Lubrication and Sliding Bearings

Literature: Kinematic Chains and Machine Components Design (Part II: Machine Components; Chapter II.5 – Lubrication and Sliding Bearings, p. 607 – 638)
Author: Dan B. Marghitu
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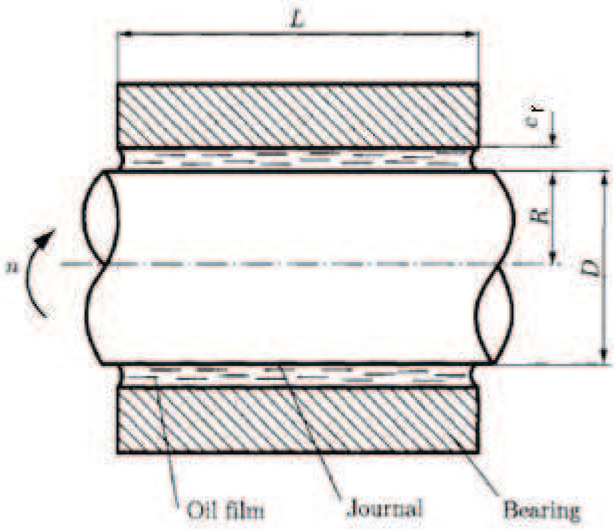
Dynamic Viscosity Units

	SI – Standard [Pa·s]	ASTM – Standard [cP]	British Standard [Reyn]
SI [Pa·s]	1	1000 cP	$\approx 1.4514\cdot10^{-4}$
ASTM [cP]	0.001	1	$\approx 1.4504\cdot10^{-7}$
British [Reyn]	≈ 6890	$\approx 6.8947\cdot10^{6}$	1

Hydrodynamic bearing



Nomenclature

L – bearing length, [m]
D – shaft diameter, [m]
R – shaft radius, [m]
c_r – radial clearance, [m]
c_d – diametral clearance, [m]
n – angular velocity of the shaft, [rev/s]
V – surface velocity of the shaft, [m·s]

μ - dynamic viscosity of the oil, [Pa·s]
P – load per unit surface area, [Pa]
F_f – friction force, [N]
T_f – frictional torque, [N·m]
W – radial load, [N]
S – Sommerfeld number
H – power loss, [W]
T – working temperature, [◦C]
h_0 - minimum film thickness, [mm]
p_{max} – maximum film pressure, [Pa]
ϕ - position angle of minimum film thickness
θ_{p0} - the terminating position of the oil film
θ_{pmax} – the angular position of the point of maximum pressure
Q – total flow
Q_s - side leakage flow

Expressions

Friction torque [N·m]:

$$T_f = FR = (\tau A)\,R = \left(\frac{2\pi R\mu n}{c}2\pi RL\right)R = \frac{4\pi^2\mu nLR^3}{c}$$

The radial load per unit of projected bearing area [Pa]:

$$P = \frac{W}{2RL}$$

Friction force [N]:

F_f = fW
f – friction coefficient
W – applied radial load

Friction torque [N·m]:

$$T_f = f\,W\,R = f\,(2RLP)\,R = 2R^2 fLP$$

Friction coefficient:

$$f = 2\pi^2\left(\frac{\mu\,n}{P}\right)\left(\frac{R}{c}\right)$$

Sommerfeld number:

$$S = \frac{\mu\,n}{P}\left(\frac{R}{c}\right)^2$$

Power loss [W]:

$$H = 2\,\pi\,T_f\,n$$

Problem 1

A shaft with a 120-mm diameter (Fig. II.5.17), is supported by a bearing of 100-mm length with a diametral clearance of 0.2 mm and is lubricated by oil having a viscosity of 60 mPa·s. The shaft rotates at 720 rpm. The radial load is 6000 N. Find the bearing coefficient of friction and the power loss.

Solution The pressure is calculated with the relation

$$P = \frac{W}{2RL} = \frac{6000}{2(0.06)\,(0.1)} = 500\,000\ \mathrm{N/m^2} = 500\,000\ \mathrm{Pa},$$

where $W = 6000$ N, $R = 0.06$ m, and $L = 0.1$ m.

