frac{\mu n_s}{p}$$

$l/D = 1$

$h_o/c = \frac{0.03}{0.15} = \boxed{0.2}$

From DDB T 16.6, $S = 0.0446$

$$S = \left(\frac{r}{c}\right)^2 \cdot \frac{\mu n_s}{p_o}$$

$$p = \frac{P}{lD} = \frac{50 \times 10^3}{150 \times 150} = 2.22\ N/mm^2$$

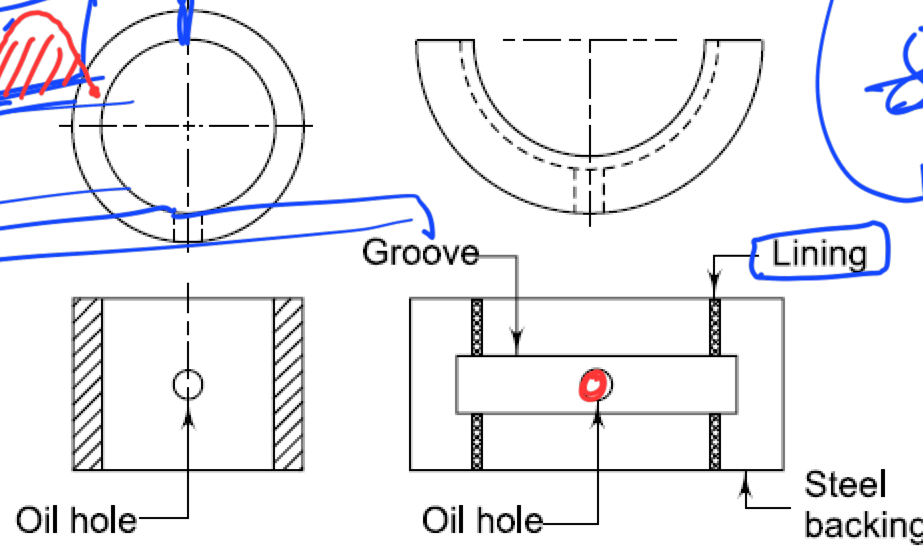
$$0.0446 = \left(\frac{75}{0.15}\right)^2 \times \frac{(8 \times 10^{-9}) \times n_s}{2.22}$$

$n_s = 49.506$ rps

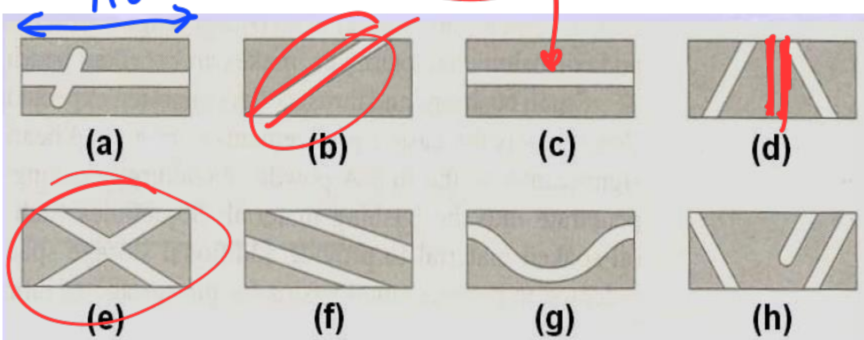
$= \boxed{2970\ rpm}$

SELF-STUDY

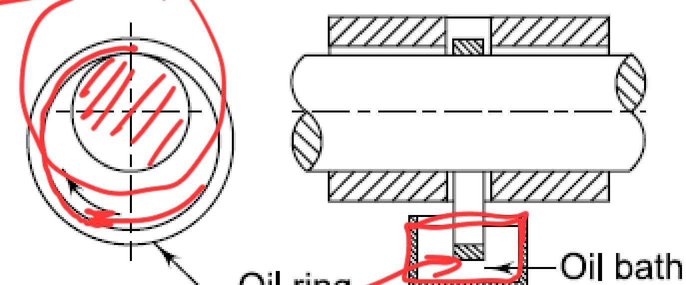
Bearing Constructions



(a) Solid bushing (b) Lined bushing



Developed View of oil-groove Patterns



Oil-ring bearing

Ref: Bhandari V.B., Design of Machine Elements (2017)
Credits: NPTEL course by IIT Kharagpur

QUIZ

Bearing with Longitudinal Groove

The journal bearing may have circumferential or longitudinal oil grooves. Which of the following is TRUE about a bearing with longitudinal groove?

