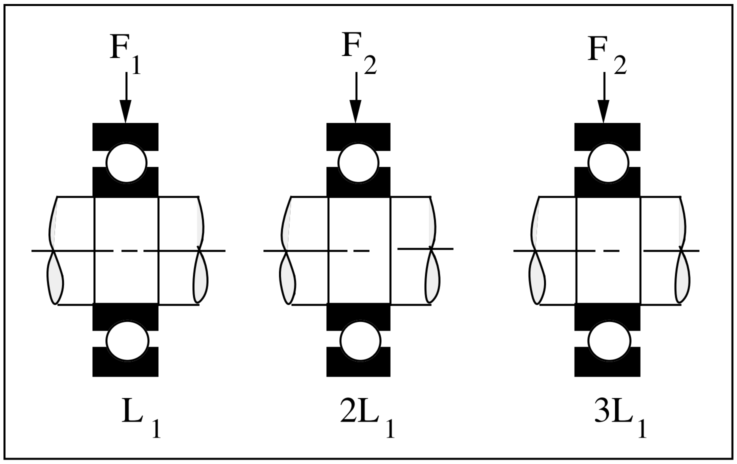
SOLUTION (14.13)

Known: A radial contact ball bearing has a given radial load.

Find: Determine the radial load change required to (a) double the life and (b) triple the life.

Schematic and Given Data:



Assumptions:
1. Ball bearing life varies inversely with the 10/3 power of the load.
2. The life given is for a 90% reliability.

Analysis:
1. Let L_1 and F_1 be the original life and load for the bearing. Let L_2 and F_2 be the new life and load.

2. Since $L_1/L_2 = (F_2/F_1)^{10/3}$, $F_2/F_1 = (L_1/L_2)^{3/10}$

3. To double the life, $L_2 = 2L_1$, and $F_2/F_1 = (1/2)^{3/10} = 0.812$ ■

4. To triple the life, $L_2 = 3L_1$, and $F_2/F_1 = (1/3)^{3/10} = 0.719$ ■

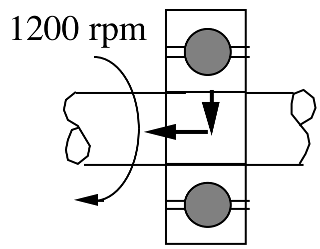
Comment: To double the bearing life the radial load must be reduced to 0.812 of its original value; to triple the bearing life the radial load must be reduced to 0.719 of its original value.

SOLUTION (14.17)

Known: A No. 204 radial ball bearing carries a radial load of 200 lb and a thrust load of 150 lb at 1800 rpm.

Find: Determine the bearing B-10 life.

Schematic and Given Data:



No. 204 Radial Bearing
F_r = 200 N, F_t = 150 N
90% reliability
steady loading
B-10 life = ?

Assumptions:
1. Table 14.2 accurately gives the bearing capacity.
2. Ball bearing life varies inversely with the 10/3 power of the load (i.e., Eq. (14.5a) is accurate).
3. The life given is for a 90% reliability.
4. The load F_e can be found from Eq. (14.3).

Analysis:
1. From Table 14.1, for a 204 bearing the bore is 20 mm.
2. From Table 14.2, for $L_R = 90 \times 10^6$ rev and a 200 series bearing, C = 3.35 kN = 752.8 lb.
3. From Fig. 14.13, for 90 percent reliability, $K_r = 1.0$.
4. From Table 14.3, $K_a = 1.0$ for a steady load.
5. The ratio F_t/F_r = 150 lb/200 lb = 0.75
6. The equivalent load from Eq. (14.3) is
   $F_e = F_r[1 + 1.115(\{F_t/F_r\} - 0.35)] = 200 \text{ lb}[1 + 1.115(\{150/200\} - 0.35)] = 289.2 \text{ lb}$
7. From Eq. (14.5a), $L = K_r L_R (C/F_e K_a)^{3.33}$
8. Substituting values into Eq. (14.5a):

$$L = 90 \times 10^6 \text{ rev} \left[\frac{752.8 \text{ lb}}{289.2 \text{ lb}}\right]^{3.33} = 2.18 \times 10^9 \text{ rev}$$

$$= \left[\frac{2.18 \times 10^9 \text{ rev}}{(60 \text{ min/hr})(1200 \text{ rev/min})}\right] = 30{,}277 \text{ hr}$$

■

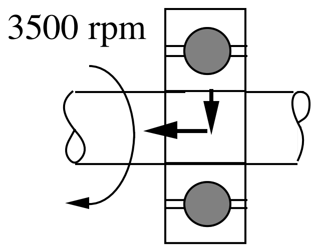
Comment: The life of 30,277 hours corresponds to about 3.5 years of continuous operation where the bearing runs 24 hours/day and 7 days/week.

SOLUTION (14.18)

Known: A No. 204 radial ball bearing has 90% reliability and carries a radial load of 1000 N and a thrust load of 250 N.

Find: Determine the B-10 bearing life.

Schematic and Given Data:



No. 204 Radial Ball Bearing
$F_r = 1000$ N, $F_t = 250$ N
90% reliability
Light-moderate shock loading
L = ? hr life

Assumptions:
1. Ball bearing life varies inversely with the 10/3 power of the load (i.e., Eq. (14.5a) is accurate).
2. The equivalent load can be accurately estimated using Eq. (14.3).

Analysis:
1. From Table 14.2, the rated load capacity, C = 3.35 kN.
2. From Fig. 14.13, for 90 percent reliability, $K_r = 1.0$.
3. From Table 14.3, $K_a = 1.5$ for light-moderate shock loading.
4. $F_t/F_r = 250/1000 = 0.25 < 0.35$.
5. From Eq. (14.3), $F_e = F_r = 1000$ N.
6. From Eq. (14.5a), $L = K_r L_R (C/F_e K_a)^{3.33}$

$$= (1)(90 \times 10^6)\left[\frac{3.35}{(1)(1.5)}\right]^{3.33} = 1.307 \times 10^9 \text{ revs}$$

$$L = \frac{1.307 \times 10^9 \text{ rev}}{} \left| \frac{\text{min}}{3500 \text{ rev}} \right| \frac{\text{hr}}{60 \text{ min}} \bigg|$$

$$= 6224 \text{ hours}$$ ■

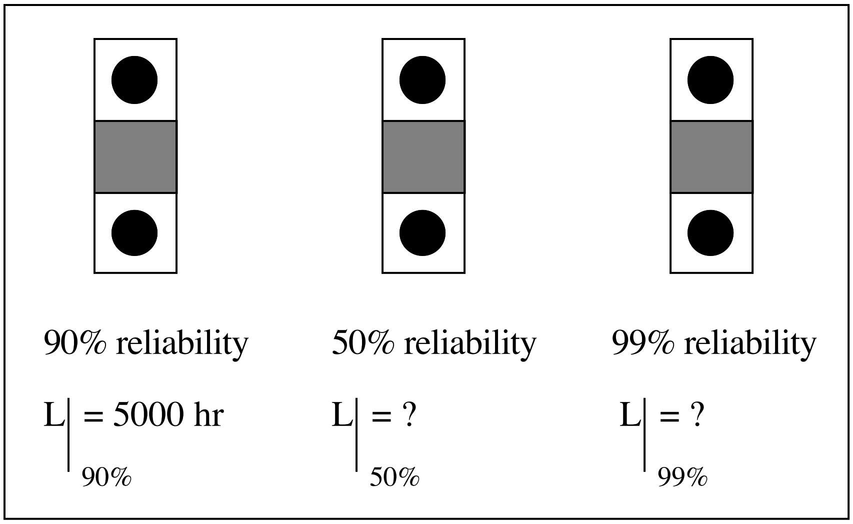
Comment: Inspection of Table 14.4 for representative bearing design lives would suggest that this bearing would be suitable for a gearing application used intermittently, where service interruption is of minor importance.

SOLUTION (14.19)

Known: A bearing has a life of 5000 hr for 90% reliability.

Find: Estimate the lives for 50% reliability and 99% reliability.

Schematic and Given Data:



Assumption: Bearing life varies inversely with the 10/3 power of the load (i.e., Eq. (14.2a) is suitable).

