Machine Design Homework 6

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[1]:
```python
# Notebook Preamble
import sympy as sp
import matplotlib.pyplot as plt
from IPython.display import display, Markdown

plt.style.use('maroon_ipynb.mplstyle')
```

Contents

1 Problem 11-1

1.1 Given

Timken rates its bearings for 3000 hours at 500 rpm.

1.2 Find

Determine the catalog rating for a ball bearing running for 10,000 hours at 1800 rpm with a load of 2.75 kN with a reliability of 90%.

1.3 Solution

Use Eq. 11-3,

$$C_{10} = F_D \left(\frac{\mathcal{L}_D n_D 60}{\mathcal{L}_R n_R 60} \right)^{1/a}$$

[2]:
```python
FD = sp.S('2.75')
nD = 1800
LD = 10_000
LR = 3_000
nR = 500
C10 = FD*(LD*nD*60/(LR*nR*60))**(1/sp.S(3))
C10  # kN
```

[2]:

6.29592833404333

2 Problem 11-3

2.1 Given

An angular-contact, inner ring rotating, 02-series ball bearing is required for an application in which the life requirement is 40 kh at 520 rpm. The design radial load is 725 lbf. The application factor is 1.4. The reliability goal is 0.90.

2.2 Find

Find the multiple of rating life x_D required and the catalog rating C_{10} with which to enter Table 11–2. Choose a bearing and estimate the existing reliability in service.

2.3 Solution

With the assumed rating life (L_R) to be 10^6,

[3]:
```
LD = 60*40_000*sp.S(520)
LR = sp.S(1e6)
xD = LD/LR
xD
```

[3]: 1248.0

Use Eq. 11-9.

$$C_{10} = a_f F_D \left(\frac{x_D}{x_0 + (\theta - x_0)[\ln(1/R_D)]^{1/b}} \right)^{1/a}$$

[4]:
```
# Weibull parameters
x0, theta = sp.S('0.02'), sp.S('4.459')
b = sp.S('1.483')

a = sp.S(3)
af = sp.S('1.4')
FD = sp.S(725)
RD = sp.S('0.9')
C10 = af*FD*(xD/(x0 + (theta - x0)*(sp.log(1/RD))**(1/b)))**(1/a)
C10  # lbf
```

[4]: 10952.2598806396

[5]:
```
# Convert to kN
C10_kN = C10*4.44822/1000
C10_kN
```

[5]: 48.7180614462586

The bearing selection is the 02-60 mm bearing with $C_{10} = 55.9\ kN$. The reliability may be estimated using Eq. 11-21.

$$R = \exp\left(-\left\{\frac{x_D\left(\frac{a_f F_D}{C_{10}}\right)^a - x_0}{\theta - x_0}\right\}^b\right)$$

[6]:
```
# Getting the reliability
C10 = sp.S('55.9')
FD = FD*4.44822/1000
R = sp.exp(-((xD*(af*FD/C10)**a - x0)/(theta - x0))**b)
R
```

[6]: 0.945295510736457

3 Problem 11-9

3.1 Given

Two ball bearings from different manufacturers are being considered for a certain application. Bearing A has a catalog rating of 2.0 kN based on a catalog rating system of 3000 hours at 500 rpm. Bearing B has a catalog rating of 7.0 kN based on a catalog that rates at 10^6 cycles.

3.2 Find

For a given application, determine which bearing can carry the larger load.

3.3 Solution

We can calculate the catalog rating for bearing A based on a one million cycle load.

[7]:
```
FA = sp.S(2)
LA = sp.S(3000)*sp.S(500)*60
LR = sp.S(1e6)
CA = (FA*(LA/LR)**sp.Rational(1, 3)).n()
CA  # kN
```

[7]: 8.96280949311433

Bearing A is the better bearing because the catalog rating at one million revolutions is greater than the catalog rating of Bearing B, which is 7 kN.

4 Problem 11-15

4.1 Given

A ball bearing has these parameters:

- Radial Load: 11 kips
- Design Life: 20 kh at 200 rpm
- Desired Reliability: 99%

The application factor is one.

4.2 Find

Determine the basic load rating with which to enter a bearing catalog of manufacturer 2 in the table below.