1) Lesser load capacity than circ. grooved bearing
2) Susceptibility to oil-whip vibrations
3) Both 1 and 2 are TRUE

SELF-STUDY

Bearing Material – Desirable Properties

- High compressive strength
- Should not weld / fuse to journal body
- If loads are fluctuating, additionally good endurance strength is required
- Bearing materials should be softer as compared to journal
- If any hard dirt particle enters lubricant, bearing material should allow the particle to get embeded in order to prevent continuous damage

  embedability
- For high temperature service, where the oil may get oxidized, bearing material should have corrosion resistance.

  acid
- Bearing material should have the ability to conform and adopt its shape to that of journal

  conformability

SELF-STUDY

Important Bearing Materials

- Babbitt or White metal
  - Tin-based or Lead-based
  - Available in 10 grades for different applications
  - Excellent conformability and embeddability
  - Unsuitable at higher temperatures and have poor fatigue strength
- Bronze
- Copper-Lead
- Tin-Aluminium
- Non-metallic
  - Graphite
  - Teflon
  - Rubber
- Sintered metal bearings
  - Porous and hold oils up to 20-30% of its volume

SELF-STUDY

Lubricating oils

- Desirable properties
  - Less sensitive to temperature-viscosity change
  - Chemically stable
  - Sufficient specific heat for heat removal
- Types of oils
  - Mineral
  - Vegetable/Animal

Chemically stable
wide range of viscosities
less tendancy to oxidise → less corrosive attack

poor →

→ maintain viscosities at higher temp. better than mineral oil

QUIZ

Mineral Oil Lubricants

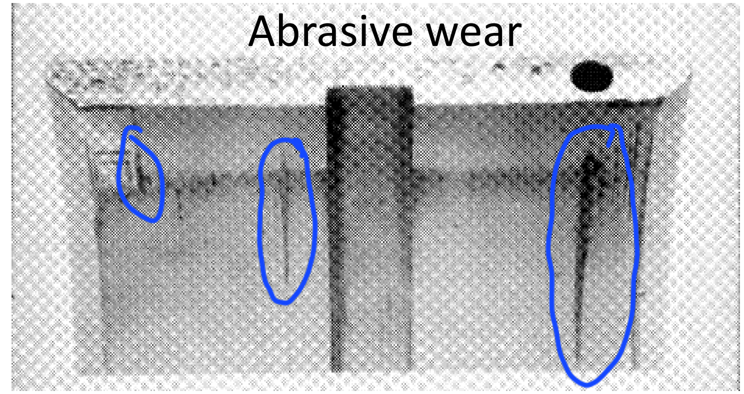
Which of the following is a NOT feature of mineral oils?

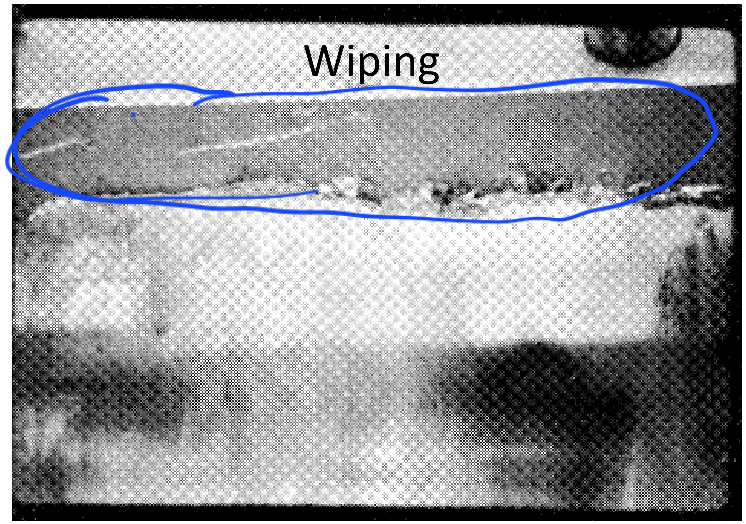
1) Less tendency to oxidise and form acids
2) Maintain viscosity at higher temperatures
3) Provide wide range of viscosity