From Eq. (II.5.11), the coefficient of friction is

$$f = 2\pi^2 \left(\frac{\mu\,n}{P}\right)\left(\frac{R}{c}\right) = 2\pi^2 \left[\frac{(0.06)(12)}{500\,000}\right]\left(\frac{60}{0.1}\right) = 0.017,$$

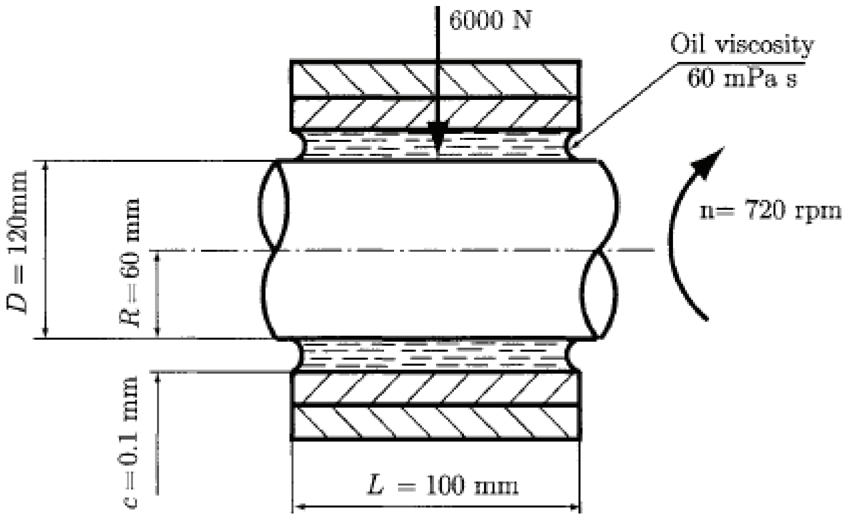
where $\mu = 60\ \mathrm{mPa \cdot s} = 0.06\ \mathrm{Pa \cdot s}$, $n = 720$ rev/min $= 12$ rev/s, $R = 60$ mm, and $c = 0.1$ mm.

The friction torque is calculated with

$$T_f = f\,W\,R = (0.017)\,(6000)\,(0.06) = 6.139\ \mathrm{N \cdot m}$$

The power loss is

$$H = 2\pi\,T_f\,n = 2\pi\ (6.139)\,(12)\ =\ 462.921\ \mathrm{N \cdot m/s} = 462.921\ \mathrm{W}.$$



Additional problem

The working temperature in this case was 60 ◦C and SAE 50 grade oil was used.
What happens to the oil working parameters if the working temperature decreases to 50◦C or rises to 100 ◦C?

Solution:

1. If T = 50 ◦C → μ = 100 mPa·s = 0.1 Pa·s

$$f = 2\pi^2\left(\frac{\mu n}{P}\right)\left(\frac{R}{c_r}\right) = 2\pi^2\left(\frac{0.1\cdot 12}{500000}\right)\left(\frac{0.06}{0.0001}\right) = 0.028$$

Increase in friction coefficient: $\frac{|0.017-0.028|}{0.017}\cdot 100\% = 65\%$

Power loss: $H = 2\pi T_f n = 2\pi\cdot 10.08\cdot 12 = 760$ W

$T_f = f\cdot W\cdot R = 0.028\cdot 6000\cdot 0.06 = 10.08$ N·m

2. If T = 100 ◦C → μ = 13 mPa·s = 0.013 Pa·s

$$f = 2\pi^2\left(\frac{\mu n}{P}\right)\left(\frac{R}{c_r}\right) = 2\pi^2\left(\frac{0.013\cdot 12}{500000}\right)\left(\frac{0.06}{0.0001}\right) = 0.0037$$

Decrease in friction coefficient: $\frac{|0.017-0.0037|}{0.017}\cdot 100\% = 78\%$

Power loss: $H = 2\pi T_f n = 2\pi\cdot 1.33\cdot 12 = 100.3$ W

$T_f = f\cdot W\cdot R = 0.0037\cdot 6000\cdot 0.06 = 1.33$ N·m

Problem 2.

A 100 mm diameter shaft is supported by a bearing of 100-mm length with a diametral clearance of 0.075 mm. It is lubricated by SAE 20 oil at the operating temperature of 70°C. The shaft rotates 3000 rpm and carries a radial load of 5000 N. Estimate the bearing coefficient of friction and power loss.

Data:

D = 100 mm = 0.1 m
L = 100 mm = 0.1 m
c_d = 0.075 mm = 0.075 · 10^{-3} m
T = 70°C
SAE 20
n = 3000 rpm = 3000/60 = 50 rev/s
W = 5000 N
f - ?
H - ?

Solution:

SAE 20 oil at T = 70°C → μ = 12.5 mPa·s = 0.0125 Pa·s

The radial load per unit of projected bearing area [Pa]:

$$P=\frac{W}{2RL}=\frac{5000}{2\cdot 0.05\cdot 0.1}=500000\ \text{Pa}$$

Friction coefficient:

$$f=2\pi^2\left(\frac{\mu n}{P}\right)\left(\frac{R}{c_r}\right)=2\pi^2\left(\frac{0.0125\cdot 50}{500000}\right)\left(\frac{0.05\cdot 2}{0.075\cdot 10^{-3}}\right)=0.033$$

Friction torque:

$$T_f=f\cdot W\cdot R=0.033\cdot 5000\cdot 0.05=8.25\ \text{N·m}$$

Power loss:

$$H=2\pi T_f n=2\pi\cdot 8.25\cdot 50=2591.8\ \text{W}$$

Problem 3

A journal bearing of 200-mm diameter, 100-mm length, and 0.1-mm radial clearance carries a load of 20 kN. The shaft rotates at 1000 rpm. The bearing is lubricated by SAE 20 oil and the average temperature of the oil film is estimated at 70°C. Determine the minimum oil film thickness, bearing coefficient of friction, maximum pressure within the oil film, angles ϕ, θ_{pmax}, and θ_{po}.