Analysis:

1. From Eq. (14.2a), $L = K_r L_R (C/F_r)^{3.33}$
2. For identical bearings with the same L_R, C, and F_r,

$$\left.\frac{L}{K_r L_R (C/F_r)^{3.33}}\right|_{90\%} = \left.\frac{L}{K_r L_R (C/F_r)^{3.33}}\right|_{50\%} = \left.\frac{L}{K_r L_R (C/F_r)^{3.33}}\right|_{99\%}$$

or

$$\left.\frac{L}{K_r}\right|_{90\%} = \left.\frac{L}{K_r}\right|_{50\%} = \left.\frac{L}{K_r}\right|_{99\%}$$

3. From Fig. 14.13, for 90% reliability, $K_r = 1.0$; for 99% reliability, $K_r = 0.21$; for 50% reliability, $K_r = 5.0$.

4. $$\frac{L_{90\%}}{1.0} = \frac{L_{50\%}}{5.0} = \frac{L_{99\%}}{0.21}$$

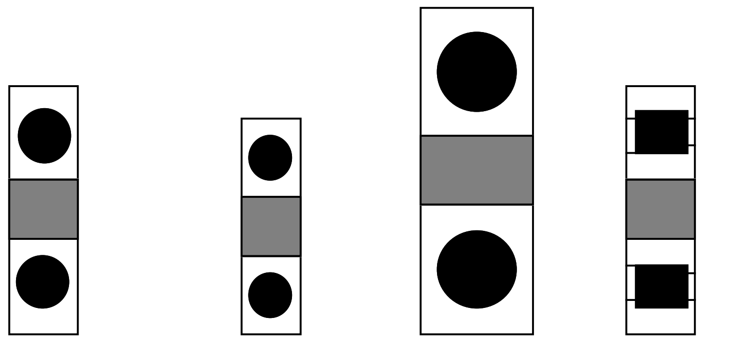
5. For $L_{90\%}$ = 5000 hours, $L_{50\%}$ = (5)(5000) = 25,000 hours ■
   and $L_{99\%}$ = (0.21)(5000) = 1,050 hours ■

Comment: A higher reliability requirement (fewer bearing failures) means a shorter life.

SOLUTION (14.20)
Known: A No. 211 radial ball bearing has a life of 5000 hr for 90% reliability.

Find: For the same application, estimate the life for 90% reliability for (a) a L11 bearing, (b) a 311 bearing, and (c) a 1211 bearing.

Schematic and Given Data:



Assumptions:
1. Bearing life varies inversely with the 10/3 power of the load (i.e., Eq. (14.1a) is suitable).
2. The loading conditions are identical for the bearings.

Analysis:
1. From Table 14.2, for the 211 bearing, C = 12.0 kN.
2. Also from Table 14.2, for the
   (a) L11 bearing, C = 8.2 kN
   (b) 311 bearing, C = 18.0 kN
   (c) 1211 bearing, C = 14.9 kN
3. From Eq. (14.1a), $L = L_R(C/F_r)^{3.33}$
4. For identical loading conditions (i.e., the same value of F_r) and for bearing rating capacities where $L_R = 90 \times 10^6$ revolutions,

$$\left.\frac{L}{C^{3.33}}\right|_{211} = \left.\frac{L}{C^{3.33}}\right|_{L11} = \left.\frac{L}{C^{3.33}}\right|_{311} = \left.\frac{L}{C^{3.33}}\right|_{1211}$$

5. $$\frac{L_{211}}{12^{3.33}} = \frac{L_{L11}}{8.2^{3.33}} = \frac{L_{311}}{18.0^{3.33}} = \frac{L_{1211}}{14.9^{3.33}}$$

6. Since $L_{211} = 5000$ hr,
   $L_{L11} = 1407$ hr, ■
   $L_{311} = 19{,}291$ hr and ■
   $L_{1211} = 10{,}280$ hr ■

Comments:

1. Bearing No. 1211 is not listed in Table 14.1. But the inner diameter for each bearing is (5)(11) = 55 mm, as the application is the same, and using Table 14.2 the rating load capacity for the 1211 bearing is obtained.

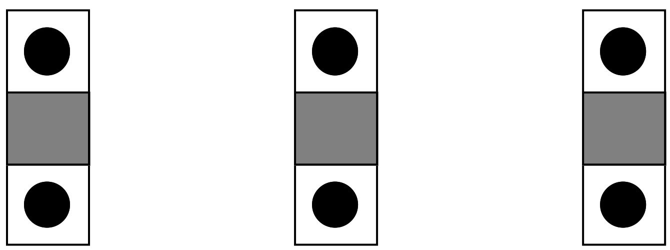
2. The 311 ball bearing has more load capacity than the 1211 roller bearing. Indeed Table 14.2 reveals that the 300 medium series has a higher load capacity than the 1200 light roller bearing for 20 mm to 80 mm bore bearings.

SOLUTION (14.21)

Known: A bearing has a life of 15,000 hr for 90% reliability.

Find: Estimate the lives for 50% reliability and 99% reliability.

Schematic and Given Data:



Assumption: Bearing life varies inversely with the 10/3 power of the load (i.e., Eq. (14.2a) is suitable).

Analysis:

1. From Eq. (14.2a), $L = K_r L_R (C/F_r)^{3.33}$
2. For identical bearings with the same L_R, C, and F_r,

$$\left.\frac{L}{K_r L_R (C/F_r)^{3.33}}\right|_{90\%} = \left.\frac{L}{K_r L_R (C/F_r)^{3.33}}\right|_{50\%} = \left.\frac{L}{K_r L_R (C/F_r)^{3.33}}\right|_{99\%}$$

or

$$\left.\frac{L}{K_r}\right|_{90\%} = \left.\frac{L}{K_r}\right|_{50\%} = \left.\frac{L}{K_r}\right|_{99\%}$$

3. From Fig. 14.13, for 90% reliability, $K_r = 1.0$; for 99% reliability, $K_r = 0.21$; for 50% reliability, $K_r = 5.0$.

4. $$\frac{L_{90\%}}{1.0} = \frac{L_{50\%}}{5.0} = \frac{L_{99\%}}{0.21}$$

5. For $L_{90\%}$ = 15000 hours, $L_{50\%}$ = (5)(15000) = 75,000 hours ■
and $L_{99\%}$ = (0.21)(15000) = 3,150 hours ■

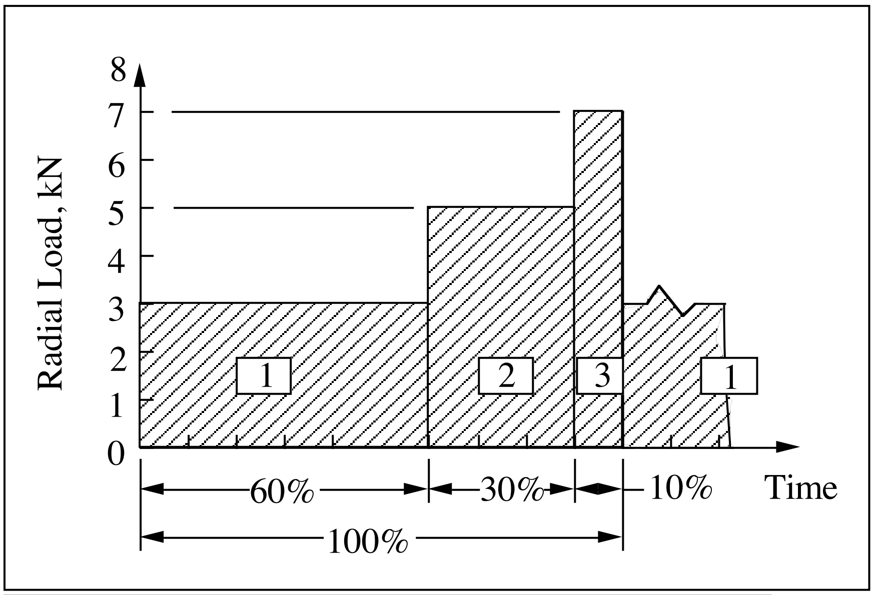
Comment: A higher reliability requirement (fewer bearing failures) means a shorter life.

