Sliding Contact Bearings

Lubrication:

Materials that reduce friction are called lubricant. And the process of using lubricant is called Lubrication.

Bearing classification based on Lubrication:

1. **Thick film lubrication:** Bearing that use thick film lubricant between the bearing housing. There is no metal to metal contact happens while in motion. The film thickness is anywhere from 8 to 20 μm.

   Thick film lubricant can be classified into two categories:

   i. **Hydrodynamic lubrication:**
   A system of lubrication in which the load supporting fluid film is created by the shape and relative motion of the sliding surfaces.
   #Note: Sometimes it is called 'self-acting' bearing.

   ii. **Hydrostatic lubrication:**
   A system of lubrication in which the load supporting fluid film, separating the two surfaces is created by an external source, like pump.
   Advantages:
   a) High load capacity at low speed.
   b) No starting friction.
   Disadvantages:
   a) Initial cost is required as due to lubricant is forced applied by pump.

   iii. **Elasto-hydrodynamic:**
   The phenomena that occurs when a lubricant is introduced between surfaces that are in rolling contact, such as mating gears or rolling bearing.
   The mathematical explanation requires the 'Hertzian theory' of contact stress and fluid mechanics.

   iv. **Solid film:**
   When bearings are operated in extreme temperatures, a solid-film lubricant such as graphite or molybdenum disulphide are used.

2. **Thin film lubrication:** Bearing that use thin film lubricant between the bearing housing. Sometime metal to metal contact happens while in motion.
3. **Zero film lubrication:** Bearing without any lubricant.

Bearing classification based on load carried:

1. **Radial bearings**
2. **Thrust bearings or axial bearings**
3. **Radial – thrust bearings**

Journal/Sleeve bearings:

The radial bearings are also called journal or sleeve bearings. The portion of the shaft inside the bearing is called journal.

Depending upon the bearing envelope, journal bearing classified are follows:

1. Full bearing
2. Partial bearing

Journal bearing – lubricants:

1. **Viscosity:**
   Internal frictional resistance offered by a fluid to change its shape or relative motion of its parts.
   Equations are straight forward from fluid mechanics (Newtonian):
   $$\tau = \mu\left({}^{dU}/_{dh}\right)$$
   Where,
   τ = shear stress
   μ = dynamic viscosity
   $\left({}^{dU}/_{dh}\right)$ = Velocity gradient
   Units of viscosity is 'centi-Poise(cP)'. $1N - s/mm^2 = (10^9)cP$

Viscosity Measurement:

Saybolt Universal Seconds method are used widely
Saybolt Universal viscosity, $z_k = \left[0.22 * SUS - {}^{180}/_{SUS}\right]$ centiStokes (cSt)
Where, SUS = Saybolt Universal Seconds
Kinematic viscosity, $\nu(m^2/s) = (10^{-6})z_k\ (cSt)$
Then, absolute viscosity, $\mu = \nu * \rho$ centPoise (cP)
Where, ρ = lubricant density (kg/m^3)

Temperature Effects on Viscosity
Viscosity Index:

Viscosity index is defined as an arbitrary number used to characterize the variation of the kinematic viscosity of lubricating oil temperature.
As per ASTM:
$$VI = \left(\frac{L - y}{L - H}\right)x100\ \%$$
An oil with VI=70 has less rate of change of viscosity with temperature compared with oil with VI=60.

Pressure Effects on Viscosity:

1. All lubricant oils experience an increase in viscosity with pressure. This effect is usually significant only at pressures higher than those encountered in sliding bearings.
2. This effects in important in elasto-hydrodynamic lubricant.

Properties of good lubricant are:

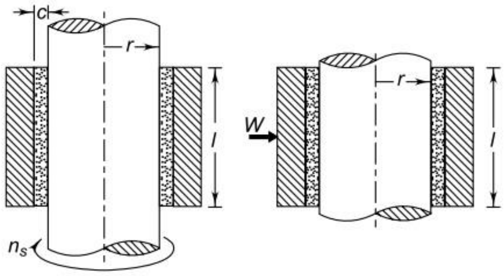
1. It should give rise to low friction.
2. It should adhere to the surface and reduce the wear.
3. It should protect the system from corrosion.
4. It should have good cleaning effect on the surface.
5. It should carry away as much heat from the surface as possible.
6. It should have thermal and oxidative stability.
7. It should have good thermal durability.
8. It should have antifoaming ability.
9. It should be compatible with seal materials.
10. It should be cheap and available in plenty

Petroff's Equation:

Petroff published his work on bearing friction in 1886.

