SOLUTION (14.4)

**Known:** A No. 204 radial ball bearing has a 5000 hr B-10 life at 900 rpm.

**Find:** Determine the bearing radial load capacity.

**Schematic and Given Data:**

![Schematic of bearing with given data]

- No. 204 Radial Bearing
- \( F_r = ? \)
- 90% reliability
- Assume: steady loading
- B-10 life = 5000 hours

**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 loading is steady.

**Analysis:**
1. From Table 14.1, for a 204 bearing the bore is 20 mm.
2. From Table 14.2, for \( L_R = 90 \times 10^6 \text{ rev} \) and a 200 series bearing, \( C = 3.35 \text{ kN} \).
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. From Eq. (14.5a), \( L = K_rL_R(C/F_cK_a)^{3.33} \)
6. Substituting and solving for \( F_c \): \( F_c = F_r = C(L_R/L)^{0.3} \)
7. Substituting values:

\[
F_r = 3.35 \text{ kN} \left[ \frac{90 \times 10^6 \text{ rev}}{(5000 \text{ hr})(60 \text{ min/hr})(900 \text{ rev/min})} \right]^{0.3} = 2409 \text{ N}
\]
SOLUTION (14.5)

Known: A No. 208 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:

```
1200 rpm

No. 208 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 208 bearing the bore is 40 mm.
2. From Table 14.2, for L_R = 90 \times 10^6 \text{ rev} and a 200 series bearing, C = 9.40 \text{ kN} = 2112.3 \text{ 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 \text{ lb}/200 \text{ 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), \[ L = K_e L_R (C/F_e K_a)^{3.33} \]
8. Substituting values into Eq. (14.5a):
   \[ L = 90 \times 10^6 \text{ rev} \left[ \frac{2112.3 \text{ lb}}{289.2 \text{ lb}} \right]^{3.33} = 6.76 \times 10^{10} \text{ rev} \]

   \[ = \left[ \frac{6.76 \times 10^{10} \text{ rev}}{(60 \text{ min/hr})(1200 \text{ rev/min})} \right] = 938,763 \text{ hr} \]

Comment: The life of 938,763 hours corresponds to about 107 years of continuous operation where the bearing runs 24 hours/day and 7 days/week—a long life!
SOLUTION (14.6)

**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:**

![Diagram of ball bearings with forces and distances](image)

**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 \( \frac{L_1}{L_2} = \left(\frac{F_2}{F_1}\right)^{10/3}, \frac{F_2}{F_1} = \left(\frac{L_1}{L_2}\right)^{3/10} \)

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 (14.7)

Known: Certain bearings are rated for a load capacity based on a life of $10^6$ revolutions.

Find: Determine the value by which the bearing rated capacities should be multiplied so they can be compared with the ratings in Table 14.2 which are based on a $90 \times 10^6$ revolution life.

Schematic and Given Data:

![Diagram of identical bearings]

$L_R |_{10^6} = 10^6$

$L_R |_{90 \times 10^6} = 90 \times 10^6$

Assumptions:
1. Ball bearing life varies inversely with the 10/3 power of the load.
2. A 90% reliability is required.

Analysis: From Eq. (14.1b), $C_{req} = F_t (L/L_R)^{0.3}$. For identical bearings with the same radial load $F_t$ and life $L$

$$\frac{C_{req} |_{10^6}}{(1/L_R)^{0.3} |_{10^6}} = \frac{C_{req} |_{90 \times 10^6}}{(1/L_R)^{0.3} |_{90 \times 10^6}}$$

Solving for $C_{req} |_{90 \times 10^6}$ gives

$$C_{req} |_{90 \times 10^6} = C_{req} |_{10^6} \frac{(1/L_R)^{0.3} |_{90 \times 10^6}}{(1/L_R)^{0.3} |_{10^6}}$$

or
\[ C_{\text{req}|0\times10^6} = C_{\text{req} |10^6} \left( \frac{1}{90 \times 10^6} \right)^{0.3} = C_{\text{req} |10^6} (0.259) \]

**Comment:** Bearings rated on a life of $10^6$ cycles will have a higher rated load capacity than identical bearings rated for a life of more than $10^6$ cycles.
SOLUTION (14.8)

**Known:** A No. 204 radial ball bearing has a 5000 hr B-10 life at 1800 rpm.

**Find:** Determine the bearing radial load capacity.

**Schematic and Given Data:**

1800 rpm

No. 204 Radial Bearing

\[ F_r = ? \]

90% reliability

Assume: steady loading

B-10 life = 5000 hours

**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 loading is steady.

**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.
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. From Eq. (14.5a), \( L = K_r L_R (C/F_s K_a)^{3.33} \)