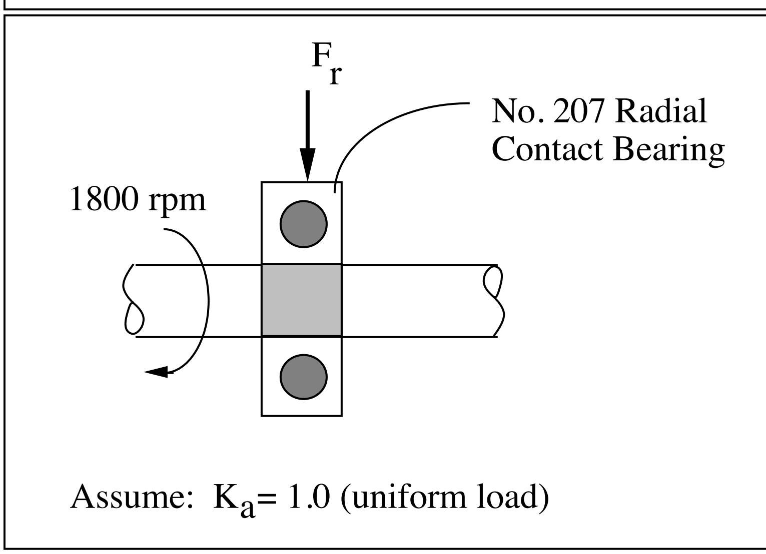
SOLUTION (14.22)

Known: A radial contact ball bearing carries a radial load of 3 kN, 5 kN, and 7 kN for 60%, 30% and 10% of the time respectively.

Find: Determine the B-10 life and the median life.

Schematic and Given Data:





Assumptions:
1. The Palmgren or Miner rule (linear cumulative damage rule) is appropriate.
2. Eq. (14.5) is appropriate.
3. Let X equal the B-10 life.

Analysis:

1. From Table 14.2, for the No. 207 radial contact bearing we have C = 8.5 kN (with $L_R = 90 \times 10^6$ and 90% reliability).
2. Eq. (14.5a) is $L = K_r L_R (C/F_e K_a)^{3.33}$. We have $F_e = F_r$, $K_a = 1.0$ and for 90% reliability, $K_r = 1.0$. Thus, $L = L_R(C/F_r)^{3.33}$.
3. With C = 8.5 kN, $L_R = 90 \times 10^6$ rev and the above equation, we have for
   (a) $F_r = 3$ kN, $L = 2887 \times 10^6$ rev
   (b) $F_r = 5$ kN, $L = 526.8 \times 10^6$ rev
   (c) $F_r = 7$ kN, $L = 171.8 \times 10^6$ rev
4. From Eq. (8.3), for k = 3,
   $$\frac{n_1}{N_1} + \frac{n_2}{N_2} + \frac{n_3}{N_3} = 1$$
5. For X minutes of operation, we have $n_1 = 1080X$ rev, $n_2 = 540X$ rev, $n_3 = 180X$ rev.
6. From part 3, $N_1 = 2887 \times 10^6$ rev, $N_2 = 526.8 \times 10^6$ rev, and $N_3 = 171.8 \times 10^6$ rev.
7. Substituting into the equation in part 4 gives
   $$\frac{1080X}{2887 \times 10^6} + \frac{540X}{526.8 \times 10^6} + \frac{180X}{171.8 \times 10^6} = 1$$
   Hence, $X = \frac{10^6}{2.4469} = 408{,}694$ minutes $= 6811$ hours ■
8. The median life equals approximately 5 times the B-10 life. Hence, the median life is 34,057 hours. ■

Comment: The general relationship that average life is equal to approximately 5 times the B-10 life was established from experimental data obtained from endurance testing of numerous bearings.

SOLUTION (14.23D)

Known: A countershaft has helical gear (B), bevel gear (D), and two supporting bearings (A and C). The shaft rotates at 1000 rpm. Loads acting on the bevel gear are known. Forces on the helical gears can be determined. Shaft dimensions are known. All shoulder fillets have a radius of 5 mm. Only bearing A takes thrust. The shaft is made of hardened steel having known values of S_u and S_y. All important surfaces are finished by grinding.

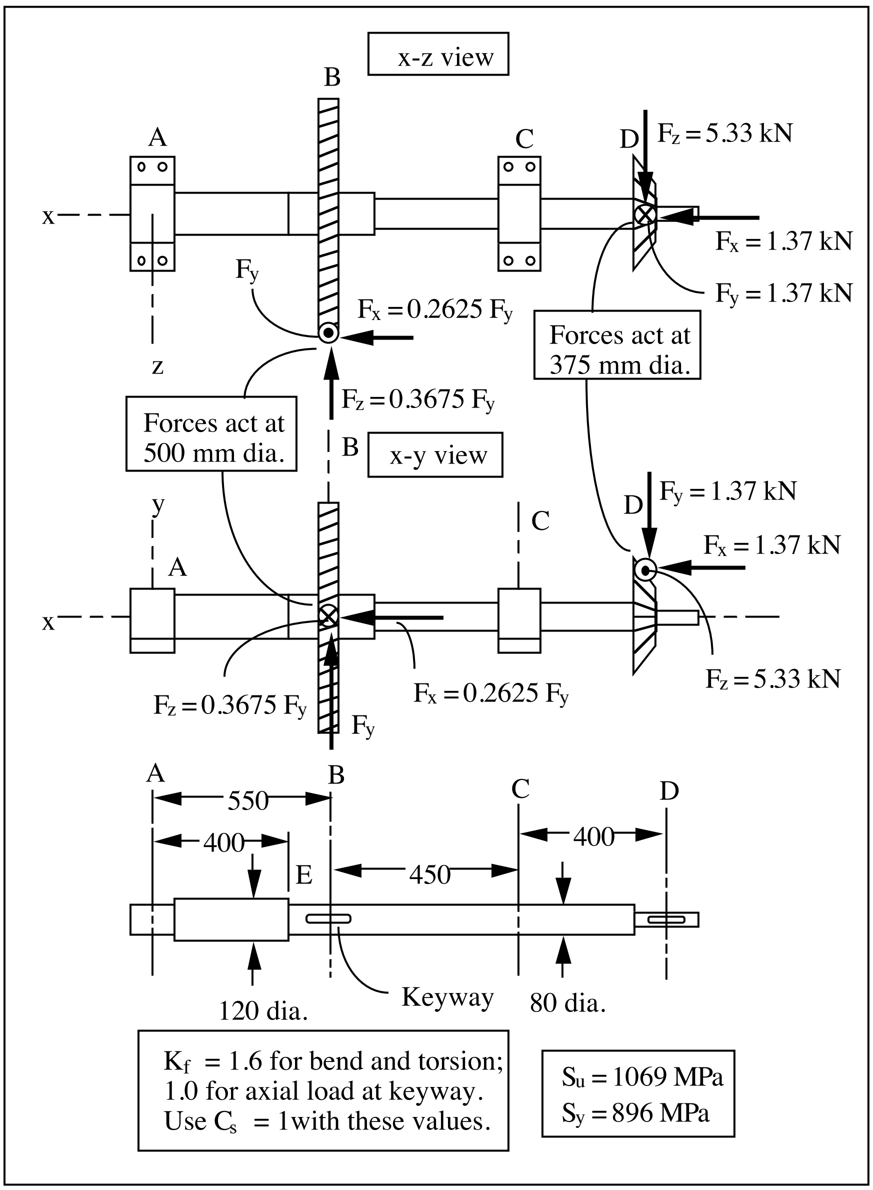
Find:

(a) Draw load, shear force, and bending moment diagrams for the shaft in the xy- and xz- planes. Also draw diagrams showing the intensity of the axial force and torque along the length of the shaft.

(b) Calculate the forces at the bearings A and C.

(c) Select a suitable bearing for this shaft.

Schematic and Given Data:



Decisions: We need to make decisions about the performance of the bearing that we will select, since this information is not given in the problem statement. Toward this end, we will select a suitable radial contact ball bearing(s) that can carry a known radial and known thrust load for 5000 hr with 98% reliability where there is light to moderate impact loading for the bearing. Also, we will select one bearing size suitable for both locations A and C.