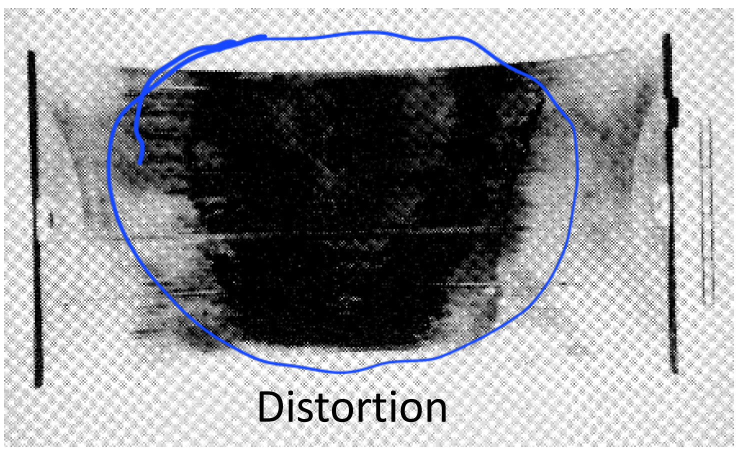
SELF-STUDY

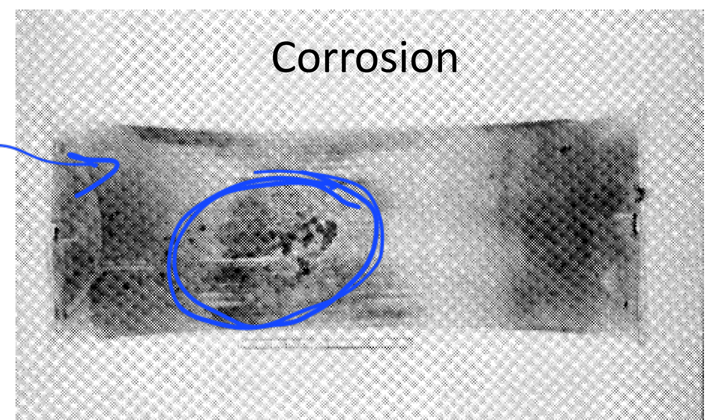
Failure Mechanisms

- Abrasive wear
- Wiping of bearing surface
- Corrosion
- Distortion





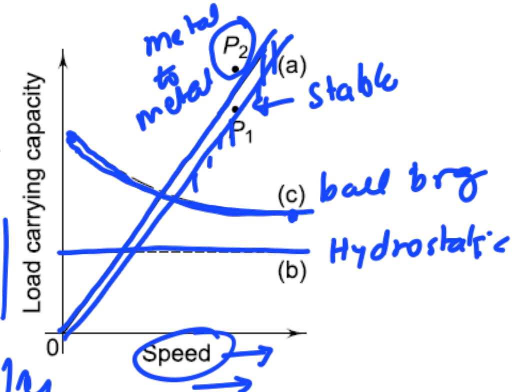




https://pdfs.semanticscholar.org/676e/8d91559fc3a6275f2924b436767d957c73e3.pdf

SELF-STUDY

Sliding vs Rolling contact bearings



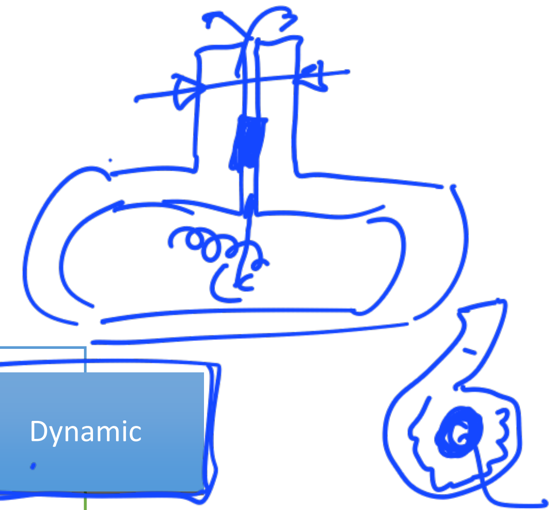
Load Characteristics of Bearings: (a) Hydrodynamic Bearing (b) Hydrostatic Bearing (c) Rolling Contact Bearing

