Chapter 11

11-1 For the deep-groove 02-series ball bearing with R = 0.90, the design life x_D, in multiples of rating life, is

$$x_D = \frac{L_D}{L_R} = \frac{60 L_D n_D}{L_{10}} = \frac{60(25\,000)350}{10^6} = 525 \qquad \textit{Ans.}$$

The design radial load is

$$F_D = 1.2(2.5) = 3.0 \text{ kN}$$

Eq. (11-9):
$$C_{10} = 3.0\left\{\frac{525}{0.02 + (4.459 - 0.02)\left[\ln(1/0.9)\right]^{1/1.483}}\right\}^{1/3}$$

C_{10} = 24.3 kN *Ans.*

Table 11-2: Choose an 02-35 mm bearing with C_{10} = 25.5 kN. *Ans.*

Eq. (11-21):
$$R = \exp\left\{-\left[\frac{525(3/25.5)^3 - 0.02}{4.459 - 0.02}\right]^{1.483}\right\} = 0.920 \qquad \textit{Ans.}$$

11-2 For the angular-contact 02-series ball bearing as described, the rating life multiple is

$$x_D = \frac{L_D}{L_R} = \frac{60 L_D n_D}{L_{10}} = \frac{60(40\,000)520}{10^6} = 1248$$

The design radial load is

$$F_D = 1.4(725) = 1015 \text{ lbf} = 4.52 \text{ kN}$$

Eq. (11-9):

$$C_{10} = 1015\left\{\frac{1248}{0.02 + (4.459 - 0.02)\left[\ln(1/0.9)\right]^{1/1.483}}\right\}^{1/3}$$
$$= 10\,930 \text{ lbf} = 48.6 \text{ kN}$$

Table 11-2: Select an 02-60 mm bearing with C_{10} = 55.9 kN. *Ans.*

Eq. (11-21):
$$R = \exp\left\{-\left[\frac{1248(4.52/55.9)^3 - 0.02}{4.439}\right]^{1.483}\right\} = 0.945 \qquad \textit{Ans.}$$

11-3 For the straight-roller 03-series bearing selection, x_D = 1248 rating lives from Prob. 11-2 solution.

$$F_D = 1.4(2235) = 3129 \text{ lbf } = 13.92 \text{ kN}$$

$$C_{10} = 13.92\left(\frac{1248}{1}\right)^{3/10} = 118 \text{ kN}$$

Table 11-3: Select an 03-60 mm bearing with C_{10} = 123 kN. *Ans.*

Eq. (11-21): $$R = \exp\left\{-\left[\frac{1248(13.92/123)^{10/3} - 0.02}{4.459 - 0.02}\right]^{1.483}\right\} = 0.917 \quad \textit{Ans.}$$

11-4 The combined reliability of the two bearings selected in Probs. 11-2 and 11-3 is

$$R = (0.945)(0.917) = 0.867 \quad \textit{Ans.}$$

We can choose a reliability goal of $\sqrt{0.90} = 0.95$ for each bearing. We make the selections, find the existing reliabilities, multiply them together, and observe that the reliability goal is exceeded due to the roundup of capacity upon table entry.

Another possibility is to use the reliability of one bearing, say R_1. Then set the reliability goal of the second as

$$R_2 = \frac{0.90}{R_1}$$

or vice versa. This gives three pairs of selections to compare in terms of cost, geometry implications, etc.

11-5 Establish a reliability goal of $\sqrt{0.90} = 0.95$ for each bearing. For an 02-series angular contact ball bearing,

$$C_{10} = 1015\left\{\frac{1248}{0.02 + 4.439\left[\ln(1/0.95)\right]^{1/1.483}}\right\}^{1/3}$$

$$= 12\,822 \text{ lbf } = 57.1 \text{ kN}$$

Select an 02-65 mm angular-contact bearing with C_{10} = 63.7 kN.

$$R_A = \exp\left\{-\left[\frac{1248(4.52/63.7)^3 - 0.02}{4.439}\right]^{1.483}\right\} = 0.962$$

For an 03-series straight roller bearing,

$$C_{10} = 13.92\left\{\frac{1248}{0.02 + 4.439\left[\ln(1/0.95)\right]^{1/1.483}}\right\}^{3/10} = 136.5 \text{ kN}$$

Select an 03-65 mm straight-roller bearing with C_{10} = 138 kN.

$$R_B = \exp\left\{-\left[\frac{1248(13.92/138)^{10/3} - 0.02}{4.439}\right]^{1.483}\right\} = 0.953$$

The overall reliability is R = (0.962)(0.953) = 0.917, which exceeds the goal.

11-6 For the straight cylindrical roller bearing specified with a service factor of 1, R = 0.95 and F_R = 20 kN.

$$x_D = \frac{L_D}{L_R} = \frac{60L_D n_D}{L_{10}} = \frac{60(8000)950}{10^6} = 456$$

$$C_{10} = 20\left\{\frac{456}{0.02 + 4.439\left[\ln(1/0.95)\right]^{1/1.483}}\right\}^{3/10} = 145 \text{ kN} \qquad \textit{Ans.}$$

11-7 Both bearings need to be rated in terms of the same catalog rating system in order to compare them. Using a rating life of one million revolutions, both bearings can be rated in terms of a Basic Load Rating.

Eq. (11-3): $$C_A = F_A\left(\frac{L_A}{L_R}\right)^{1/a} = F_A\left(\frac{L_A n_A 60}{L_R}\right)^{1/a} = 2.0\left[\frac{(3000)(500)(60)}{10^6}\right]^{1/3}$$

$$= 8.96 \text{ kN}$$

Bearing B already is rated at one million revolutions, so C_B = 7.0 kN. Since $C_A > C_B$, bearing A can carry the larger load. *Ans.*

11-8 F_D = 2 kN, $L_D = 10^9$ rev, R = 0.90

Eq. (11-3): $$C_{10} = F_D\left(\frac{L_D}{L_R}\right)^{1/a} = 2\left(\frac{10^9}{10^6}\right)^{1/3} = 20 \text{ kN} \qquad \textit{Ans.}$$

11-9 F_D = 800 lbf, $\mathcal{L}_D$ = 12 000 hours, n_D = 350 rev/min, R = 0.90

Eq. (11-3): $$C_{10} = F_D\left(\frac{L_D n_D 60}{L_R}\right)^{1/a} = 800\left(\frac{12\,000(350)(60)}{10^6}\right)^{1/3} = 5050 \text{ lbf} \quad \textit{Ans}$$

11-10 F_D = 4 kN, $\mathcal{L}_D$ = 8 000 hours, n_D = 500 rev/min, R = 0.90

Eq. (11-3): $$C_{10} = F_D\left(\frac{L_D n_D 60}{L_R}\right)^{1/a} = 4\left(\frac{8\,000(500)(60)}{10^6}\right)^{1/3} = 24.9 \text{ kN} \quad \textit{Ans}$$

11-11 F_D = 650 lbf, n_D = 400 rev/min, R = 0.95

$\mathcal{L}_D$ = (5 years)(40 h/week)(52 week/year) = 10 400 hours

Assume an application factor of one. The multiple of rating life is

$$x_D = \frac{L_D}{L_R} = \frac{(10\,400)(400)(60)}{10^6} = 249.6$$

Eq. (11-9): $$C_{10} = (1)(650)\left\{\frac{249.6}{0.02 + 4.439\left[\ln(1/0.95)\right]^{1/1.483}}\right\}^{1/3}$$

$$= 4800 \text{ lbf} \quad \textit{Ans.}$$

11-12 F_D = 9 kN, $L_D = 10^8$ rev, R = 0.99

Assume an application factor of one. The multiple of rating life is

$$x_D = \frac{L_D}{L_R} = \frac{10^8}{10^6} = 100$$

Eq. (11-9): $$C_{10} = (1)(9)\left\{\frac{100}{0.02 + 4.439\left[\ln(1/0.99)\right]^{1/1.483}}\right\}^{1/3}$$

$$= 69.2 \text{ kN} \quad \textit{Ans.}$$

11-13 F_D = 11 kips, $\mathcal{L}_D$ = 20 000 hours, n_D = 200 rev/min, R = 0.99

Assume an application factor of one. Use the Weibull parameters for Manufacturer 2 in Table 11-6.