Assumptions:

1. No eccentricity between bearings and journal.
2. The bearing is subjected to light load, i.e. oil film is not supporting any load.
3. No lubricant flow in the axial direction.



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

Where,

$f =$ Co-efficient of friction of bearing.

$r =$ radius of the journal (mm)

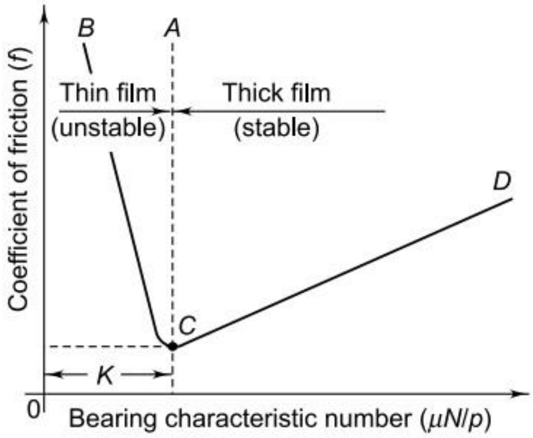
$c =$ radial clearance (mm)

$\mu =$ viscosity of the lubricant (cP)

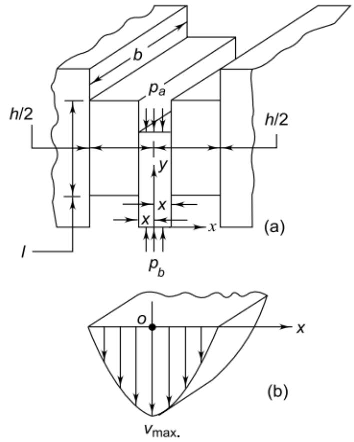
$n_s =$ journal speed (rev/sec)

$p =$ bearing pressure (N/mm^2)

McKee's Investigation for stable lubrication:



Viscous flow through rectangular slot:



$$Q = \frac{\Delta p b h^3}{12 \mu l}$$

Where,

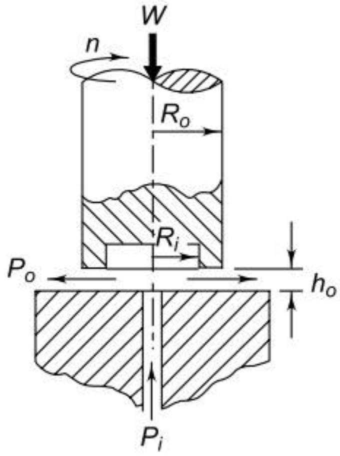
Q = flow of the lubricant (mm^3/s)

l = length of the bearing (mm)

Δp = Pressure difference between the two sides of the central slice.($p_a - p_b$) (N/mm^2)

b & h are dimensions of the slot in a plane perpendicular to the direction of flow. (mm)

Hydrostatic thrust bearing:



$$Q = \frac{\pi P_i h_o^3}{6\mu \ln\left(\frac{R_o}{R_i}\right)}$$

$$W = \frac{\pi P_i}{2}\left[\frac{R_o^2 - R_i^2}{\ln\left(\frac{R_o}{R_i}\right)}\right]$$

Where,
Q = flow of the lubricant (mm^3/s)
h_0 = fluid film thickness (mm)
μ = viscosity of the lubricant (cP)

W = thrust load (N)
R_o = Outer radius of the shaft (mm)
R_i = Radius of the recess or the pocket (mm)
P_o = Outlet or atmospheric pressure (N/mm^2)
P_i = Supply of inlet pressure (N/mm^2)

Energy losses in Hydrostatic Bearing:

$$(kW)_p = Q(P_i - P_o)(10^{-6})$$

$(kW)_p$ = Power loss due to pumping.