Sliding Contact Bearing	Rolling Contact Bearing
Suitable for __high__ load and speed	Suitable for __moderate__ load and speed
__Suitable__ for shock loading	__Less suitable__ for shock loading
__Larger__ value of starting torque	__Smaller__ value of starting torque
__Lesser__ amount of operating friction losses	__Higher__ amount of operating friction losses
__Less__ radial space and __large__ axial space	__More__ radial space and __small__ axial space
Lubrication system is __complex__	Lubrication system is __simpler__
Shaft axis is __eccentric__ w.r.t. bearing axis	Shaft axis is __concentric__ w.r.t. bearing axis
__less__ noise	__More__ noise
__High__ cost	__Less__ cost

Ref: Bhandari V.B., Design of Machine Elements (2017)

SELF-STUDY

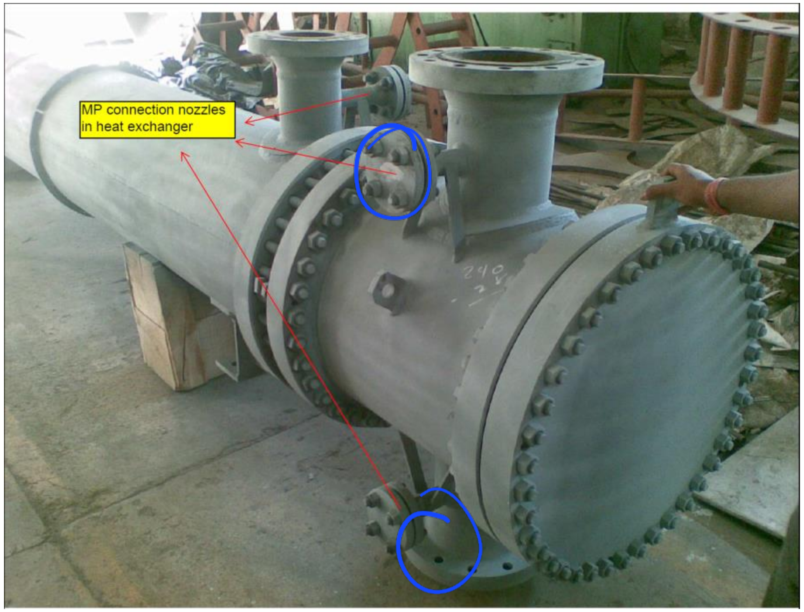
Mechanical Seals

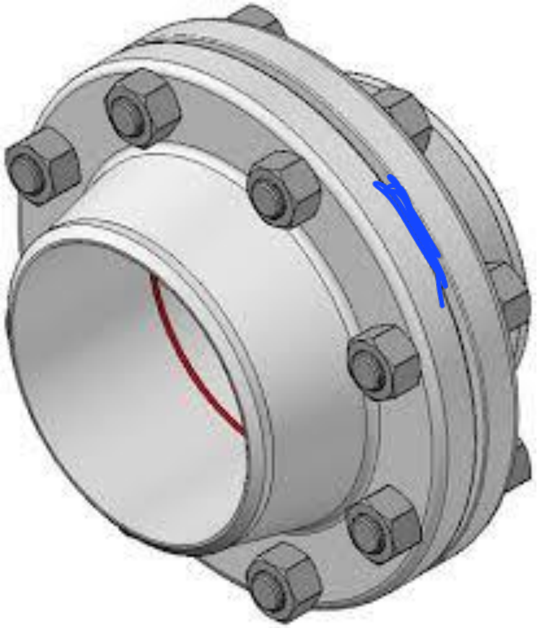


- Mechanical Seals
  - Static
    - Sealants
    - O-ring
    - Flat gasket
      - Metallic
      - Non-metallic
  - Dynamic
    - Contacting
      - Axial or mechanical face
      - Packings/Stuffing box
      - Radial Lip
    - Non-contacting
      - Labyrinth
      - Viscoseal
    - Reciprocating shafts
      - Packing
      - O-ring
      - Diaphragm
      - Piston rings