The multiple of rating life is

$$x_D = \frac{L_D}{L_R} = \frac{(20\,000)(200)(60)}{10^6} = 240$$

Eq. (11-9): $$C_{10} = (1)(11)\left\{\frac{240}{0.02 + 4.439\left[\ln(1/0.99)\right]^{1/1.483}}\right\}^{1/3}$$

$$= 113 \text{ kips} \quad \textit{Ans.}$$

11-14 From the solution to Prob. 3-68, the ground reaction force carried by the bearing at C is $R_C = F_D = 178$ lbf. Use the Weibull parameters for Manufacturer 2 in Table 11-6.

$$x_D = \frac{L_D}{L_R} = \frac{15\,000(1200)(60)}{10^6} = 1080$$

Eq. (11-10): $$C_{10} = a_f F_D \left[\frac{x_D}{x_0 + (\theta - x_0)(1 - R_D)^{1/b}}\right]^{1/a}$$

$$C_{10} = 1.2(178)\left[\frac{1080}{0.02 + (4.459 - 0.02)(1 - 0.95)^{1/1.483}}\right]^{1/3}$$

$$= 2590 \text{ lbf} \quad \textit{Ans.}$$

11-15 From the solution to Prob. 3-69, the ground reaction force carried by the bearing at C is $R_C = F_D = 1.794$ kN. Use the Weibull parameters for Manufacturer 2 in Table 11-6.

$$x_D = \frac{L_D}{L_R} = \frac{15\,000(1200)(60)}{10^6} = 1080$$

Eq. (11-10): $$C_{10} = a_f F_D \left[\frac{x_D}{x_0 + (\theta - x_0)(1 - R_D)^{1/b}}\right]^{1/a}$$

$$C_{10} = 1.2(1.794)\left[\frac{1080}{0.02 + (4.459 - 0.02)(1 - 0.95)^{1/1.483}}\right]^{1/3}$$

$$= 26.1 \text{ kN} \quad \textit{Ans.}$$

11-16 From the solution to Prob. 3-70, $R_{Cz} = -327.99$ lbf, $R_{Cy} = -127.27$ lbf

$$R_C = F_D = \left[(-327.99)^2 + (-127.27)^2\right]^{1/2} = 351.8 \text{ lbf}$$

Use the Weibull parameters for Manufacturer 2 in Table 11-6.

$$x_D = \frac{L_D}{L_R} = \frac{15\,000(1200)(60)}{10^6} = 1080$$

Eq. (11-10): $$C_{10} = a_f F_D \left[\frac{x_D}{x_o + (\theta - x_o)(1 - R_D)^{1/b}} \right]^{1/a}$$

$$C_{10} = 1.2(351.8)\left[\frac{1080}{0.02 + (4.459 - 0.02)(1 - 0.95)^{1/1.483}} \right]^{1/3}$$

$$= 5110 \text{ lbf} \quad \textit{Ans.}$$

11-17 From the solution to Prob. 3-71, R_{Cz} = –150.7 N, R_{Cy} = –86.10 N

$$R_C = F_D = \left[(-150.7)^2 + (-86.10)^2 \right]^{1/2} = 173.6 \text{ N}$$

Use the Weibull parameters for Manufacturer 2 in Table 11-6.

$$x_D = \frac{L_D}{L_R} = \frac{15\,000(1200)(60)}{10^6} = 1080$$

Eq. (11-10): $$C_{10} = a_f F_D \left[\frac{x_D}{x_0 + (\theta - x_0)(1 - R_D)^{1/b}} \right]^{1/a}$$

$$C_{10} = 1.2(173.6)\left[\frac{1080}{0.02 + (4.459 - 0.02)(1 - 0.95)^{1/1.483}} \right]^{1/3}$$

$$= 2520 \text{ N} \quad \textit{Ans.}$$

11-18 From the solution to Prob. 3-77, R_{Az} = 444 N, R_{Ay} = 2384 N

$$R_A = F_D = \left(444^2 + 2384^2 \right)^{1/2} = 2425 \text{ N} = 2.425 \text{ kN}$$

Use the Weibull parameters for Manufacturer 2 in Table 11-6. The design speed is equal to the speed of shaft *AD*,

$$n_D = \frac{d_F}{d_C} n_i = \frac{125}{250}(191) = 95.5 \text{ rev/min}$$

$$x_D = \frac{L_D}{L_R} = \frac{12\,000(95.5)(60)}{10^6} = 68.76$$

Eq. (11-10): $$C_{10} = a_f F_D \left[\frac{x_D}{x_0 + (\theta - x_0)(1 - R_D)^{1/b}} \right]^{1/a}$$

$$C_{10} = (1)(2.425)\left[\frac{68.76}{0.02 + (4.459 - 0.02)(1 - 0.95)^{1/1.483}} \right]^{1/3}$$

$$= 11.7 \text{ kN} \quad \textit{Ans.}$$

11-19 From the solution to Prob. 3-79, R_{Az} = 54.0 lbf, R_{Ay} = 140 lbf

$$R_A = F_D = \left(54.0^2 + 140^2\right)^{1/2} = 150.1 \text{ lbf}$$

Use the Weibull parameters for Manufacturer 2 in Table 11-6. The design speed is equal to the speed of shaft *AD*,

$$n_D = \frac{d_F}{d_C} n_i = \frac{10}{5}(280) = 560 \text{ rev/min}$$

$$x_D = \frac{L_D}{L_R} = \frac{14\,000(560)(60)}{10^6} = 470.4$$

Eq. (11-10): $$C_{10} = a_f F_D \left[\frac{x_D}{x_0 + (\theta - x_0)(1 - R_D)^{1/b}} \right]^{1/a}$$

$$C_{10} = (1)(150.1)\left[\frac{470.4}{0.02 + (4.459 - 0.02)(1 - 0.98)^{1/1.483}} \right]^{3/10}$$

$$= 1320 \text{ lbf}$$ *Ans.*

11-20 **(a)** $F_a = 3$ kN, $F_r = 7$ kN, $n_D = 500$ rev/min, $V = 1.2$

From Table 11-2, with a 65 mm bore, C_0 = 34.0 kN.

$$F_a / C_0 = 3 / 34 = 0.088$$

From Table 11-1, $0.28 \le e \le 3.0$.

$$\frac{F_a}{VF_r} = \frac{3}{(1.2)(7)} = 0.357$$

Since this is greater than *e*, interpolating Table 11-1 with F_a / C_0 = 0.088, we obtain X_2 = 0.56 and Y_2 = 1.53.

Eq. (11-12): $$F_e = X_i VF_r + Y_i F_a = (0.56)(1.2)(7) + (1.53)(3) = 9.29 \text{ kN}$$ *Ans.*

$F_e > F_r$ so use F_e.