Data:

D = 200 mm = 0.2 m
L = 100 mm = 0.1 m
C_r = 0.1 mm = $0.1 \cdot 10^{-3}$ m
SAE 20
T = 70°C
n = 1000 rpm = 1000/60 = 16.67 rev/s
W = 20kN = 20000 N
h_0 - ?
f - ?
P_{max} - ?
ϕ - ?
θ_{Pmax}- ?
θ_{P0} - ?

Solution:

SAE 20 oil at T = 70°C → μ = 12.5 mPa·s = 0.0125 Pa·s
The radial load per unit of projected bearing area [Pa]:

$$P=\frac{W}{DL}=\frac{20000}{0.2\cdot 0.1}=1000000\ \text{Pa}$$

Sommerfeld number:

$$S = \frac{\mu n}{P}\left(\frac{R}{c_r}\right)^2 = \frac{0.0125 \cdot 16.67}{1000000}\left(\frac{0.1}{0.1 \cdot 10^{-3}}\right)^2 = 0.208$$

The following parameters are determined on the diagrams according to the Sommerfeld number and to the ratio: $\frac{L}{D} = \frac{0.1}{0.2} = \frac{1}{2}$.

Minimum thickness variable (graph):

$$\frac{h_0}{c_r} \cong 0.32 \quad \Rightarrow \quad h_0 = 0.32 c_r = 0.32 \cdot 0.0001 = 3.2 \cdot 10^{-5} \text{ m}$$

$$h_0 = 0.032 \text{ mm}$$

Coefficient of friction variable (graph):

$$\frac{R}{c_r} f \cong 6 \quad \Rightarrow \quad f = \frac{6 \cdot c_r}{R} = \frac{6 \cdot 0.0001}{0.1} = 0.006$$

Maximum film pressure ratio (graph):

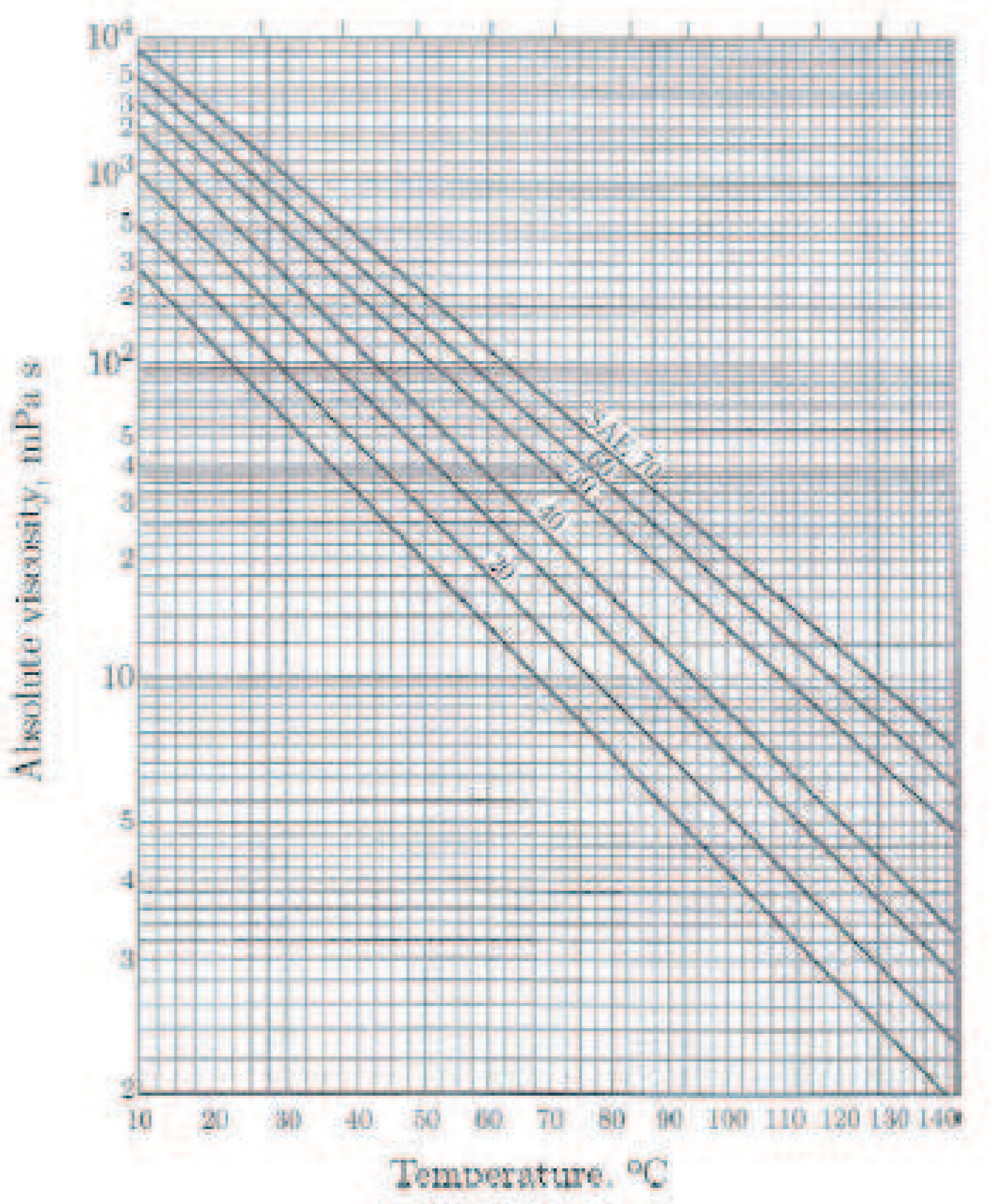
$$\frac{P}{p_{\max}} \cong 0.325 \quad \Rightarrow \quad p_{\max} = \frac{P}{0.325} = \frac{1000000}{0.325} = 3076923\, Pa = 3.08 Mpa$$