Assumptions:
1. The shaft is manufactured as specified with regard to the critical shaft geometry and surface finish.
2. The shaft has been properly designed and will not fail.
3. The bearing selected will last for 5000 hr with 98% reliability.
4. There is light to moderate impact loading for the bearing.

Analysis:

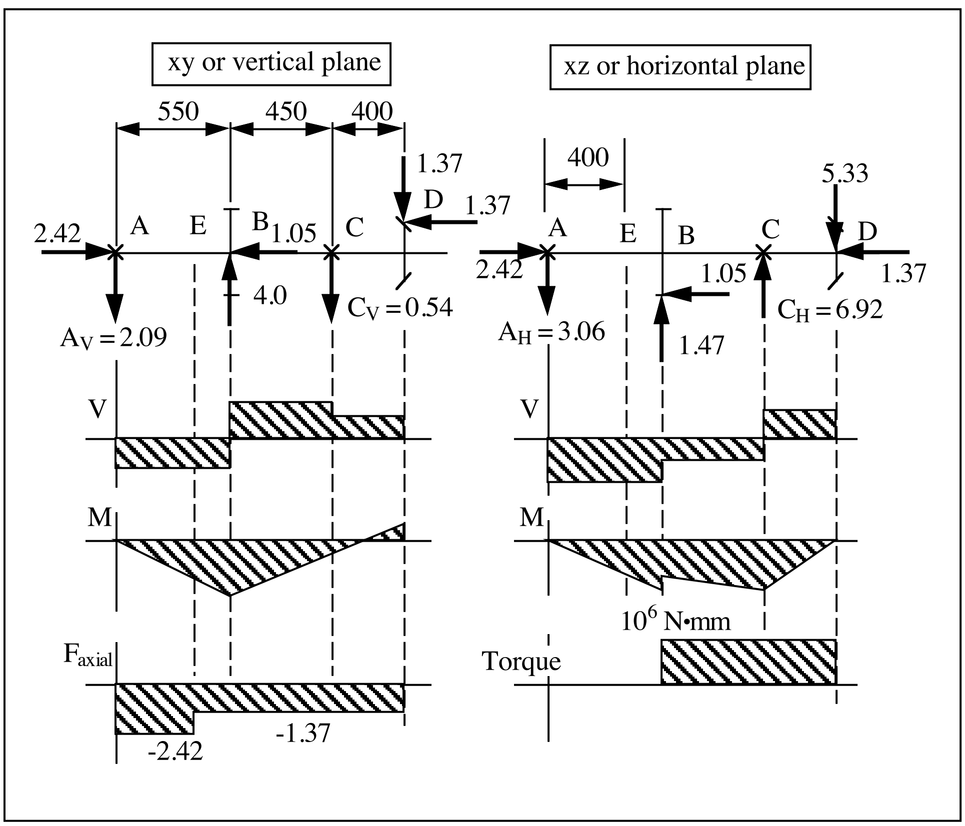
(a1) Load determination

Helical gear forces:

For $\sum M_x = 0$, the torque at the two gears must be equal. Therefore, F_y (250 mm) = 5.33(187.5 mm). Hence, $F_y = 4.00$ kN.

From the given data, $F_x = .2625F_y = 1.05$ kN; $F_z = .3675\ F_y = 1.47$ kN.

(a2) Determine shaft loads in the xy and xz planes



(b1) Determination of forces at A and C

Vertical forces:

$$\sum M_A = 0: \quad C_v = \frac{4(550) + 1.37(187.5) - 1.37(1400)}{1000} = 0.54 \text{ kN downward}$$

$$\sum F = 0: \quad A_v = 4 - 0.54 - 1.37 = 2.09 \text{ kN downward}$$

Horizontal forces:

$$\sum M_A = 0: \quad C_H = \frac{1.05(250) - 1.47(550) + 5.33(1400)}{1000} = 6.92 \text{ kN upward}$$

$$\sum F = 0: \quad A_H = 1.47 + 6.92 - 5.33 = 3.06 \text{ kN downward}$$

Thrust forces:

$$\sum F = 0: \quad A_{thrust} = 1.05 + 1.37 = 2.42 \text{ kN rightward}$$

(b2) Determination of bearing forces at A

The radial force at bearing A is

$$A_r = \sqrt{(A_v^2 + A_H^2)} = \sqrt{(2.09^2 + 3.06^2)} = 3.71 \text{ kN}$$

The thrust force at bearing A is

$$A_t = 2.42 \text{ kN}$$

(b3) Determination of bearing forces at C

The radial force at bearing C is

$$C_r = \sqrt{(C_v^2 + C_H^2)} = \sqrt{(0.54^2 + 6.92^2)} = 6.94 \text{ kN}$$

There is no thrust force at bearing C.

(c) Selection of a suitable bearing for the shaft size and loads – *known* and *find*

From the drawing, the shaft size is 80 mm at C and at A. This will be the bearing inner bore size.

From the force analysis we know the bearing loads at A and C. Also, we have a known shaft speed of 1000 rpm.

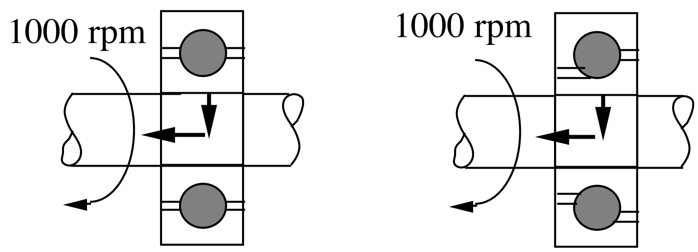
From the design decisions listed above we know that the bearing needs to carry a known radial and a known thrust load for 5000 hr life with 98% reliability for light to moderate impact loading for the bearing.

We now need to complete the analysis and identify a bearing suitable for locations A and C.

The figure below better defines the bearing selection problem

Schematic and Given Data (for the bearing selection problem):

Bearing A	Bearing C
F_r = 3.71 kN,	F_r = 6.94 kN
F_t = 2.42 kN	F_t = 0.0 kN
98% reliability	98% reliability
L = 5000 hr life	L = 5000 hr life
light-moderate impact	light-moderate impact



Assumptions for bearing selection:

1. The inner ring of the bearing fits with enough interference to prevent relative motion during operation.
2. The internal fits between the balls and their races are correct.
3. Bearing misalignment is no more than 15'.
4. The bearing selected will last for 5000 hr with 98% reliability with a shaft speed of 1000 rpm.
5. There is light to moderate impact loading for the bearing.

Analysis for bearing selection:

• Bearing A

1. F_r = 3.71 kN, F_t = 2.42 kN
2. F_t/F_r = 0.6523
3. From Table 14.3, for light-moderate impact, K_a = 1.5.
4. L = 5000 hours = (5000 hours)(1000 rev/min)(60 min/hr) = 3×10^8 rev.
5. From Table 14.3, with 98% reliability we have K_r = 0.33.
6. The life corresponding to rated capacity, $L_R = 90 \times 10^6$.
7. For a radial bearing, Eq. (14.3) gives $F_e = F_r\,[1 + 1.115(F_t/F_r - 0.35)]$ = 3.71[1 + 1.115(0.6523-0.3500] = 4.96 kN.
8. For a radial bearing, from Eq. (14.5b), the required value of rated capacity for the application, $C_{req} = F_e K_a\,(L/K_r L_R)^{0.3}$ = (4.96 kN)(1.5)[300E6)/(0.33)(90E6)]$^{0.3}$ = (4.96)(3.0019) = 14.89 kN. ■

9. From Table 14.2, a 216 radial bearing with a rated capacity of 18.4 kN would be sufficient for bearing A.

10. For an angular bearing, from Eq. (14.5), the required value of rated capacity for the application, $C_{req} = F_rK_a\,(L/K_rL_R)^{0.3}$ = (3.71 kN)(1.5)[300E6)/(0.33)(90E6)] $^{0.3}$ = (3.71)(3.0019) = 11.13 kN.