(b) Use Eq. (11-10) to determine the necessary rated load the bearing should have to carry the equivalent radial load for the desired life and reliability. Use the Weibull parameters for Manufacturer 2 in Table 11-6.

$$x_D = \frac{L_D}{L_R} = \frac{10\,000(500)(60)}{10^6} = 300$$

Eq. (11-10):

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

$$C_{10} = (1)(9.29)\left[\frac{300}{0.02 + (4.459 - 0.02)(1 - 0.95)^{1/1.483}} \right]^{1/3}$$

$$= 73.4 \text{ kN}$$

From Table 11-2, the 65 mm bearing is rated for 55.9 kN, which is less than the necessary rating to meet the specifications. This bearing should not be expected to meet the load, life, and reliability goals. *Ans.*

11-21 **(a)** $F_a = 2$ kN, $F_r = 5$ kN, $n_D = 400$ rev/min, $V = 1$

From Table 11-2, 30 mm bore, C_{10} = 19.5 kN, C_0 = 10.0 kN

$$F_a / C_0 = 2 / 10 = 0.2$$

From Table 11-1, $0.34 \le e \le 0.38$.

$$\frac{F_a}{VF_r} = \frac{2}{(1)(5)} = 0.4$$

Since this is greater than e, interpolating Table 11-1, with $F_a / C_0 = 0.2$, we obtain $X_2 = 0.56$ and $Y_2 = 1.27$.

Eq. (11-12): $F_e = X_i V F_r + Y_i F_a = (0.56)(1)(5) + (1.27)(2) = 5.34$ kN *Ans.*

$F_e > F_r$ so use F_e.

(b) Solve Eq. (11-10) for x_D.

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

$$x_D = \left(\frac{19.5}{(1)(5.34)} \right)^3 \left[0.02 + (4.459 - 0.02)(1 - 0.99)^{1/1.483} \right]$$

$$x_D = 10.66$$

$$x_D = \frac{L_D}{L_R} = \frac{\mathrm{L}_D n_D (60)}{10^6}$$

$$\mathrm{L}_D = \frac{x_D (10^6)}{n_D (60)} = \frac{10.66(10^6)}{(400)(60)} = 444 \text{ h} \quad \textit{Ans.}$$

11-22 $F_r = 8$ kN, $R = 0.9$, $L_D = 10^9$ rev

Eq. (11-3): $$C_{10} = F_D\left(\frac{L_D}{L_R}\right)^{1/a} = 8\left(\frac{10^9}{10^6}\right)^{1/3} = 80 \text{ kN}$$

From Table 11-2, select the 85 mm bore. *Ans.*

11-23 $F_r = 8$ kN, $F_a = 2$ kN, $V = 1$, $R = 0.99$

Use the Weibull parameters for Manufacturer 2 in Table 11-6.

$$x_D = \frac{L_D}{L_R} = \frac{10\,000(400)(60)}{10^6} = 240$$

First guess: Choose from middle of Table 11-1, $X = 0.56$, $Y = 1.63$

Eq. (11-12): $F_e = 0.56(1)(8) + 1.63(2) = 7.74$ kN

$F_e < F_r$, so just use F_r as the design load.

Eq. (11-10): $$C_{10} = a_f F_D\left[\frac{x_D}{x_o + (\theta - x_o)(1 - R_D)^{1/b}}\right]^{1/a}$$

$$C_{10} = (1)(8)\left[\frac{240}{0.02 + (4.459 - 0.02)(1 - 0.99)^{1/1.483}}\right]^{1/3} = 82.5 \text{ kN}$$

From Table 11-2, try 85 mm bore with $C_{10} = 83.2$ kN, $C_0 = 53.0$ kN

Iterate the previous process:

$F_a / C_0 = 2 / 53 = 0.038$

Table 11-1: $0.22 \le e \le 0.24$

$$\frac{F_a}{VF_r} = \frac{2}{1(8)} = 0.25 > e$$

Interpolate Table 11-1 with $F_a / C_0 = 0.038$ to obtain $X_2 = 0.56$ and $Y_2 = 1.89$.

Eq. (11-12): $F_e = 0.56(1)8 + 1.89(2) = 8.26 > F_r$

Eq. (11-10): $$C_{10} = (1)(8.26)\left[\frac{240}{0.02 + (4.459 - 0.02)(1 - 0.99)^{1/1.483}}\right]^{1/3} = 85.2 \text{ kN}$$

Table 11-2: Move up to the 90 mm bore with $C_{10} = 95.6$ kN, $C_0 = 62.0$ kN.

Iterate again:

$F_a / C_0 = 2 / 62 = 0.032$

Table 11-1: Again, $0.22 \le e \le 0.24$

$$\frac{F_a}{VF_r} = \frac{2}{1(8)} = 0.25 > e$$

Interpolate Table 11-1 with $F_a / C_0 = 0.032$ to obtain $X_2 = 0.56$ and $Y_2 = 1.95$.

Eq. (11-12): $F_e = 0.56(1)8 + 1.95(2) = 8.38 > F_r$

Eq. (11-10): $$C_{10} = (1)(8.38)\left[\frac{240}{0.02 + (4.459 - 0.02)(1 - 0.99)^{1/1.483}}\right]^{1/3} = 86.4 \text{ kN}$$

The 90 mm bore is acceptable. *Ans.*

11-24 $F_r = 8$ kN, $F_a = 3$ kN, $V = 1.2, R = 0.9, L_D = 10^8$ rev

First guess: Choose from middle of Table 11-1, $X = 0.56$, $Y = 1.63$

Eq. (11-12): $F_e = 0.56(1.2)(8) + 1.63(3) = 10.3$ kN

$F_e > F_r$

Eq. (11-3): $$C_{10} = F_e\left(\frac{L_D}{L_R}\right)^{1/a} = 10.3\left(\frac{10^8}{10^6}\right)^{1/3} = 47.8 \text{ kN}$$

From Table 11-2, try 60 mm with $C_{10} = 47.5$ kN, $C_0 = 28.0$ kN

Iterate the previous process:

$F_a / C_0 = 3 / 28 = 0.107$

Table 11-1: $0.28 \le e \le 0.30$

$$\frac{F_a}{VF_r} = \frac{3}{1.2(8)} = 0.313 > e$$

Interpolate Table 11-1 with $F_a / C_0 = 0.107$ to obtain $X_2 = 0.56$ and $Y_2 = 1.46$

Eq. (11-12): $F_e = 0.56(1.2)(8) + 1.46(3) = 9.76 \text{ kN} > F_r$

Eq. (11-3): $$C_{10} = 9.76\left(\frac{10^8}{10^6}\right)^{1/3} = 45.3 \text{ kN}$$

From Table 11-2, we have converged on the 60 mm bearing. *Ans.*

11-25 $F_r = 10$ kN, $F_a = 5$ kN, $V = 1$, $R = 0.95$

Use the Weibull parameters for Manufacturer 2 in Table 11-6.

$$x_D = \frac{L_D}{L_R} = \frac{12\,000(300)(60)}{10^6} = 216$$

First guess: Choose from middle of Table 11-1, X = 0.56, Y = 1.63

Eq. (11-12): $F_e = 0.56(1)(10) + 1.63(5) = 13.75$ kN

$F_e > F_r$, so use F_e as the design load.

Eq. (11-10): $$C_{10} = a_f F_D \left[\frac{x_D}{x_0 + (\theta - x_0)(1 - R_D)^{1/b}} \right]^{1/a}$$

$$C_{10} = (1)(13.75) \left[\frac{216}{0.02 + (4.459 - 0.02)(1 - 0.95)^{1/1.483}} \right]^{1/3} = 97.4 \text{ kN}$$

From Table 11-2, try 95 mm bore with C_{10} = 108 kN, C_0 = 69.5 kN
Iterate the previous process:

F_a / C_0 = 5 / 69.5 = 0.072

Table 11-1: $0.27 \le e \le 0.28$

$$\frac{F_a}{VF_r} = \frac{5}{1(10)} = 0.5 > e$$

Interpolate Table 11-1 with F_a / C_0 = 0.072 to obtain X_2 = 0.56 and Y_2 = 1.62 $\cong$ 1.63

Since this is where we started, we will converge back to the same bearing. The 95 mm bore meets the requirements. *Ans.*

11-26 $F_r = 9$ kN, $F_a = 3$ kN, $V = 1.2$, $R = 0.99$

Use the Weibull parameters for Manufacturer 2 in Table 11-6.

$$x_D = \frac{L_D}{L_R} = \frac{10^8}{10^6} = 100$$

First guess: Choose from middle of Table 11-1, X = 0.56, Y = 1.63

Eq. (11-12): $F_e = 0.56(1.2)(9) + 1.63(3) = 10.9$ kN

$F_e > F_r$, so use F_e as the design load.