Reading material: Myer Kutz (ed.), Mechanical Engineers' Handbook, Vol.1, Chapter 33 (2006)

Static Seals





Static Seals

(i) metallic or elastomer o-rings

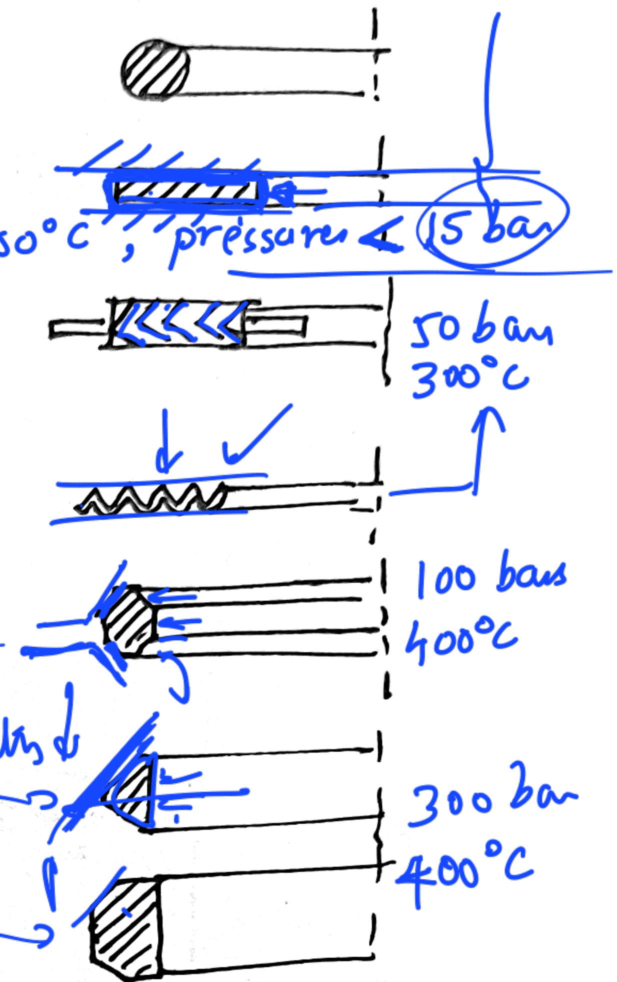
(ii) PTFE, Grafoil or ceramic sheet

(iii) Spiral wound metal with PTFE, Grafoil or ceramic filling

(iv) Corrugated or flat metal (Al, Cu, Iron)

(v) Octagonal ring (Fe, Soft steel, SS)