11. From Table 14.2, a 216 angular bearing with a rated capacity of 22.5 kN would be sufficient for bearing A.

• Bearing C

1. $F_r = 6.94$ kN, $F_t = 0.0$ kN, $F_t/F_r = 0.0$

2. $F_e = F_r = 6.94$ kN

3. From Table 14.3, for light-moderate impact, $K_a = 1.5$.

4. L = 5000 hours = (5000 hours)(1000 rev/min)(60 min/hr) = 3×10^8 rev.

5. From Table 14.3, with 98% reliability we have $K_r = 0.33$.

6. The life corresponding to rated capacity, $L_R = 90 \times 10^6$.

7. For a radial bearing, Eq. (14.3) gives $F_e = F_r = 6.94$ kN.

8. For a radial bearing, from Eq. (14.5b), the required value of rated capacity for the application, $C_{req} = F_eK_a\,(L/K_rL_R)^{0.3}$ = (6.94 kN)(1.5)[300E6)/(0.33)(90E6)] $^{0.3}$ = (6.94)(3.0019) = 20.83 kN.

9. A 216 radial bearing with a rated capacity of 18.4 kN would not be sufficient for bearing A. A 216 angular bearing with a rated capacity of 22.5 kN would be sufficient for bearing A.

10. From Table 14.2, for C_{req} = 20.83 kN we can select a No. 316 radial ball bearing that has a bearing load capacities of 28.0 kN.

• Bearing A and C

1. The location at A requires a load capacity of 14.89 kN for a radial bearing or 11.13 kN for an angular bearing. The location at C requires a radial bearing or an angular bearing with a load capacity of 20.83 kN.

2. A No. 316 radial ball bearing with a bearing load capacity of 28.0 kN has an 80 mm inner race diameter. The shaft diameter is 80 mm. The capacity of the No. 316 radial ball bearing will allow this bearing to be used at both position A and C.

3. We will select bearing No. 316 for both bearings A and C. ■

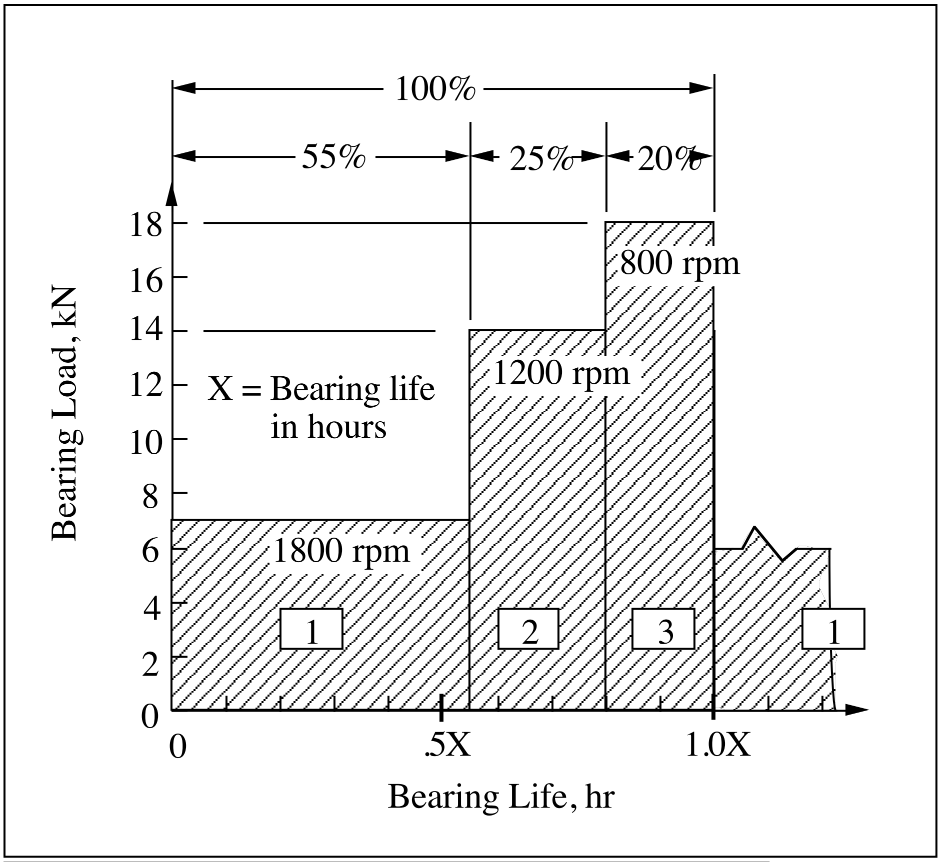
Comment: A 80 mm bore angular ball bearing could also be selected as it has a higher rated load capacity, C, than the radial ball bearing.

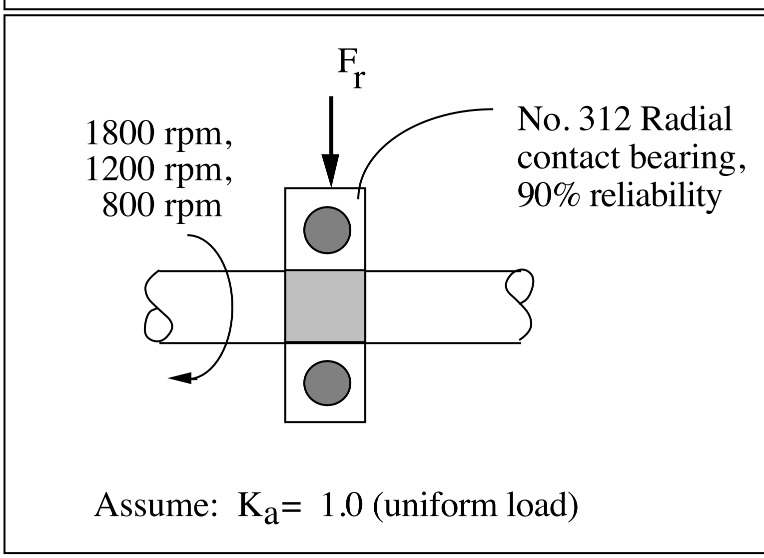
SOLUTION (14.24)

Known: A No. 312 radial contact ball bearing is loaded uniformly with three different loads and for three different periods.

Find: Estimate the bearing life for 90% reliability.

Schematic and Given Data: The load versus life (hr) diagram can be constructed from the given data:





Assumptions:

1. The change in load occurs without shock.
2. The bearing life varies inversely with the 10/3 power of the load.
3. Miner's rule is appropriate for this analysis.

Analysis:

1. From Table 14.2, for a No. 312 ball bearing, C = 20 kN for 90×10^6 revolution life with 90 percent reliability.
2. From Fig. 14.13, for 90% reliability, $K_r = 1.0$.
3. From Table 14.3, for no impact $K_a = 1.0$.
4. With $K_r = 1.0$, $L_R = 90 \times 10^6$, and $K_a = 1.0$, Eq. (14.5a) becomes
   $L = 90 \times 10^6 (C/F_e)^{3.33}$
5. With the above equation, for C = 20 kN, we have for
   (a) $F_e = 7$ kN, $L = 2.968 \times 10^9$
   (b) $F_e = 14$ kN, $L = 2.952 \times 10^8$
   (c) $F_e = 18$ kN, $L = 1.278 \times 10^8$
6. Let X equal the total bearing life in hours.
7. The number of cycles at 7 kN, n_1 = (.55X hours)(1800 rev/min)(60 min/hr)
   = 59,400X cycles.
   Likewise, at 14 kN, n_2 = (.25X hours)(1200 rev/min)(60 min/hr)
   = 18,000X cycles.
   And at 18 kN, n_3 = (.20X hours)(800 rev/min)(60 min/hr)
   = 9600X cycles.
8. With $N_i = L_i$, i = 1,2,3, Eq. (8.3) becomes

   $$\frac{n_1}{N_1} + \frac{n_2}{N_2} + \frac{n_3}{N_3} = 1$$

   or $$\frac{59{,}400X}{2.968 \times 10^9} + \frac{18{,}000X}{2.952 \times 10^8} + \frac{9600X}{1.278 \times 10^8} = 1$$