Eq. (11-10): $$C_{10} = a_f F_D \left[\frac{x_D}{x_0 + (\theta - x_0)(1 - R_D)^{1/b}} \right]^{1/a}$$

$$C_{10} = (1)(10.9)\left[\frac{100}{0.02+(4.459-0.02)(1-0.99)^{1/1.483}}\right]^{1/3} = 83.9 \text{ kN}$$

From Table 11-2, try 90 mm bore with C_{10} = 95.6 kN, C_0 = 62.0 kN. Try this bearing. Iterate the previous process:

$$F_a / C_0 = 3 / 62 = 0.048$$

Table 11-1: $0.24 \le e \le 0.26$

$$\frac{F_a}{VF_r} = \frac{3}{1.2(9)} = 0.278 > e$$

Interpolate Table 11-1 with F_a / C_0 = 0.048 to obtain X_2 = 0.56 and Y_2 = 1.79

Eq. (11-12): $F_e = 0.56(1.2)(9)+1.79(3) = 11.4 \text{ kN} > F_r$

$$C_{10} = \frac{11.4}{10.9} 83.9 = 87.7 \text{ kN}$$

From Table 11-2, this converges back to the same bearing. The 90 mm bore meets the requirements. *Ans.*

11-27 **(a)** $n_D = 1200$ rev/min, $L_D = 15$ kh, $R = 0.95$, $a_f = 1.2$

From Prob. 3-72, R_{Cy} = 183.1 lbf, R_{Cz} = –861.5 lbf.

$$R_C = F_D = \left[183.1^2 + (-861.5)^2\right]^{1/2} = 881 \text{ lbf}$$

$$x_D = \frac{L_D}{L_R} = \frac{15\,000(1200)(60)}{10^6} = 1080$$

Eq. (11-10): $$C_{10} = 1.2(881)\left[\frac{1080}{0.02+4.439(1-0.95)^{1/1.483}}\right]^{1/3}$$

$$= 12\,800 \text{ lbf} = 12.8 \text{ kips} \quad \textit{Ans.}$$

(b) Results will vary depending on the specific bearing manufacturer selected. A general engineering components search site such as www.globalspec.com might be useful as a starting point.

11-28 **(a)** $n_D = 1200$ rev/min, $L_D = 15$ kh, $R = 0.95$, $a_f = 1.2$

From Prob. 3-72, R_{Oy} = –208.5 lbf, R_{Oz} = 259.3 lbf.

$$R_C = F_D = \left[259.3^2 + (-208.5)^2\right]^{1/2} = 333 \text{ lbf}$$

$$x_D = \frac{L_D}{L_R} = \frac{15\,000(1200)(60)}{10^6} = 1080$$

Eq. (11-10): $$C_{10} = 1.2(333)\left[\frac{1080}{0.02 + 4.439(1-0.95)^{1/1.483}}\right]^{1/3}$$

$$= 4837 \text{ lbf} = 4.84 \text{ kips} \quad \textit{Ans.}$$

(b) Results will vary depending on the specific bearing manufacturer selected. A general engineering components search site such as www.globalspec.com might be useful as a starting point.

11-29 **(a)** $n_D = 900$ rev/min, $L_D = 12$ kh, $R = 0.98$, $a_f = 1.2$

From Prob. 3-73, R_{Cy} = 8.319 kN, R_{Cz} = –10.830 kN.

$$R_C = F_D = \left[8.319^2 + (-10.830)^2\right]^{1/2} = 13.7 \text{ kN}$$

$$x_D = \frac{L_D}{L_R} = \frac{12\,000(900)(60)}{10^6} = 648$$

Eq. (11-10): $$C_{10} = 1.2(13.7)\left[\frac{648}{0.02 + 4.439(1-0.98)^{1/1.483}}\right]^{1/3} = 204 \text{ kN} \quad \textit{Ans.}$$

(b) Results will vary depending on the specific bearing manufacturer selected. A general engineering components search site such as www.globalspec.com might be useful as a starting point.

11-30 **(a)** $n_D = 900$ rev/min, $L_D = 12$ kh, $R = 0.98$, $a_f = 1.2$

From Prob. 3-73, R_{Oy} = 5083 N, R_{Oz} = 494 N.

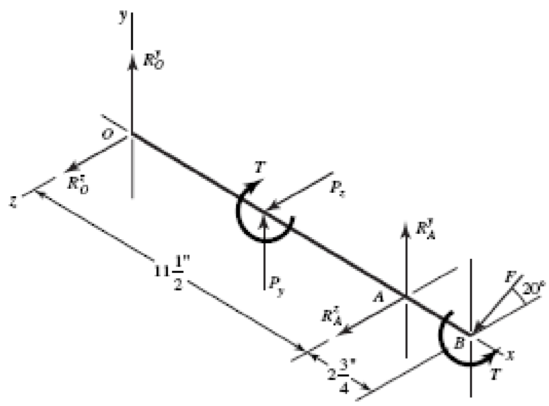
$$R_C = F_D = \left(5083^2 + 494^2\right)^{1/2} = 5106 \text{ N} = 5.1 \text{ kN}$$

$$x_D = \frac{L_D}{L_R} = \frac{12\,000(900)(60)}{10^6} = 648$$

Eq. (11-10): $$C_{10} = 1.2(5.1)\left[\frac{648}{0.02 + 4.439(1-0.98)^{1/1.483}}\right]^{1/3} = 76.1 \text{ kN} \quad \textit{Ans.}$$

(b) Results will vary depending on the specific bearing manufacturer selected. A general engineering components search site such as www.globalspec.com might be useful as a starting point.

11-31 Assume concentrated forces as shown.



$$P_z = 8(28) = 224 \text{ lbf}$$
$$P_y = 8(35) = 280 \text{ lbf}$$
$$T = 224(2) = 448 \text{ lbf} \cdot \text{in}$$
$$\Sigma T^x = -448 + 1.5F\cos 20^\circ = 0$$
$$F = \frac{448}{1.5(0.940)} = 318 \text{ lbf}$$

$$\Sigma M_O^z = 5.75P_y + 11.5R_A^y - 14.25F\sin 20^\circ = 0$$
$$5.75(280) + 11.5R_A^y - 14.25(318)(0.342) = 0$$
$$R_A^y = -5.24 \text{ lbf}$$
$$\Sigma M_O^y = -5.75P_z - 11.5R_A^z - 14.25F\cos 20^\circ = 0$$
$$-5.75(224) - 11.5R_A^z - 14.25(318)(0.940) = 0$$
$$R_A^z = -482 \text{ lbf}; \quad R_A = \left[(-482)^2 + (-5.24)^2\right]^{1/2} = 482 \text{ lbf}$$
$$\Sigma F^z = R_O^z + P_z + R_A^z + F\cos 20^\circ = 0$$
$$R_O^z + 224 - 482 + 318(0.940) = 0$$
$$R_O^z = -40.9 \text{ lbf}$$
$$\Sigma F^y = R_O^y + P_y + R_A^y - F\sin 20^\circ = 0$$
$$R_O^y + 280 - 5.24 - 318(0.342) = 0$$
$$R_O^y = -166 \text{ lbf}$$
$$R_O = \left[(-40.9)^2 + (-166)^2\right]^{1/2} = 171 \text{ lbf}$$