6. Substituting and solving for \( F_e \): \( F_e = F_r = C (L_R/L)^{0.3} \)
7. Substituting values:

\[
F_r = 3.35 \text{ kN} \left[ \frac{90 \times 10^6 \text{ rev}}{(5000 \text{ hr})(60 \text{ min/hr})(1800 \text{ rev/min})} \right]^{0.3} = 1957 \text{ N}
\]
SOLUTION (14.9)

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:

<table>
<thead>
<tr>
<th>1200 rpm</th>
<th>No. 204 Radial Bearing</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>( F_r = 200 \text{ N} ), ( F_t = 150 \text{ N} )</td>
</tr>
<tr>
<td></td>
<td>90% reliability</td>
</tr>
<tr>
<td></td>
<td>steady loading</td>
</tr>
<tr>
<td></td>
<td>B-10 life = ?</td>
</tr>
</tbody>
</table>

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 \( L_R = 90 \times 10^6 \text{ rev} \) and a 200 series bearing, \( C = 3.35 \text{ kN} = 752.8 \text{ lb} \).
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 \( F_t/F_r = 150 \text{ lb}/200 \text{ lb} = 0.75 \)
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 (14.10)

**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:**

- 3500 rpm
- No. 204 Radial Ball Bearing
- \( F_r = 1000 \text{ N} \), \( F_t = 250 \text{ N} \)
- 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, \( C = 3.35 \text{ kN} \).
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), \( F_e = F_r = 1000 \text{ N} \).
6. From Eq. (14.5a), \( L = K_r L_R (C/F_e K_a)^{3.33} \)

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

\[
L = \frac{1.307 \times 10^9 \text{ rev}}{3500 \text{ rev/hr}} \frac{1 \text{ min}}{60 \text{ min}} = 6224 \text{ hours}
\]

**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 (14.11)

**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:**

<table>
<thead>
<tr>
<th></th>
<th>90% reliability</th>
<th>50% reliability</th>
<th>99% reliability</th>
</tr>
</thead>
<tbody>
<tr>
<td>L</td>
<td>5000 hr</td>
<td>?</td>
<td>?</td>
</tr>
<tr>
<td>Reliability</td>
<td>90%</td>
<td>50%</td>
<td>99%</td>
</tr>
</tbody>
</table>

**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 \( F_r, \)

\[
\frac{L}{K_r L_R (C/F_r)^{3.33}}_{90\%} = \frac{L}{K_r L_R (C/F_r)^{3.33}}_{50\%} = \frac{L}{K_r L_R (C/F_r)^{3.33}}_{99\%}
\]

or

\[
\frac{L}{K_r}_{90\%} = \frac{L}{K_r}_{50\%} = \frac{L}{K_r}_{99\%}
\]

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 (14.12)

**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:**

![Schematic Diagram]

No. 211  No. L11  No. 311  No. 1211
L = 5000 hr  L = ?  L = ?  L = ?

**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, \( C = 12.0 \text{ kN} \).
2. Also from Table 14.2, for the
   (a) L11 bearing, \( C = 8.2 \text{ kN} \)
   (b) 311 bearing, \( C = 18.0 \text{ kN} \)
   (c) 1211 bearing, \( C = 14.9 \text{ kN} \)
3. From Eq. (14.1a), \( L = L_R(C/F_T)^{3.33} \)
4. For identical loading conditions (i.e., the same value of \( F_T \)) and for bearing rating capacities where \( L_R = 90 \times 10^6 \) revolutions,
   \[
   \frac{L}{C^{3.33}}_{211} = \frac{L}{C^{3.33}}_{L11} = \frac{L}{C^{3.33}}_{311} = \frac{L}{C^{3.33}}_{1211}
   \]
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 \( L_{211} = 5000 \text{ hr} \),
   \( L_{L11} = 1407 \text{ hr} \),
   \( L_{311} = 19,291 \text{ hr} \) and
   \( L_{1211} = 10,280 \text{ hr} \)
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 (14.13)**

**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:**

<table>
<thead>
<tr>
<th></th>
<th>90% reliability</th>
<th>50% reliability</th>
<th>99% reliability</th>
</tr>
</thead>
<tbody>
<tr>
<td>(L)</td>
<td>15,000 hr</td>
<td>(L) = ?</td>
<td>(L) = ?</td>
</tr>
<tr>
<td></td>
<td>90%</td>
<td>50%</td>
<td>99%</td>
</tr>
</tbody>
</table>

**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 \(F_r\),
   
   \[
   \frac{L}{K_r L_R (C/F_r)^{3.33}}\bigg|_{90\%} = \frac{L}{K_r L_R (C/F_r)^{3.33}}\bigg|_{50\%} = \frac{L}{K_r L_R (C/F_r)^{3.33}}\bigg|_{99\%}