   Hence, X = 6406 hours ■

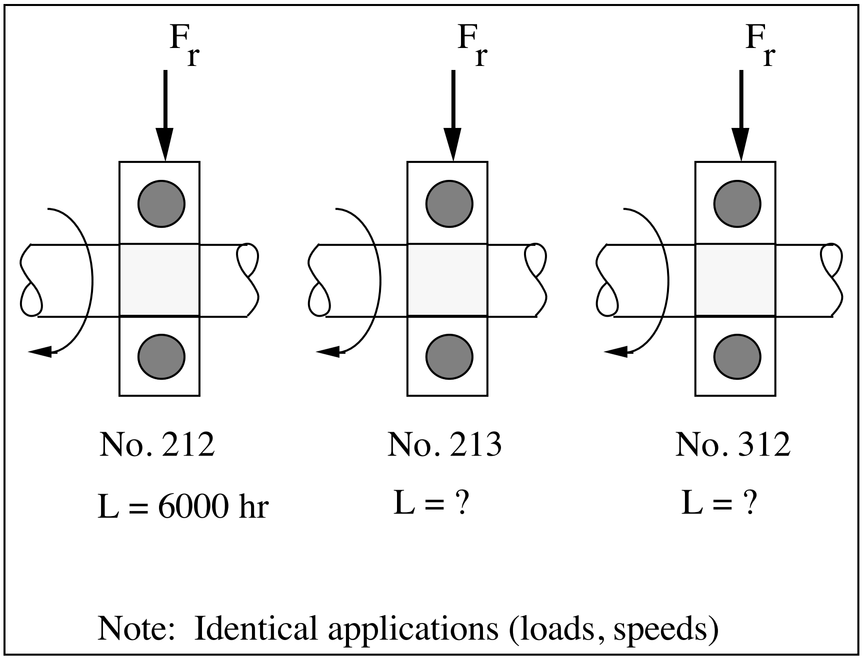
9. The cumulative damage of each of three loads is respectively, 13%, 39%, and 48%; i.e., (n_i/L_i), i = 1,2,3. ■

SOLUTION (14.25)

Known: Three radial ball bearings are used in the same application. The life of the No. 212 bearing is 6000 hr.

Find: Determine the bearing life for the No. 213 and the No. 312 bearings.

Schematic and Given Data:



Assumptions:

1. Ball bearing life varies inversely with the 10/3 power of the load (i.e., Eq. (14.5a) is accurate).
2. The loading conditions are identical for the bearings.

Analysis:

1. From Table 14.2, for radial ball bearings
   No. 212, C = 13.6 kN, $L_R = 90 \times 10^6$
   No. 213, C = 16.0 kN, $L_R = 90 \times 10^6$
   No. 312, C = 20.0 kN, $L_R = 90 \times 10^6$
2. From Eq. (14.1a)

$$\left.\frac{L}{L_R(C/F_r)^{3.33}}\right]_{No.\,212} = \left.\frac{L}{L_R(C/F_r)^{3.33}}\right]_{No.\,213} = \left.\frac{L}{L_R(C/F_r)^{3.33}}\right]_{No.\,312}$$

3. Since both the radial load and the life corresponding to rated capacity are the same for each bearing, the above equation reduces to

$$\left.\frac{L}{C^{3.33}}\right]_{No.\,212} = \left.\frac{L}{C^{3.33}}\right]_{No.\,213} = \left.\frac{L}{C^{3.33}}\right]_{No.\,312}$$

or $$\frac{6000 \text{ hours}}{13.6^{3.33}} = \frac{L_{213}}{16^{3.33}} = \frac{L_{312}}{20^{3.33}}$$

Hence, L_{213} = 10,308 hr, and L_{312} = 21,672 hr

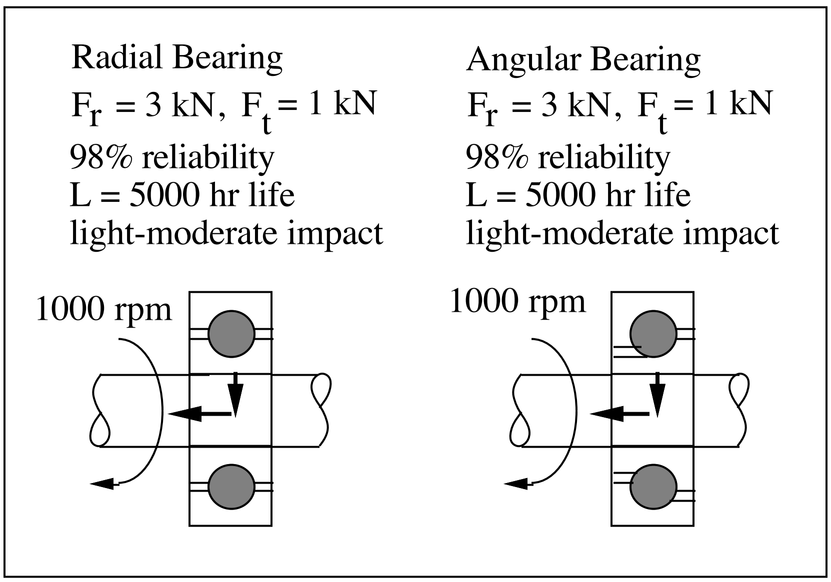
Comment: This problem can be solved by noting that the life varies directly with the 3.33 power of the bearing rated load capacity, C.

SOLUTION (14.26D)

Known: A ball bearing carries a known radial and a known thrust load for 5000 hr with 98% reliability.

Find: Select a suitable bearing: (a) radial, (b) angular.

Schematic and Given Data:



Assumptions:
1. The inner ring of the bearing fits with enough interference to prevent relative motion during operation.
2. The internal fits between the balls and their races are correct.
3. Bearing misalignment is no more than 15'.

Analysis:
1. From Eqs. (14.3) and (14.4), for F_t/F_r = 1/3 = 0.33, we have $F_e = F_r$.
2. From Fig. 14.13, for 98% reliability we have K_r = 0.33.
3. From Table 14.3, for light-moderate impact, K_a = 1.5.
4. $$L = 5000 \text{ hours} = \frac{5000 \text{ hours}}{} \bigg| \frac{1000 \text{ rev}}{\text{min}} \bigg| \frac{60 \text{ min}}{\text{hour}} \bigg| = 3 \times 10^8 \text{ rev}$$

5. For the radial bearing with $F_e = F_r = 3$ kN, $K_a = 1.5$, $L = 3 \times 10^8$ rev, $K_r = 0.33$ and $L_R = 90 \times 10^6$ rev, Eq. (14.5b) gives

$$C_{req} = (3\text{kN})(1.5)\left[\frac{3 \times 10^8 \text{ rev}}{(0.33)(90 \times 10^6 \text{ rev})}\right]^{0.3} = 9.01 \text{ kN}$$

6. The bearing load capacity for the angular bearing is the same as for the radial bearing.
7. From Table 14.2, for $C_{req} = 9.01$ kN we select a No. 208 radial ball bearing and a No. 208 angular ball bearing that have bearing load capacities of 9.40 kN and 9.90 kN respectively. ■

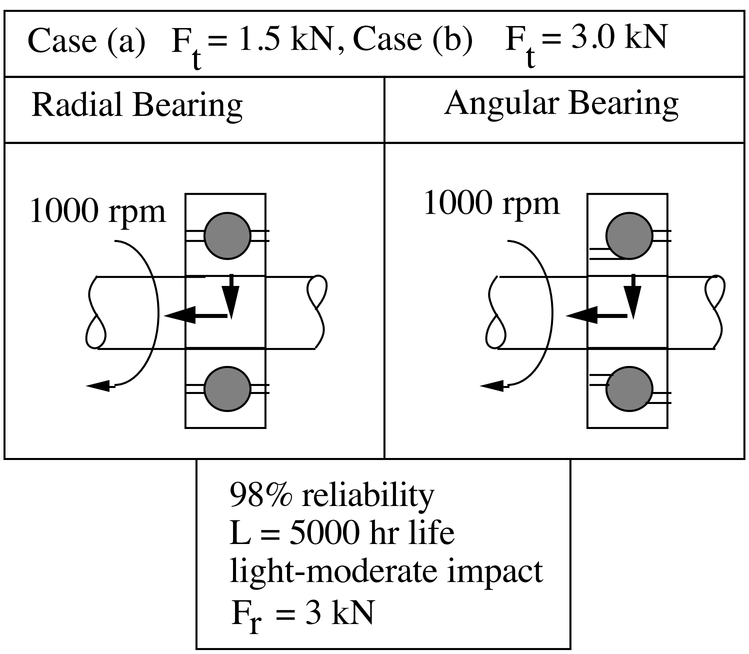
Comment: For 40 mm bore sizes and above, the angular ball bearing has a higher rated load capacity, C, than the radial ball bearing.