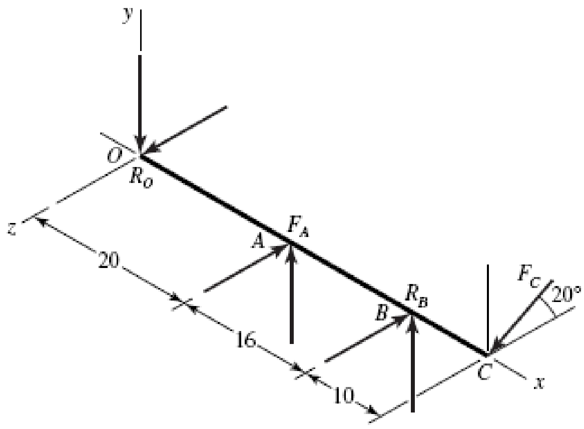
So the reaction at *A* governs.
Reliability Goal: $\sqrt{0.92} = 0.96$

$$F_D = 1.2(482) = 578 \text{ lbf}$$
$$x_D = 35\,000(350)(60)/10^6 = 735$$
$$C_{10} = 578\left\{\frac{735}{0.02 + (4.459 - 0.02)\left[\ln(1/0.96)\right]^{1/1.483}}\right\}^{1/3}$$
$$= 6431 \text{ lbf} = 28.6 \text{ kN}$$

From Table 11-2, a 40 mm bore angular contact bearing is sufficient with a rating of 31.9 kN. *Ans.*

11-32 For a combined reliability goal of 0.95, use $\sqrt{0.95} = 0.975$ for the individual bearings.

$$x_D = \frac{40\,000(420)(60)}{10^6} = 1008$$



The resultants of the given forces are

R_O = [(–387)^2 + 467^2]$^{1/2}$ = 607 lbf
R_B = [316^2 + (–1615)^2]$^{1/2}$ = 1646 lbf

At O:

Eq. (11-9): $$C_{10} = 1.2(607)\left\{\frac{1008}{0.02 + (4.459 - 0.02)\left[\ln(1/0.975)\right]^{1/1.483}}\right\}^{1/3}$$
$$= 9978 \text{ lbf} = 44.4 \text{ kN}$$

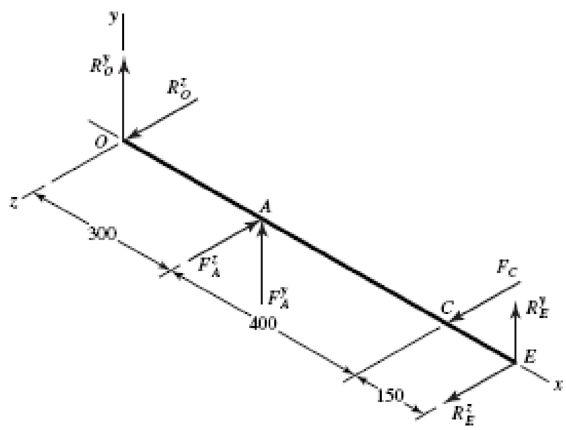
From Table 11-2, select an 02-55 mm angular-contact ball bearing with a basic load rating of 46.2 kN. *Ans.*

At B:

Eq. (11-9): $$C_{10} = 1.2(1646)\left\{\frac{1008}{0.02 + (4.459 - 0.02)\left[\ln(1/0.975)\right]^{1/1.483}}\right\}^{3/10}$$
$$= 20\,827 \text{ lbf} = 92.7 \text{ kN}$$

From Table 11-3, select an 02-75 mm or 03-55 mm cylindrical roller. *Ans.*

11-33 The reliability of the individual bearings is $R = \sqrt{0.98} = 0.9899$
From statics,



$T = (270 - 50) = (P_1 - P_2)125$
$\quad = (P_1 - 0.15\,P_1)125$
$P_1 = 310.6$ N,
$P_2 = 0.15\,(310.6) = 46.6$ N
$P_1 + P_2 = 357.2$ N $\quad F_A^y = 357.2 \sin 45^\circ = 252.6 \text{ N} = F_A^z$

$$\sum M_O^z = 850 R_E^y + 300(252.6) = 0 \Rightarrow R_E^y = -89.2 \text{ N}$$
$$\sum F^y = 252.6 - 89.2 + R_O^y = 0 \Rightarrow R_O^y = -163.4 \text{ N}$$
$$\sum M_O^y = -850 R_E^z - 700(320) + 300(252.6) = 0 \Rightarrow R_E^z = -174.4 \text{ N}$$
$$\sum F^z = -174.4 + 320 - 252.6 + R_O^z = 0 \Rightarrow R_O^z = 107 \text{ N}$$

$$R_O = \sqrt{(-163.4)^2 + 107^2} = 195 \text{ N}$$
$$R_E = \sqrt{(-89.2)^2 + (-174.4)^2} = 196 \text{ N}$$

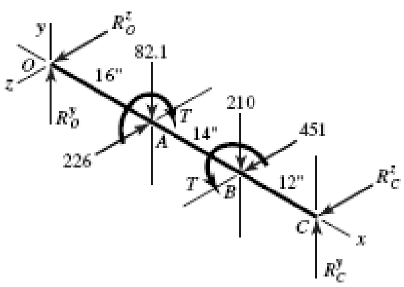
The radial loads are nearly the same at O and E. We can use the same bearing at both locations.

$$x_D = \frac{60\,000(1500)(60)}{10^6} = 5400$$

Eq. (11-9): $\quad C_{10} = 1(0.196)\left\{\dfrac{5400}{0.02 + 4.439\left[\ln(1/0.9899)\right]^{1/1.483}}\right\}^{1/3} = 5.7 \text{ kN}$

From Table 11-2, select an 02-12 mm deep-groove ball bearing with a basic load rating of 6.89 kN. *Ans.*

11-34 $\quad R = \sqrt{0.96} = 0.980$



$$T = 12(240 \cos 20^\circ) = 2706 \text{ lbf} \cdot \text{in}$$

$$F = \frac{2706}{6 \cos 25^\circ} = 498 \text{ lbf}$$

In xy-plane:

$$\Sigma M_O^z = -16(82.1) - 30(210) + 42 R_C^y = 0$$
$$R_C^y = 181 \text{ lbf}$$

$$R_O^y = 82.1 + 210 - 181 = 111.1 \text{ lbf}$$

In *xz*-plane:

$$\Sigma M_O^y = 16(226) - 30(451) - 42R_C^z = 0$$

$$R_C^z = -236 \text{ lbf}$$

$$R_O^z = 226 - 451 + 236 = 11 \text{ lbf}$$

$$R_O = \left(111.1^2 + 11^2\right)^{1/2} = 112 \text{ lbf} \quad \textit{Ans.}$$

$$R_C = \left(181^2 + 236^2\right)^{1/2} = 297 \text{ lbf} \quad \textit{Ans.}$$

$$x_D = \frac{50\,000(300)(60)}{10^6} = 900$$

$$\left(C_{10}\right)_O = 1.2(112)\left\{\frac{900}{0.02 + 4.439\left[\ln(1/0.980)\right]^{1/1.483}}\right\}^{1/3}$$

$$= 1860 \text{ lbf} = 8.28 \text{ kN}$$

$$\left(C_{10}\right)_C = 1.2(297)\left\{\frac{900}{0.02 + 4.439\left[\ln(1/0.980)\right]^{1/1.483}}\right\}^{1/3}$$

$$= 4932 \text{ lbf} = 21.9 \text{ kN}$$

Bearing at *O*: Choose a deep-groove 02-17 mm. *Ans.*
Bearing at *C*: Choose a deep-groove 02-35 mm. *Ans.*

11-35 Shafts subjected to thrust can be constrained by bearings, one of which supports the thrust. The shaft floats within the endplay of the second (roller) bearing. Since the thrust force here is larger than any radial load, the bearing absorbing the thrust (bearing *A*) is heavily loaded compared to bearing *B*. Bearing *B* is thus likely to be oversized and may not contribute measurably to the chance of failure. If this is the case, we may be able to obtain the desired combined reliability with bearing *A* having a reliability near 0.99 and bearing *B* having a reliability near 1. This would allow for bearing *A* to have a lower capacity than if it needed to achieve a reliability of $\sqrt{0.99}$. To determine if this is the case, we will start with bearing *B*.