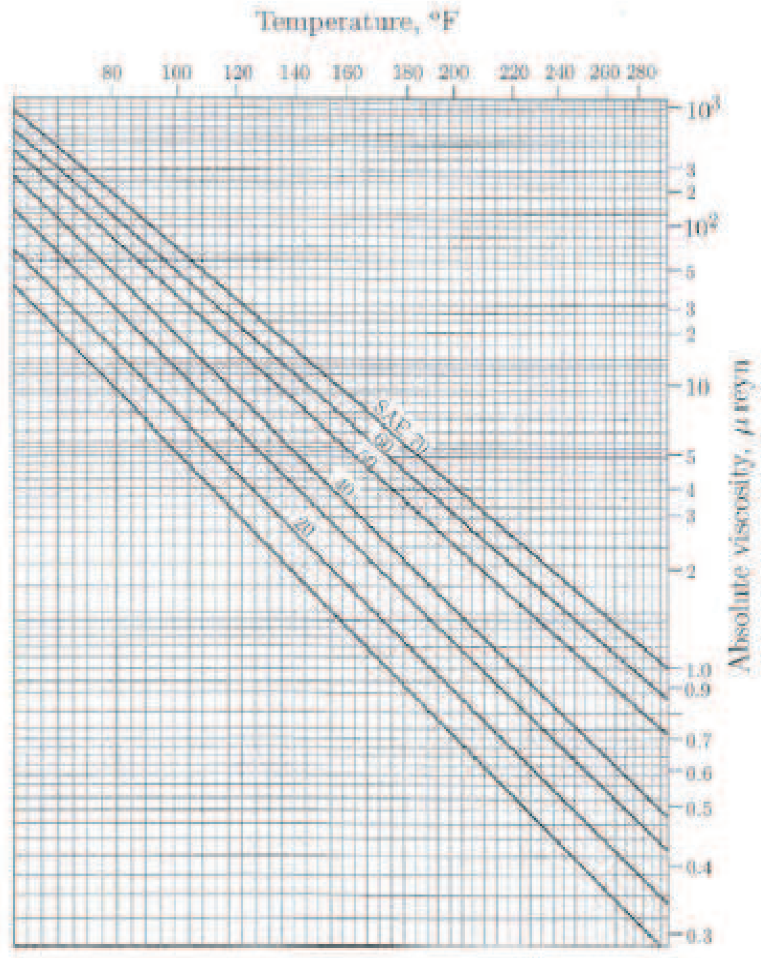
Position of minimum film thickness (graph):
$\phi = 43^\circ$

Terminating position of oil film (graph):
$\theta_{P0} = 57^\circ$

Position of maximum film pressure (graph):
$\theta_{P0} = 17.5^\circ$

Lubrication – Diagrams and Graphs




Temperature, °F
80
100
120
140
160
180
200
220
240
260
280
10^3
3
2
10^2
5
3
2
10
5
4
3
2
1.0
0.9
0.7
0.6
0.5
0.4
0.3
Absolute viscosity, μ reyn
SAE 70
60
50
40
20