Manufacturer	Rating Life Revolutions	x_0	θ	b
1	$90 \cdot 10^6$	0	4.48	1.5
2	$1 \cdot 10^6$	0.02	4.459	1.483

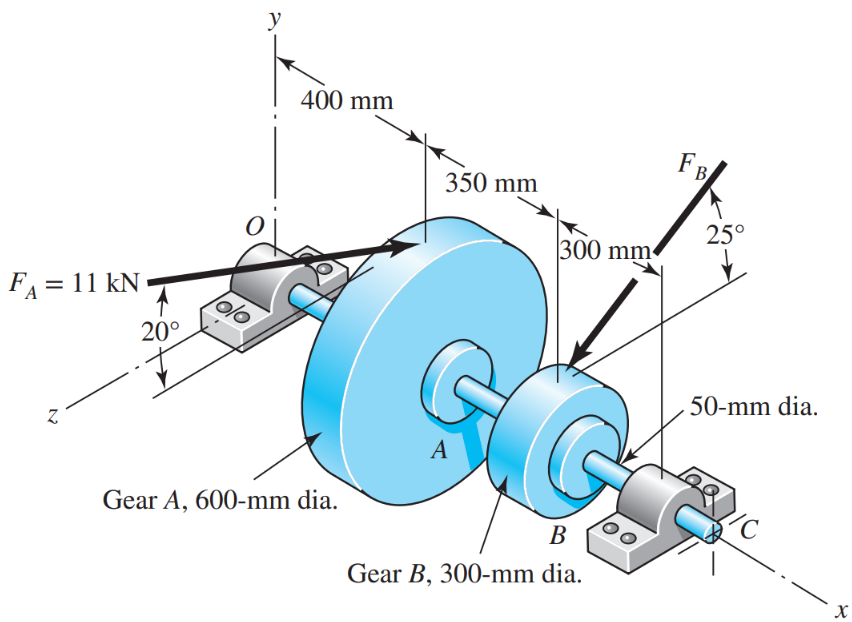
4.3 Solution

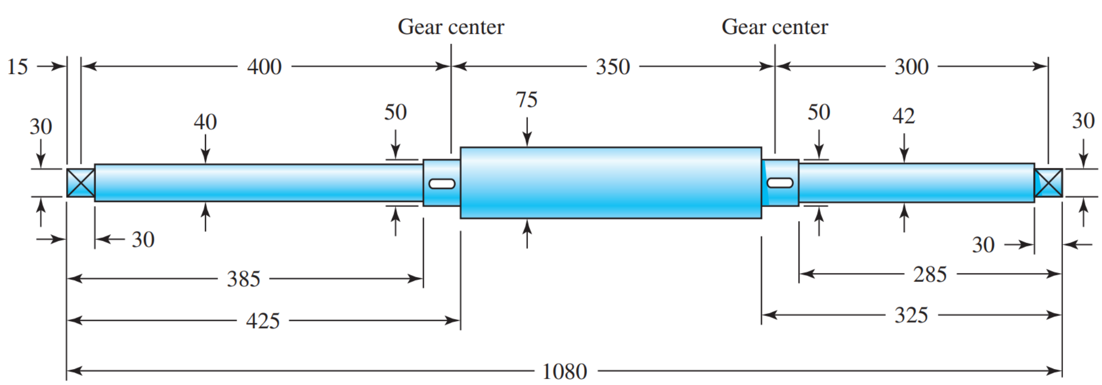
[8]:
```
a, b = sp.S(3), sp.S('1.483')
theta, x0 = sp.S(4.459), sp.S('0.02')
af = 1

LD = sp.S(20_000)*sp.S(200)*60
LR = sp.S(1e6)
FD = sp.S(11_000)
RD = sp.S('0.99')
xD = LD/LR
C10 = af*FD*(xD/(x0 + (theta - x0)*(sp.log(1/RD))**(1/b)))**(1/a)
C10  # lbf
```

[8]:
```
113307.639282462
```

5 Problem 11-31

5.1 Given





From the above figures, The effective centers of the gears for force transmission are shown. The dimensions for the bearing surfaces (indicated with the cross markings) have been estimated. The shaft rotates at 900 rpm, and the desired bearing life is 12 kh with a 98 percent reliability in each bearing. Assume the data for manufacturer 2 in the previous problem is used. The application factor is 1.2.