Bearing B (straight roller bearing)

$$x_D = \frac{30\,000(500)(60)}{10^6} = 900$$

$$F_r = \left(36^2 + 67^2\right)^{1/2} = 76.1 \text{ lbf} = 0.339 \text{ kN}$$

Try a reliability of 1 to see if it is readily obtainable with the available bearings.

Eq. (11-9): $$C_{10} = 1.2(0.339)\left\{\frac{900}{0.02+4.439\left[\ln(1/1.0)\right]^{1/1.483}}\right\}^{3/10} = 10.1 \text{ kN}$$

The smallest capacity bearing from Table 11-3 has a rated capacity of 16.8 kN. Therefore, we select the 02-25 mm straight cylindrical roller bearing. *Ans.*

Bearing at A (angular-contact ball)
With a reliability of 1 for bearing *B*, we can achieve the combined reliability goal of 0.99 if bearing *A* has a reliability of 0.99.

$$F_r = \left(36^2 + 212^2\right)^{1/2} = 215 \text{ lbf} = 0.957 \text{ kN}$$
$$F_a = 555 \text{ lbf} = 2.47 \text{ kN}$$

Trial #1:
Tentatively select an 02-85 mm angular-contact with C_{10} = 90.4 kN and C_0 = 63.0 kN.

$$\frac{F_a}{C_0} = \frac{2.47}{63.0} = 0.0392$$
$$x_D = \frac{30\,000(500)(60)}{10^6} = 900$$

Table 11-1: Interpolating, X_2 = 0.56, Y_2 = 1.88

Eq. (11-12): $$F_e = 0.56(0.957) + 1.88(2.47) = 5.18 \text{ kN}$$

Eq. (11-9): $$C_{10} = 1.2(5.18)\left\{\frac{900}{0.02+4.439\left[\ln(1/0.99)\right]^{1/1.483}}\right\}^{1/3}$$
$$= 99.54 \text{ kN} > 90.4 \text{ kN}$$

Trial #2:
Tentatively select a 02-90 mm angular-contact ball with C_{10} = 106 kN and C_0 = 73.5 kN.

$$\frac{F_a}{C_0} = \frac{2.47}{73.5} = 0.0336$$

Table 11-1: Interpolating, X_2 = 0.56, Y_2 = 1.93

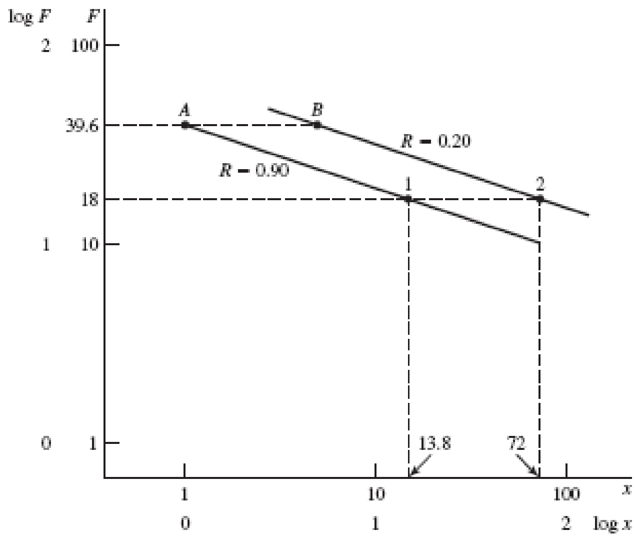
$$F_e = 0.56(0.957) + 1.93(2.47) = 5.30 \text{ kN}$$
$$C_{10} = 1.2(5.30)\left\{\frac{900}{0.02+4.439\left[\ln(1/0.99)\right]^{1/1.483}}\right\}^{1/3} = 102 \text{ kN} < 106 \text{ kN} \quad \text{O.K.}$$

Select an 02-90 mm angular-contact ball bearing. *Ans.*

11-36 We have some data. Let's estimate parameters b and θ from it. In Fig. 11-5, we will use line AB. In this case, B is to the right of A.

For F = 18 kN, $$(x)_1 = \frac{115(2000)(60)}{10^6} = 13.8$$

This establishes point 1 on the R = 0.90 line.



The R = 0.20 locus is above and parallel to the R = 0.90 locus. For the two-parameter Weibull distribution, x_0 = 0 and points A and B are related by [see Eq. (11-8)]:

$$x_A = \theta\left[\ln(1/0.90)\right]^{1/b} \qquad (1)$$
$$x_B = \theta\left[\ln(1/0.20)\right]^{1/b}$$

and x_B/x_A is in the same ratio as 600/115. Eliminating θ,

$$b = \frac{\ln\left[\ln(1/0.20)/\ln(1/0.90)\right]}{\ln(600/115)} = 1.65 \quad \textit{Ans.}$$

Solving for θ in Eq. (1),

$$\theta = \frac{x_A}{\left[\ln(1/R_A)\right]^{1/1.65}} = \frac{1}{\left[\ln(1/0.90)\right]^{1/1.65}} = 3.91 \quad \textit{Ans.}$$

Therefore, for the data at hand,

$$R = \exp\left[-\left(\frac{x}{3.91}\right)^{1.65}\right]$$

Check R at point B: x_B = (600/115) = 5.217

$$R = \exp\left[-\left(\frac{5.217}{3.91}\right)^{1.65}\right] = 0.20$$

Note also, for point 2 on the R = 0.20 line,

$$\log(5.217) - \log(1) = \log(x_m)_2 - \log(13.8)$$
$$(x_m)_2 = 72$$

11-37 This problem is rich in useful variations. Here is one.

Decision: Make straight roller bearings identical on a given shaft. Use a reliability goal of $(0.99)^{1/6}$ = 0.9983.

Shaft a

$$F_A^r = (239^2 + 111^2)^{1/2} = 264 \text{ lbf} = 1.175 \text{ kN}$$
$$F_B^r = (502^2 + 1075^2)^{1/2} = 1186 \text{ lbf} = 5.28 \text{ kN}$$

Thus the bearing at B controls.

$$x_D = \frac{10\,000(1200)(60)}{10^6} = 720$$
$$0.02 + 4.439[\ln(1/0.9983)]^{1/1.483} = 0.080\,26$$
$$C_{10} = 1.2(5.28)\left(\frac{720}{0.080\,26}\right)^{0.3} = 97.2 \text{ kN}$$

Select an 02-80 mm with C_{10} = 106 kN. *Ans.*

Shaft b

$$F_C^r = (874^2 + 2274^2)^{1/2} = 2436 \text{ lbf} \quad \text{or} \quad 10.84 \text{ kN}$$
$$F_D^r = (393^2 + 657^2)^{1/2} = 766 \text{ lbf} \quad \text{or} \quad 3.41 \text{ kN}$$

The bearing at C controls.

$$x_D = \frac{10\,000(240)(60)}{10^6} = 144$$

$$C_{10} = 1.2(10.84)\left(\frac{144}{0.080\ 26}\right)^{0.3} = 123 \text{ kN}$$

Select an 02-90 mm with C_{10} = 142 kN. *Ans.*

Shaft c

$$F_E^r = \left(1113^2 + 2385^2\right)^{1/2} = 2632 \text{ lbf} \quad \text{or} \quad 11.71 \text{ kN}$$

$$F_F^r = \left(417^2 + 895^2\right)^{1/2} = 987 \text{ lbf} \quad \text{or} \quad 4.39 \text{ kN}$$

The bearing at E controls.