SOLUTION (14.27D)

Known: Radial and angular bearings are to operate for 5000 hr with 98% reliability with known combinations of radial and thrust loads.

Find: Select suitable (a) radial and (b) angular bearings for each load combination.

Schematic and Given Data:



Assumptions:
1. The inner ring of the bearing fits with enough interference to prevent relative motion during operation.
2. The internal fits between the balls and their races are correct.
3. Bearing misalignment is 15' or less.

Analysis:

1. From Table 14.3, for light-moderate impact, $K_a = 1.5$.
2. $L = 5000$ hours = (5000 hours)(1000 rev/min)(60 min/hr) = 3×10^8 rev.
3. From Table 14.3, with 98% reliability we have $K_r = 0.33$.
4. The life corresponding to rated capacity, $L_R = 90 \times 10^6$.
5. From Eq. (14.5b),
   $C_{req} = F_e K_a (L/K_r L_R)^{0.3} = F_e(1.5)(300/(0.33)(90))^{0.3} = 3.00\ F_e$.

(a)

6. For $F_t = 1.5$ kN, $F_t/F_r = 0.5$.
7. For the radial bearing, Eq. (14.3) gives $F_e = (3.0)(1 + 1.115(0.15)) = 3.50$ kN.
8. The required value of rated capacity for the application, $C_{req} = 3(3.50) = 10.5$ kN.
9. Select bearing No. 211. ■
10. For the angular bearing, Eq. (14.4) gives $F_e = F_r = 3.0$ kN.
11. $C_{req} = (3)(3.0) = 9$ kN.
12. Select 40 mm bore bearing No. 208. ■

(b)

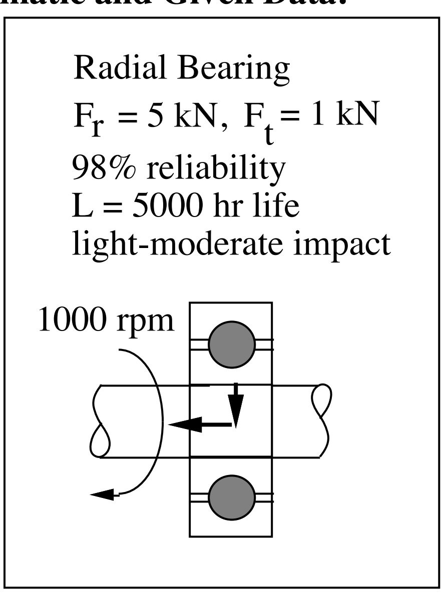
13. For $F_t = 3.0$ kN, $F_t/F_r = 1.0$.
14. For the radial bearing, Eq. (14.3) gives $F_e = (3.0)(1 + 1.115(0.65)) = 5.17$ kN.
15. $C_{req} = (3)(5.17) = 15.52$ kN.
16. Select bearing No. 213. ■
17. For the angular bearing, Eq. (14.4) gives $F_e = (3.0)(1.0 + 0.870(0.32)) = 3.84$ kN.
18. $C_{req} = (3)(3.84) = 11.51$ kN.
19. Select bearing No. 211. ■

SOLUTION (14.28)

Known: A ball bearing carries a known radial and a known thrust load for 5000 hr with 98% reliability.

Find: Select a suitable radial contact bearing.

Schematic and Given Data:



Assumptions:

1. The inner ring of the bearing fits with enough interference to prevent relative motion during operation.
2. The internal fits between the balls and their races are correct.
3. Bearing misalignment is no more than 15'.

Analysis:

1. From Eqs. (14.3) and (14.4), for $F_t/F_r = 1/5 = 0.20$, we have $F_e = F_r$.
2. From Fig. 14.13, for 98% reliability we have $K_r = 0.33$.
3. From Table 14.3, for light-moderate impact, $K_a = 1.5$.
4. $L = 5000 \text{ hours} = \dfrac{5000 \text{ hours}}{} \bigg| \dfrac{1000 \text{ rev}}{\text{min}} \bigg| \dfrac{60 \text{ min}}{\text{hour}} \bigg| = 3 \times 10^8 \text{ rev}$
5. For the radial bearing with $F_e = F_r = 5$ kN, $K_a = 1.5$, $L = 3 \times 10^8$ rev, $K_r = 0.33$ and $L_R = 90 \times 10^6$ rev, Eq. (14.5b) gives

$$C_{req} = (5 \text{ kN})(1.5) \left[\frac{3 \times 10^8 \text{ rev}}{(0.33)(90 \times 10^6 \text{ rev})} \right]^{0.3} = 15.02 \text{ kN}$$

6. From Table 14.2, for $C_{req} = 15.02$ kN we select a No. 213 radial ball bearing that has a bearing load capacity of 16.0 kN. ■

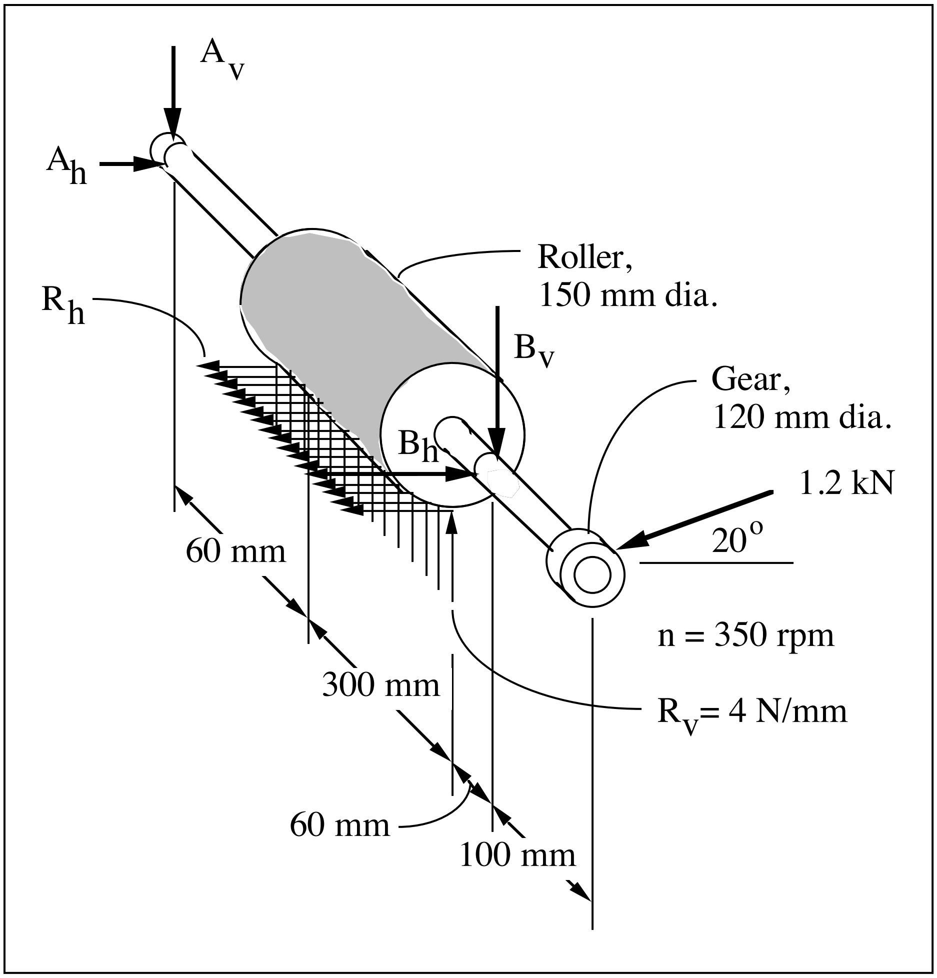
Comment: A 65 mm bore angular ball bearing could also be selected as it has a higher rated load capacity, C, than the radial ball bearing.

SOLUTION (14.29D)

Known: A printing roll is driven by a gear. The bottom surface of the roll is in contact with a similar roll that applies a uniform (upward) loading.

Find: Select identical 200 series ball bearings for A and B.