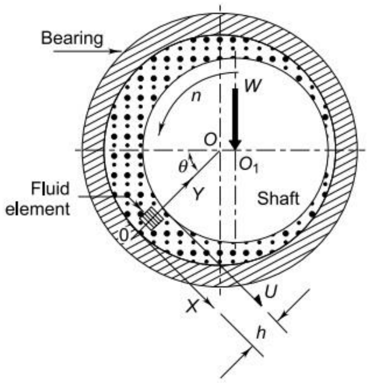
$$(kW)_f = \left(\frac{2\pi^3}{3600\ x\ 10^6}\right)\frac{\mu n^2(R_o^4 - R_o^4)}{h_o}$$

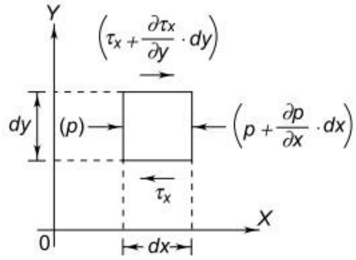
$(kW)_p$ = Power loss due to friction.

$$(kW)_t = (kW)_p + (kW)_f$$

$(kW)_f$ = Total power loss.

Reynold's Equation:
Osborne Reynolds carried out theoretical analysis of journal bearings in 1880. This is a fundamental equation for hydro-dynamic lubrication.
Assumptions:
1. Lubricant is an incompressible, constant viscosity, Newtonian fluid.
2. The inertia and gravitational forces in the oil film are negligible.
3. Pressure is constant across the film thickness due to very low film thickness.
4. The shaft and the bearings are rigid.
5. There is continuous supply of lubricant (Laminar flow).

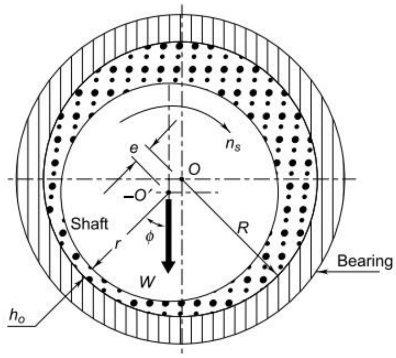




$$\frac{\partial}{\partial x}\left[h^3\frac{\partial p}{\partial x}\right]+\frac{\partial}{\partial z}\left[h^3\frac{\partial p}{\partial z}\right]=6\mu U\left(\frac{\partial h}{\partial x}\right)$$

[#derivation: Design of Machine Elements, V B Bhandari]

Solution of Reynold's equation:
Raimondi and Boyd Method:



$$\varepsilon = 1-\left(\frac{h_0}{c}\right)$$

Where,
ε = Eccentricity ratio = $(Eccentricity/Radial\ Clearance\ (c))$
h_0 = minimum film thickness (mm) due to eccentricity.
c = radial clearance(mm)

Sommerfeld's solution: (Most important for bearing design)

Sommerfeld number is given by,

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

Relation between Petroff's Equation and Sommerfeld' number:

$$\left(\frac{r}{c}\right)f = \phi\left[\left(\frac{r}{c}\right)^2\left(\frac{\mu n_s}{p}\right)\right]$$

Where,
ϕ = functional relationship.
Co-efficient of friction variable is given by,

$$CFV = \left(\frac{r}{c}\right)f$$

Frictional torque,

$$(M_t)_t = fWr$$

And Frictional Power,

$$(kW)_f = \frac{2\pi n_s (M_t)_t}{10^6}$$

Flow variable,

$$FV = \frac{Q}{rcn_s l}$$

Where,

Q = flow of the lubricant (mm^3/s)
l = length of the bearing (mm)

Temperature rise of the lubricating oil:
Heat generated,

$$H_g = (4\pi)(10^{-6})rcn_s lp(CFV) \text{ kW}$$

Heat carried away by the lubricant,

$$H_c = C_p \Delta t \rho (rcn_s l)(FV)(10^{-6}) \text{ kW}$$

Where,
C_p = Specific heat of lubricating oil (kJ/Kg^0C)
Δt = Temperature rise (^{0}C)

Therefore, temperature rise,

$$\Delta t = \left(\frac{4\pi p}{\rho C_p}\right)\frac{(CFV)}{(FV)}$$

And average temperature rise,

$$T_{av} = T_i + \left(\frac{\Delta t}{2}\right)$$

For exercise, derivation and details study, please go through the source.
source: 1. Design of Machine Elements by V B Bhandari.
2. NPTEL : https://nptel.ac.in/courses/112/106/112106137/
3. Shigley's Mechanical Engineering Design (reference)

For any doubt or explanations, please contact : sunny.aliah13@gmail.com