$$x_D = \frac{10\,000(80)(60)}{10^6} = 48$$

$$C_{10} = 1.2(11.71)\left(\frac{48}{0.080\,26}\right)^{0.3} = 95.7 \text{ kN}$$

Select an 02-80 mm with C_{10} = 106 kN. *Ans.*

11-38 Express Eq. (11-1) as

$$F_1^a L_1 = C_{10}^a L_{10} = K$$

For a ball bearing, a = 3 and for an 02-30 mm angular contact bearing, C_{10} = 20.3 kN.

$$K = (20.3)^3\left(10^6\right) = 8.365\left(10^9\right)$$

At a load of 18 kN, life L_1 is given by:

$$L_1 = \frac{K}{F_1^a} = \frac{8.365\left(10^9\right)}{18^3} = 1.434\left(10^6\right) \text{ rev}$$

For a load of 30 kN, life L_2 is:

$$L_2 = \frac{8.365\left(10^9\right)}{30^3} = 0.310\left(10^6\right) \text{ rev}$$

In this case, Eq. (6-57) – the Palmgren-Miner cycle-ratio summation rule – can be expressed as

$$\frac{l_1}{L_1} + \frac{l_2}{L_2} = 1$$

Substituting,

$$\frac{200\,000}{1.434(10^6)} + \frac{l_2}{0.310(10^6)} = 1$$

$$l_2 = 0.267(10^6) \text{ rev} \quad \textit{Ans.}$$

11-39 *Total life in revolutions*

Let:

l = total turns
f_1 = fraction of turns at F_1
f_2 = fraction of turns at F_2

From the solution of Prob. 11-38, $L_1 = 1.434(10^6)$ rev and $L_2 = 0.310(10^6)$ rev.

Palmgren-Miner rule:

$$\frac{l_1}{L_1} + \frac{l_2}{L_2} = \frac{f_1 l}{L_1} + \frac{f_2 l}{L_2} = 1$$

from which

$$l = \frac{1}{f_1 / L_1 + f_2 / L_2}$$

$$l = \frac{1}{\left\{0.40 / \left[1.434(10^6)\right]\right\} + \left\{0.60 / \left[0.310(10^6)\right]\right\}}$$

$$= 451\,585 \text{ rev} \quad \textit{Ans.}$$

Total life in loading cycles

4 min at 2000 rev/min = 8000 rev/cycle

6 min at 2000 rev/min = 12 000 rev/cycle

Total rev/cycle = 8000 + 12 000 = 20 000

$$\frac{451\,585 \text{ rev}}{20\,000 \text{ rev/cycle}} = 22.58 \text{ cycles} \quad \textit{Ans.}$$

Total life in hours

$$\left(10\frac{\text{min}}{\text{cycle}}\right)\left(\frac{22.58\text{ cycles}}{60\text{ min/h}}\right)=3.76\text{ h} \quad \textit{Ans.}$$

11-40 $F_{rA}=560$ lbf

$F_{rB}=1095$ lbf

$F_{ae}=200$ lbf

$$x_D=\frac{L_D}{L_R}=\frac{40\,000(400)(60)}{90(10^6)}=10.67$$

$$R=\sqrt{0.90}=0.949$$

Eq. (11-18): $F_{iA}=\dfrac{0.47F_{rA}}{K_A}=\dfrac{0.47(560)}{1.5}=175.5\text{ lbf}$

Eq. (11-18): $F_{iB}=\dfrac{0.47F_{rB}}{K_B}=\dfrac{0.47(1095)}{1.5}=343.1\text{ lbf}$

$F_{iA}\le ?\ge (F_{iB}+F_{ae})$

$175.5\text{ lbf}\le(343.1+200)=543.1$ lbf, so Eq. (11-19) applies.

We will size bearing *B* first since its induced load will affect bearing *A*, but is not itself affected by the induced load from bearing *A* [see Eq. (11-19)].

From Eq. (11-19*b*), $F_{eB}=F_{rB}=1095$ lbf.

Eq. (11-10): $F_{RB}=1.4(1095)\left(\dfrac{10.67}{4.48(1-0.949)^{1/1.5}}\right)^{3/10}=3607\text{ lbf}$ *Ans.*

Select cone 32305, cup 32305, with 0.9843 in bore, and rated at 3910 lbf with $K=1.95$. *Ans.*

With bearing *B* selected, we re-evaluate the induced load from bearing *B* using the actual value for *K*.

Eq. (11-18): $F_{iB}=\dfrac{0.47F_{rB}}{K_B}=\dfrac{0.47(1095)}{1.95}=263.9\text{ lbf}$

Find the equivalent radial load for bearing *A* from Eq. (11-19), which still applies.

Eq. (11-19*a*): $F_{eA}=0.4F_{rA}+K_A(F_{iB}+F_{ae})$

$F_{eA}=0.4(560)+1.5(263.9+200)=920\text{ lbf}$

$$F_{eA} > F_{rA}$$

Eq. (11-10): $$F_{RA} = 1.4(920)\left(\frac{10.67}{4.48(1-0.949)^{1/1.5}}\right)^{3/10} = 3030 \text{ lbf}$$

Tentatively select cone M86643, cup M86610, with 1 in bore, and rated at 3250 lbf with K = 1.07. Iterating with the new value for K, we get F_{eA} = 702 lbf and F_{rA} = 2312 lbf. *Ans.*

By using a bearing with a lower K, the rated load decreased significantly, providing a higher than requested reliability. Further examination with different combinations of bearing choices could yield additional acceptable solutions.

11-41 The thrust load on shaft CD is from the axial component of the force transmitted through the bevel gear, and is directed toward bearing C. By observation of Fig. 11-14, direct mounted bearings would allow bearing C to carry the thrust load. *Ans.*

From the solution to Prob. 3-74, the axial thrust load is F_{ae} = 362.8 lbf, and the bearing radial forces are F_{Cx} = 287.2 lbf, F_{Cz} = 500.9 lbf, F_{Dx} = 194.4 lbf, and F_{Dz} = 307.1 lbf. Thus, the radial forces are

$$F_{rC} = \sqrt{287.2^2 + 500.9^2} = 577 \text{ lbf}$$
$$F_{rD} = \sqrt{194.4^2 + 307.1^2} = 363 \text{ lbf}$$

The induced loads are

Eq. (11-18): $$F_{iC} = \frac{0.47F_{rC}}{K_C} = \frac{0.47(577)}{1.5} = 181 \text{ lbf}$$

Eq. (11-18): $$F_{iD} = \frac{0.47F_{rD}}{K_D} = \frac{0.47(363)}{1.5} = 114 \text{ lbf}$$

Check the condition on whether to apply Eq. (11-19) or Eq. (11-20), where bearings C and D are substituted, respectively, for labels A and B in the equations.

$$F_{iC} \le ? \ge F_{iD} + F_{ae}$$
$$181 \text{ lbf} < 114 + 362.8 = 476.8 \text{ lbf, so Eq.(11-19) applies}$$

Eq. (11-19*a*): $$F_{eC} = 0.4F_{rC} + K_C\left(F_{iD} + F_{ae}\right)$$
$$= 0.4(577) + 1.5(114 + 362.8) = 946 \text{ lbf} > F_{rC,} \text{ so use } F_{eC}$$

Assume for tapered roller bearings that the specifications for Manufacturer 1 in Table 11-6 are applicable.

$$x_D = \frac{L_D}{L_R} = \frac{10^8}{90\left(10^6\right)} = 1.11$$

$$R = \sqrt{0.90} = 0.949$$

Eq. (11-10): $F_{RC} = 1\left(946\right)\left(\frac{1.11}{4.48\left(1-0.949\right)^{1/1.5}}\right)^{3/10} = 1130 \text{ lbf}$ *Ans.*

Eq. (11-19*b*): $F_{eD} = F_{rD} = 363 \text{ lbf}$

Eq. (11-10): $F_{RD} = 1\left(363\right)\left(\frac{1.11}{4.48\left(1-0.949\right)^{1/1.5}}\right)^{3/10} = 433 \text{ lbf}$ *Ans.*