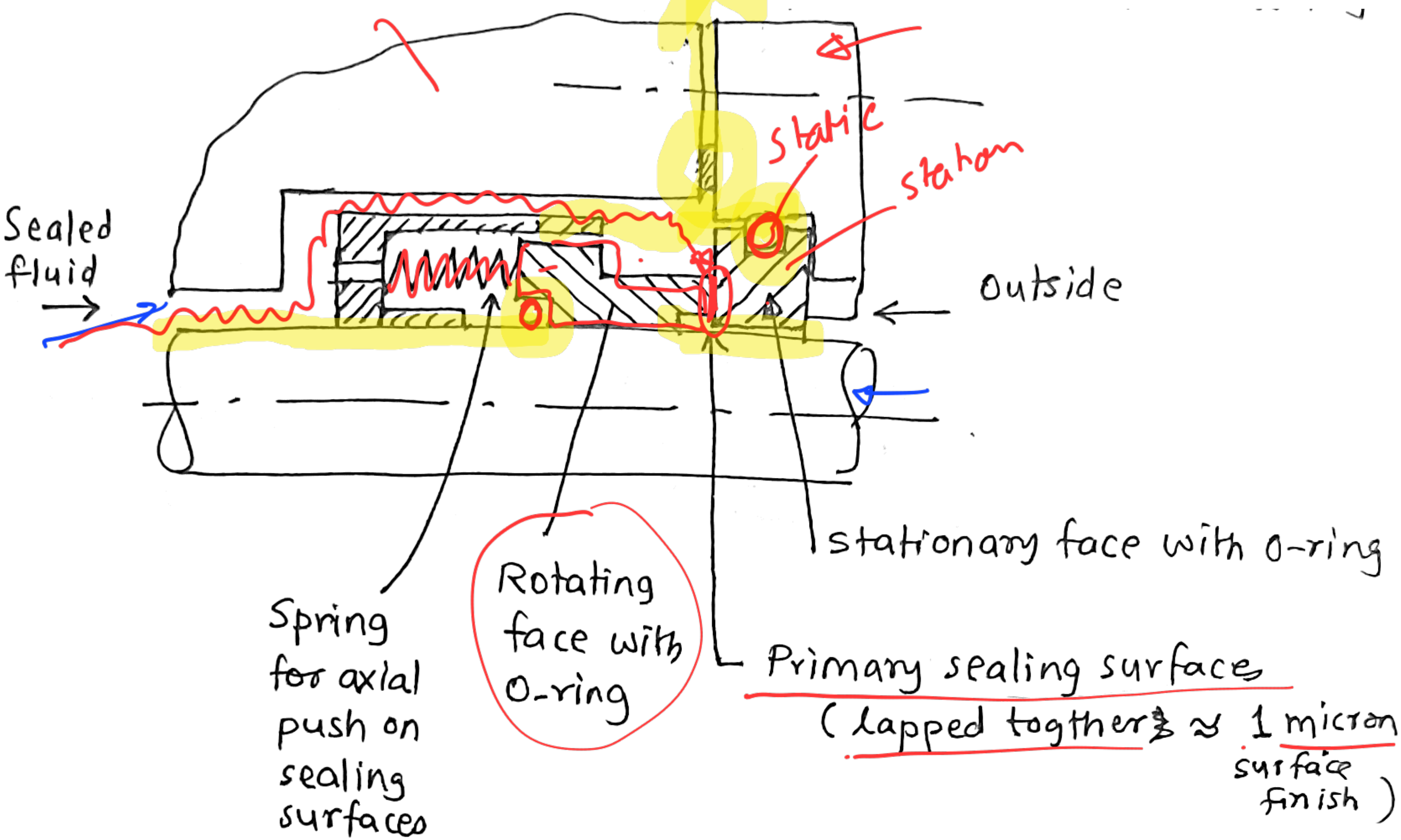
(vi) High pressure, metallic
- Delta
- Double conical