Schematic and Given Data:



Decisions/Assumptions:

1. Use a design life of 30,000 hours as suggested by Table 14.4.
2. A reliability of 90% is desired.
3. The application factor, K_a = 1.1 (Table 14.3, favorable gearing).

Analysis:

1. Since the printing roll is in static equilibrium, the summation of torques equals zero.
   [Σ Torque = 0]: $R_h(75) - 1200(\cos 20)(60) = 0$
   Hence, R_h = 901.6 N
2. Also, the summation of moments, the summation of horizontal forces, and the summation of vertical forces should each be zero.
   Horizontal forces:
   [Σ M_a = 0]: $901.6(210) + 1200(\cos 20)(520) - B_h(420) = 0$
   Hence, B_h = 1846.9 N

[Σ F_h = 0]: $901.6 + 1200(\cos 20) - 1846.9 - A_h = 0$
Hence, $A_h = 182.3$ N

Vertical forces:

[Σ M_a = 0]: $4(300)(210) - 1200(\sin 20)(520) - B_v(420) = 0$
Hence, $B_v = 91.9$ N

[Σ F_v = 0]: $-A_v - 91.9 + 4(300) - 1200(\sin 20) = 0$
Hence, $A_v = 697.7$ N

3. The bearing radial loads are:

   Bearing A: $F_r = \sqrt{182.3^2 + 697.7^2} = 721$ N

   Bearing B: $F_r = \sqrt{1846.9^2 + 91.9^2} = 1849$ N

4. Since the radial load on bearing B is greater than on bearing A, the bearing selection will be based on bearing B.

5. From Eq. (14.5b), $C_{req} = F_e K_a (L/K_r L_R)^{0.3}$
   where $F_e = F_r = 1849$ N
   Also, $K_a = 1.1$ (Table 14.3, favorable gearing) and $K_r = 1.0$ for 90% reliability.

   $$L = \frac{350 \text{ rev}}{\text{min}} \left| \frac{60 \text{ min}}{1 \text{ hr}} \right| \frac{30{,}000 \text{ hr}}{1} \right| = 630 \times 10^6 \text{ rev}$$

6. Therefore, $C_{req} = 1849(1.1)\left[\frac{630 \times 10^6}{(1)(90 \times 10^6)}\right]^{0.3} = 3646$ N

7. From Table 14.2, select 25 mm bore bearing 205. ■

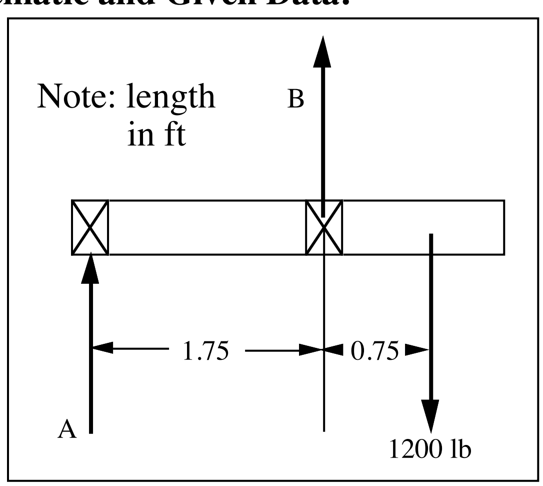
Comment: The shaft size requirement may necessitate use of a larger bore bearing.

SOLUTION (14.30D)

Known: A chain idler sprocket is driven by a roller chain.

Find: Select identical 200 series ball bearings for A and B.

Schematic and Given Data:



Decisions/Assumptions:
1. Use a design life of 30,000 hours as suggested by Table 14.4.
2. A reliability of 90% is desired.
3. The application factor, $K_a = 1.1$ (Table 14.3, favorable gearing).

Analysis:
1. Since the chain sprocket is an idler, the force in the slack side chain strand equals the force in the tight side of the chain minus bearing friction torque generated forces.
2. Also, the summation of moments, the summation of forces, should each be zero.
   $[\Sigma M_a = 0]$: $1200(2.50) - B(1.75) = 0$ Hence, $B = 1714.3$ lb
   $[\Sigma F_h = 0]$:- $1200 + 1714.3 + A_h = 0$ Hence, $A = -514.3$ lb
3. The bearing radial loads are:
   Bearing A: $F_r = 514.3$ lb Bearing B: $F_r = 1714.3$ lb
4. Since the radial load on bearing B is greater than on bearing A, the bearing selection will be based on bearing B.
5. From Eq. (14.5b), $C_{req} = F_e K_a (L/K_r L_R)^{0.3}$
   where $F_e = F_r = 1714.3$ lb
   Also, $K_a = 1.1$ (Table 14.3, favorable gearing) and $K_r = 1.0$ for 90% reliability.

$$L = \frac{350 \text{ rev}}{\text{min}}\left|\frac{60 \text{ min}}{1 \text{ hr}}\right|\frac{30{,}000 \text{ hr}}{1}\right| = 630 \times 10^6 \text{ rev}$$

6. Therefore, $C_{req} = 1714.3(1.1)\left[\dfrac{630 \times 10^6}{(1)(90 \times 10^6)}\right]^{0.3} = 3380.4 \text{ lb} = 15{,}036 \text{ N}$

7. From Table 14.2, select 65 mm bore bearing 213. ■

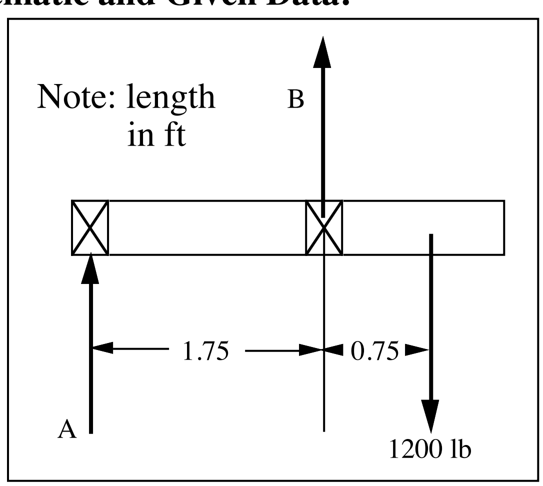
Comment: The shaft size requirement may necessitate use of a larger bore bearing.

SOLUTION (14.31D)

Known: A chain idler sprocket is driven by a roller chain.

Find: Select identical 200 series ball bearings for A and B.

Schematic and Given Data:



Decisions/Assumptions:

1. Use a design life of 30,000 hours as suggested by Table 14.4.
2. A reliability of 90% is desired.
3. The application factor, $K_a = 1.1$ (Table 14.3, favorable gearing).

Analysis:

1. Since the chain sprocket is an idler, the force in the slack side chain strand equals the force in the tight side of the chain minus bearing friction torque generated forces.
2. Also, the summation of moments, the summation of forces, should each be zero.
   $[\Sigma M_a = 0]$: $1200(2.50) - B(1.75) = 0$ Hence, $B = 1714.3$ lb
   $[\Sigma F_h = 0]$: $-1200 + 1714.3 + A_h = 0$ Hence, $A = -514.3$ lb
3. The bearing radial loads are:
   Bearing A: $F_r = 514.3$ lb Bearing B: $F_r = 1714.3$ lb
4. Since the radial load on bearing B is greater than on bearing A, the bearing selection will be based on bearing B.
5. From Eq. (14.5b), $C_{req} = F_e K_a (L/K_r L_R)^{0.3}$
   where $F_e = F_r = 1714.3$ lb
   Also, $K_a = 1.1$ (Table 14.3, favorable gearing) and $K_r = 1.0$ for 90% reliability.

   $$L = \frac{275 \text{ rev}}{\text{min}}\left|\frac{60 \text{ min}}{1 \text{ hr}}\right|\frac{30{,}000 \text{ hr}}{1}\right| = 495 \times 10^6 \text{ rev}$$

6. Therefore, $C_{req} = 1714.3(1.1)\left[\dfrac{495 \times 10^6}{(1)(90 \times 10^6)}\right]^{0.3} = 3144.8 \text{ lb} = 13{,}988 \text{ N}$
7. From Table 14.2, select 65 mm bore bearing 213. ■

Comment: The shaft size requirement may necessitate use of a larger bore bearing.