11-42 The thrust load on shaft *AB* is from the axial component of the force transmitted through the bevel gear, and is directed to the right. By observation of Fig. 11-14, indirect mounted bearings would allow bearing *A* to carry the thrust load. *Ans.*

From the solution to Prob. 3-76, the axial thrust load is F_{ae} = 92.8 lbf, and the bearing radial forces are F_{Ay} = 639.4 lbf, F_{Az} = 1513.7 lbf, F_{By} = 276.6 lbf, and F_{Bz} = 705.7 lbf. Thus, the radial forces are

$$F_{rA} = \sqrt{639.4^2 + 1513.7^2} = 1643 \text{ lbf}$$

$$F_{rB} = \sqrt{276.6^2 + 705.7^2} = 758 \text{ lbf}$$

The induced loads are

Eq. (11-18): $F_{iA} = \frac{0.47F_{rA}}{K_A} = \frac{0.47\left(1643\right)}{1.5} = 515 \text{ lbf}$

Eq. (11-18): $F_{iB} = \frac{0.47F_{rB}}{K_B} = \frac{0.47\left(758\right)}{1.5} = 238 \text{ lbf}$

Check the condition on whether to apply Eq. (11-19) or Eq. (11-20).

$$F_{iA} \leq ? \geq F_{iB} + F_{ae}$$

$$515 \text{ lbf} > 238 + 92.8 = 330.8 \text{ lbf, so Eq.(11-20) applies}$$

Notice that the induced load from bearing *A* is sufficiently large to cause a net axial force to the left, which must be supported by bearing *B*.

Eq. (11-20*a*): $F_{eB} = 0.4F_{rB} + K_B\left(F_{iA} - F_{ae}\right)$

$$= 0.4\left(758\right) + 1.5\left(515 - 92.8\right) = 937 \text{ lbf} > F_{rB,} \text{ so use } F_{eB}$$

Assume for tapered roller bearings that the specifications for Manufacturer 1 in Table 11-6 are applicable.

$$x_D = \frac{L_D}{L_R} = \frac{500\left(10^6\right)}{90\left(10^6\right)} = 5.56$$

$$R = \sqrt{0.90} = 0.949$$

Eq. (11-10): $$F_{RB} = 1(937)\left(\frac{5.56}{4.48(1-0.949)^{1/1.5}}\right)^{3/10} = 1810 \text{ lbf} \quad \textit{Ans.}$$

Eq. (11-19*b*): $$F_{eA} = F_{rA} = 1643 \text{ lbf}$$

Eq. (11-10): $$F_{RA} = 1(1643)\left(\frac{5.56}{4.48(1-0.949)^{1/1.5}}\right)^{3/10} = 3180 \text{ lbf} \quad \textit{Ans.}$$

11-43 The lower bearing is compressed by the axial load, so it is designated as bearing *A*.

$$F_{rA} = 25 \text{ kN}$$
$$F_{rB} = 12 \text{ kN}$$
$$F_{ae} = 5 \text{ kN}$$

Eq. (11-18): $$F_{iA} = \frac{0.47F_{rA}}{K_A} = \frac{0.47(25)}{1.5} = 7.83 \text{ kN}$$

Eq. (11-18): $$F_{iB} = \frac{0.47F_{rB}}{K_B} = \frac{0.47(12)}{1.5} = 3.76 \text{ kN}$$

Check the condition on whether to apply Eq. (11-19) or Eq. (11-20)

$$F_{iA} \leq ? \geq F_{iB} + F_{ae}$$
$$7.83 \text{ kN} < 3.76 + 5 = 8.76 \text{ kN, so Eq.(11-19) applies}$$

Eq. (11-19*a*): $$F_{eA} = 0.4F_{rA} + K_A\left(F_{iB} + F_{ae}\right)$$
$$= 0.4(25) + 1.5(3.76 + 5) = 23.1 \text{ kN} < F_{rA,} \text{ so use } F_{rA}$$

$$L_D = (250 \text{ rev/min})\left(\frac{60 \text{ min}}{\text{hr}}\right)\left(\frac{8 \text{ hr}}{\text{day}}\right)\left(\frac{5 \text{ day}}{\text{week}}\right)\left(\frac{52 \text{ weeks}}{\text{yr}}\right)(5 \text{ yrs})$$
$$= 156\left(10^6\right) \text{ rev}$$

Assume for tapered roller bearings that the specifications for Manufacturer 1 in Table 11-6 are applicable.

Eq. (11-3): $$F_{RA} = a_f F_D\left[\frac{L_D}{L_R}\right]^{3/10} = 1.2(25)\left[\frac{156\left(10^6\right)}{90\left(10^6\right)}\right]^{3/10} = 35.4 \text{ kN} \quad \textit{Ans.}$$

Eq. (11-19*b*): $$F_{eB} = F_{rB} = 12 \text{ kN}$$

Eq. (11-3): $F_{RB} = 1.2(12)\left[\dfrac{156}{90}\right]^{3/10} = 17.0 \text{ kN}$ *Ans.*

11-44 The left bearing is compressed by the axial load, so it is properly designated as bearing *A*.

$$F_{rA} = 875 \text{ lbf}$$
$$F_{rB} = 625 \text{ lbf}$$
$$F_{ae} = 250 \text{ lbf}$$

Assume $K = 1.5$ for each bearing for the first iteration. Obtain the induced loads.

Eq. (11-18): $F_{iA} = \dfrac{0.47F_{rA}}{K_A} = \dfrac{0.47(875)}{1.5} = 274 \text{ lbf}$

Eq. (11-18): $F_{iB} = \dfrac{0.47F_{rB}}{K_B} = \dfrac{0.47(625)}{1.5} = 196 \text{ lbf}$

Check the condition on whether to apply Eq. (11-19) or Eq. (11-20).

$$F_{iA} \le ? \ge F_{iB} + F_{ae}$$
$$274 \text{ lbf} < 196 + 250 \text{ lbf, so Eq.(11-19) applies}$$

We will size bearing *B* first since its induced load will affect bearing *A*, but it is not affected by the induced load from bearing *A* [see Eq. (11-19)].

From Eq. (11-19*b*), $F_{eB} = F_{rB} = 625$ lbf.

Eq. (11-3): $F_{RB} = a_f F_D \left[\dfrac{L_D}{L_R}\right]^{3/10} = 1(625)\left[\dfrac{90\,000(150)(60)}{90(10^6)}\right]^{3/10}$

$$F_{RB} = 1208 \text{ lbf}$$

Select cone 07100, cup 07196, with 1 in bore, and rated at 1570 lbf with $K = 1.45$. *Ans.*

With bearing *B* selected, we re-evaluate the induced load from bearing *B* using the actual value for *K*.

Eq. (11-18): $F_{iB} = \dfrac{0.47F_{rB}}{K_B} = \dfrac{0.47(625)}{1.45} = 203 \text{ lbf}$

Find the equivalent radial load for bearing *A* from Eq. (11-19), which still applies.

Eq. (11-19*a*): $F_{eA} = 0.4F_{rA} + K_A\left(F_{iB} + F_{ae}\right)$

$$= 0.4(875) + 1.5(203 + 250) = 1030 \text{ lbf}$$

$$F_{eA} > F_{rA}$$

Eq. (11-3): $F_{RA} = a_f F_D \left[\frac{L_D}{L_R}\right]^{3/10} = 1(1030)\left[\frac{90\,000(150)(60)}{90(10^6)}\right]^{3/10}$

$$F_{RA} = 1990 \text{ lbf}$$

Any of the bearings with 1-1/8 in bore are more than adequate. Select cone 15590, cup 15520, rated at 2480 lbf with K = 1.69. Iterating with the new value for K, we get F_{eA} = 1120 lbf and F_{rA} = 2160 lbf. The selected bearing is still adequate. *Ans.*