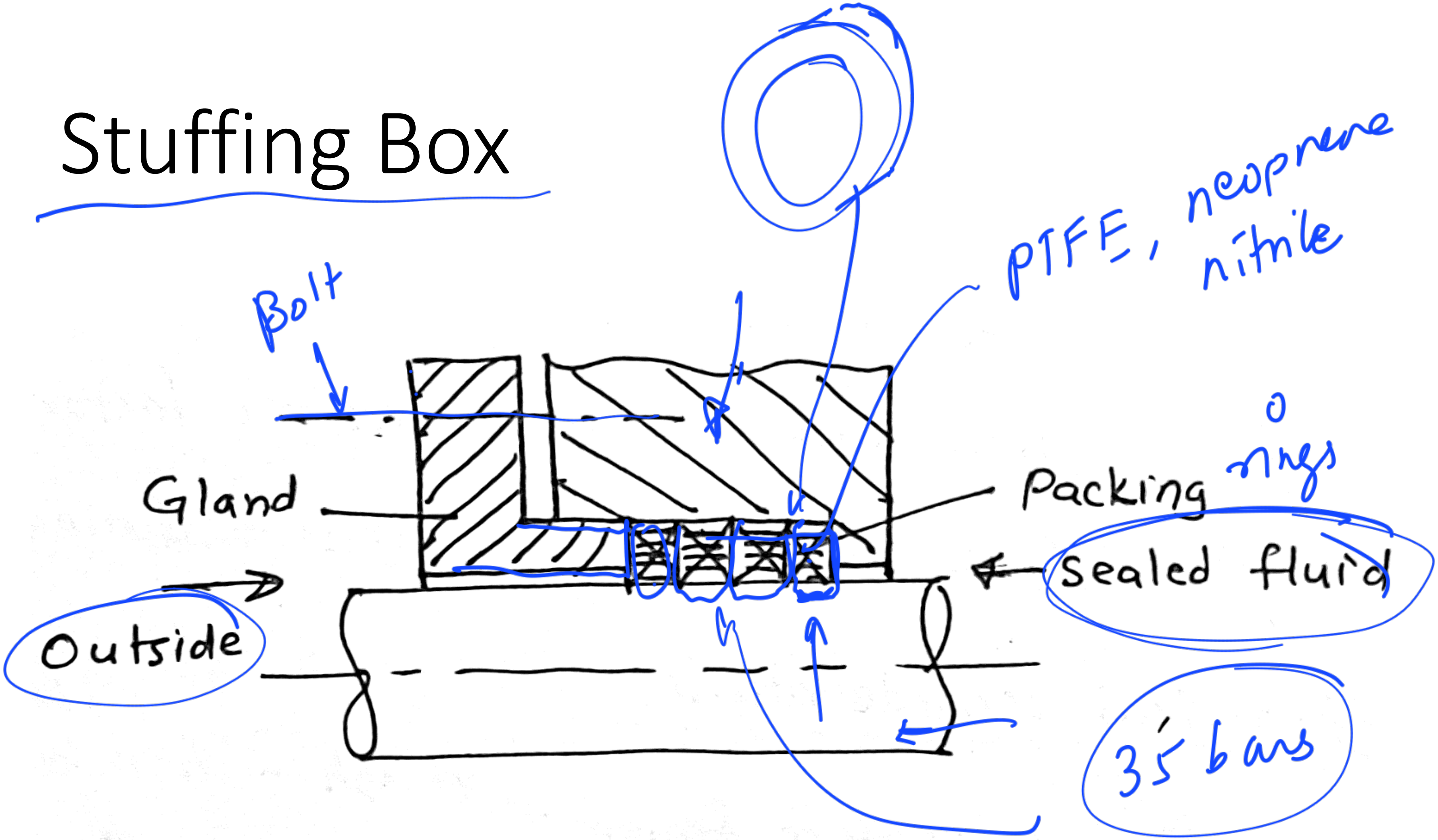
Mechanical Face Seal

Dynamic

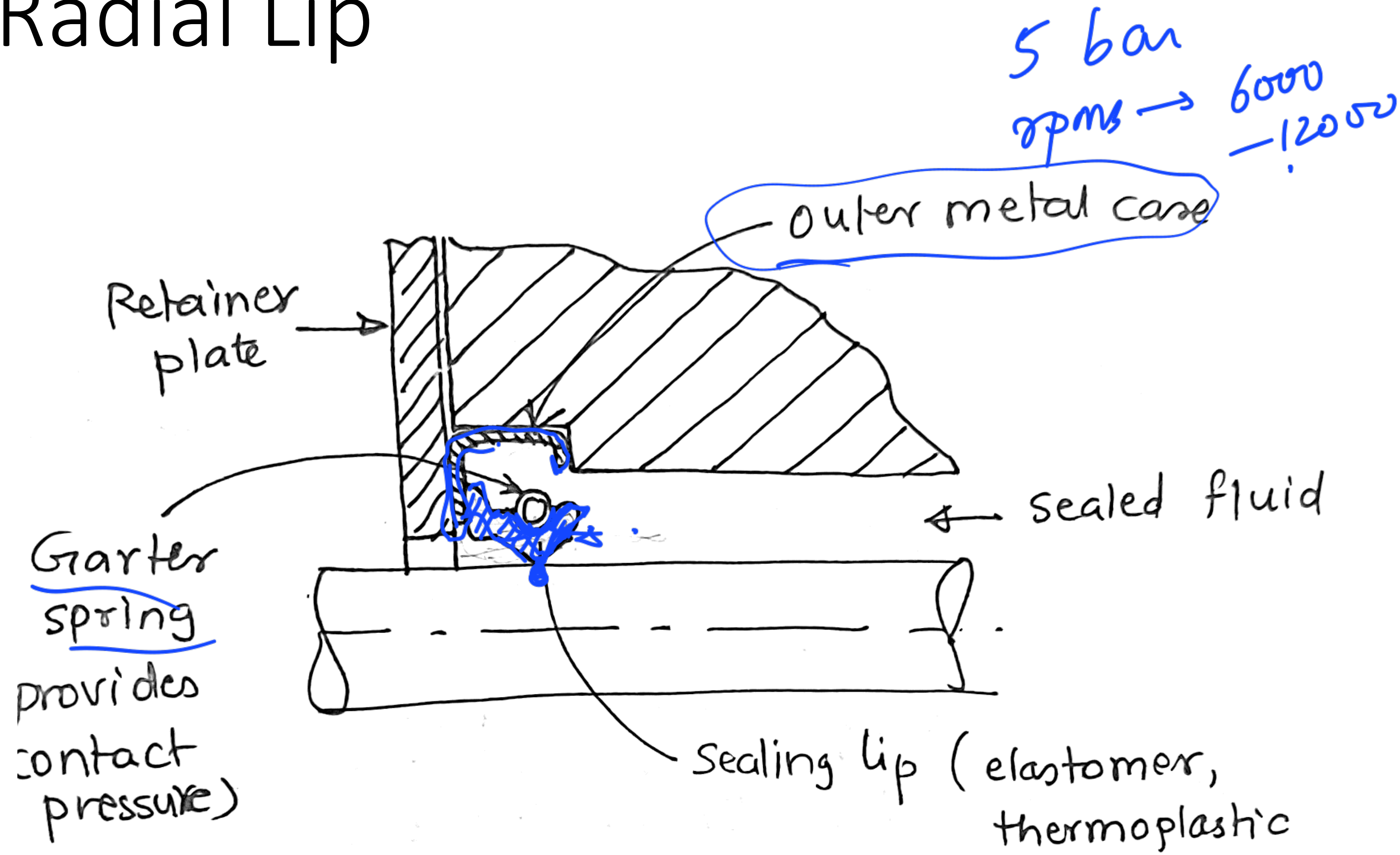
pumps, compressor



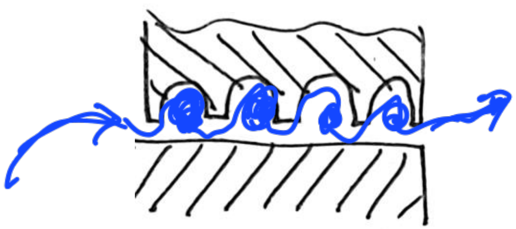
Stuffing Box



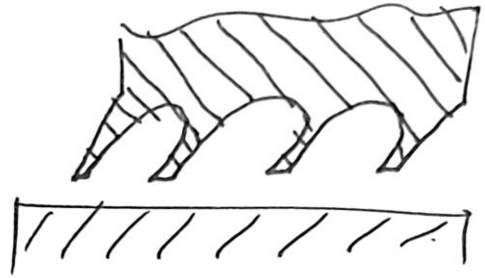
Radial Lip


5 bar
rpms → 6000
-12000
outer metal case
Retainer plate
Garter spring provides contact pressure)
sealed fluid
Sealing lip (elastomer, thermoplastic

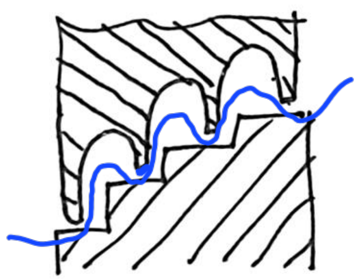
Labyrinth seal – Non-contact



straight



Inclined



stepped

Summary

- Bearing constructions
  - Solid
  - Lined
  - Oil groove constructions
- Bearing Materials
  - Desirable properties
  - Babbitt, Bronze, Copper-Lead, Tin-Aluminium, Non-metal
- Lubricating oils
  - Desirable properties
  - Mineral and Vegetable/Animal oils
- Failure Mechanisms
  - Abrasive wear
  - Wiping of bearing surface
  - Corrosion
  - Distortion
- Compare sliding and rolling contact bearings
- Mechanical Seals
  - Static
  - Dynamic