5.2 Find

a. Obtain a basic load rating for a ball bearing at the right end.
b. Use an online bearing catalog to find a specific bearing that satisfies the needed basic load rating and the geometry requirements. If necessary, indicate appropriate adjustments to the dimensions of the bearing surface.

5.3 Solution

All we need is the magnitude of the reaction force that occurs at section C.

[9]:

```python
# Solving the reactions
Oy, Oz, Cy, Cz = sp.symbols('O_y O_z C_y C_z')
FA = sp.S(11_000)  # N

# The torque on A is equal to the torque on B
FB = FA*sp.cos(sp.rad(20))*sp.S('0.3')/(sp.S('0.15')*sp.cos(sp.rad(25)))
FB.n()  # N
```

[9]: 22810.3939445176

[10]:

```python
eq1 = sp.Eq(Oy + Cy, FA*sp.sin(sp.rad(20)) + FB*sp.sin(sp.rad(25)))  # Fy
eq2 = sp.Eq(Oz + Cz + FB*sp.cos(sp.rad(25)) - FA*sp.cos(sp.rad(20)), 0)  # Fz
eq3 = sp.Eq(Cy*sp.S(400 + 350 + 300)/1000 - FA*sp.sin(sp.rad(20))*sp.S(400)/
 ↪1000 - FB*sp.sin(sp.rad(25))*sp.S(400 + 350)/1000, 0)
eq4 = sp.Eq(FA*sp.cos(sp.rad(20))*sp.S(400)/1000 - FB*sp.cos(sp.rad(25))*sp.
 ↪S(400 + 350)/1000 - Cz*sp.S(400 + 350 + 300)/1000, 0)

for eq in [eq1, eq2, eq3, eq4]:
    display(eq)

display(Markdown('---'))

# sol = sp.solve([eq1, eq2, eq3, eq4], (Oy, Oz, Cy, Cz), dict=True)[0]
sol = sp.nsolve([eq1, eq2, eq3, eq4], (Oy, Oz, Cy, Cz), (30, 30, 30, 30),␣
 ↪dict=True)[0]
for key, value in sol.items():
    display(sp.Eq(key, value.n()))
```

$$C_y + O_y = 11000 \sin\left(\frac{\pi}{9}\right) + \frac{22000.0 \sin\left(\frac{5\pi}{36}\right)\cos\left(\frac{\pi}{9}\right)}{\cos\left(\frac{5\pi}{36}\right)}$$

$$C_z + O_z + 11000.0 \cos\left(\frac{\pi}{9}\right) = 0$$

$$\frac{21C_y}{20} - \frac{16500.0 \sin\left(\frac{5\pi}{36}\right)\cos\left(\frac{\pi}{9}\right)}{\cos\left(\frac{5\pi}{36}\right)} - 4400 \sin\left(\frac{\pi}{9}\right) = 0$$

$$-\frac{21C_z}{20} - 12100.0 \cos\left(\frac{\pi}{9}\right) = 0$$

$$O_y = 5083.30546315649$$

$$O_z = 492.21994422119$$

$$C_y = 8319.00515187848$$

$$C_z = -10828.8387728662$$

Use the magnitude of the force acting at section C.

[11]:
```python
FD = sp.sqrt(sol[Cy]**2 + sol[Cz]**2)
FD  # lbf
```

[11]:

13655.387064661

5.3.1 Part A

[12]:
```python
# Weibull parameters
x0, theta = sp.S('0.02'), sp.S('4.459')
b = sp.S('1.483')

LD = 60*12_000*sp.S(900)
LR = sp.S(1e6)
xD = LD/LR

a = sp.S(3)
af = sp.S('1.2')
RD = sp.S('0.98')
# For reliabilities above 90% use this equation
C10 = af*FD*(xD/(x0 + (theta - x0)*(1 - RD)**(1/b)))**(1/a)
C10/1000  # kN
```

[12]:

203.679318422368

5.3.2 Part B

Though the suppliers have done a terrible job of displaying units, I believe this bearing has a 30 mm bore diameter and has a basic load rating of 1870 kN.