   \]
   
   or
   
   \[
   \frac{L}{K_r}\bigg|_{90\%} = \frac{L}{K_r}\bigg|_{50\%} = \frac{L}{K_r}\bigg|_{99\%}
   \]

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 (14.14)

**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:**

Assume: $K_a = 1.0$ (uniform load)

**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 $C = 8.5 \text{ kN}$ (with $L_R = 90 \times 10^6$ and 90% reliability).
2. Eq. (14.5a) is $L = K_t L_R (C/F_e K_a)^{3.33}$. We have $F_e = F_t$, $K_a = 1.0$ and for 90% reliability, $K_t = 1.0$. Thus, $L = L_R (C/F_t)^{3.33}$.
3. With $C = 8.5 \text{ kN}$, $L_R = 90 \times 10^6 \text{ rev}$ and the above equation, we have for
(a) $F_t = 3 \text{ kN}$, $L = 2887 \times 10^6 \text{ rev}$
(b) $F_t = 5 \text{ kN}$, $L = 526.8 \times 10^6 \text{ rev}$
(c) $F_t = 7 \text{ kN}$, $L = 171.8 \times 10^6 \text{ rev}$
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 $n_1 = 1080X \text{ rev}$, $n_2 = 540X \text{ rev}$, $n_3 = 180X \text{ rev}$.
6. From part 3, $N_1 = 2887 \times 10^6 \text{ rev}$, $N_2 = 526.8 \times 10^6 \text{ rev}$, and $N_3 = 171.8 \times 10^6 \text{ rev}$.
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, $X = \frac{10^6}{2.4469} = 408,694 \text{ minutes} = 6811 \text{ hours}$
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 (14.15)

**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:

![Diagram of load versus life (hr)](image)

Assume: $K_a = 1.0$ (uniform load)
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 $90 \times 10^6$ 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

Comment: 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 (14.16)

**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:**

![Diagram showing three bearings with loads](image)

- **No. 212:** $L = 6000$ hr
- **No. 213:** $L = ?$
- **No. 312:** $L = ?$

*Note: Identical applications (loads, speeds)*

**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)

   \[
   \frac{L}{L_R(C/F_r)^{3.33}} \bigg|_{\text{No. 212}} = \frac{L}{L_R(C/F_r)^{3.33}} \bigg|_{\text{No. 213}} = \frac{L}{L_R(C/F_r)^{3.33}} \bigg|_{\text{No. 312}}
   \]

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

   \[
   \frac{L}{C^{3.33}} \bigg|_{\text{No. 212}} = \frac{L}{C^{3.33}} \bigg|_{\text{No. 213}} = \frac{L}{C^{3.33}} \bigg|_{\text{No. 312}}
   \]
or \[
\frac{6000 \text{ hours}}{13.6^{3.33}} = \frac{L_{213}}{16^{3.33}} = \frac{L_{312}}{20^{3.33}}
\]

Hence, \(L_{213} = 10,308 \text{ hr}\), and \(L_{312} = 21,672 \text{ hr}\)

**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 (14.17D)

**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:**

<table>
<thead>
<tr>
<th>Radial Bearing</th>
<th>Angular Bearing</th>
</tr>
</thead>
<tbody>
<tr>
<td>$F_r = 3 \text{ kN}$, $F_t = 1 \text{ kN}$</td>
<td>$F_r = 3 \text{ kN}$, $F_t = 1 \text{ kN}$</td>
</tr>
<tr>
<td>98% reliability</td>
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</tr>
<tr>
<td>$L = 5000 \text{ hr life}$</td>
<td>$L = 5000 \text{ hr life}$</td>
</tr>
<tr>
<td>light-moderate impact</td>
<td>light-moderate impact</td>
</tr>
</tbody>
</table>

1000 rpm

**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. $L = 5000 \text{ hours} = \frac{5000 \text{ hours}}{\frac{1000 \text{ rev}}{\text{min}}} \times \frac{60 \text{ min}}{\text{hour}} = 3 \times 10^8 \text{ rev}$
5. For the radial bearing with $F_r = F_t = 3 \text{ kN}$, $K_a = 1.5$, $L = 3 \times 10^8 \text{ rev}$, $K_r = 0.33$ and $L_R = 90 \times 10^6 \text{ rev}$, 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 $C_{req} = 9.01 \text{ kN}$ 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 (14.18D)

**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:**

<table>
<thead>
<tr>
<th>Case (a)</th>
<th>$F_t = 1.5 \text{ kN}$</th>
<th>Case (b)</th>
<th>$F_t = 3.0 \text{ kN}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Radial Bearing</td>
<td><img src="radial_bearing.png" alt="Diagram" /></td>
<td>Angular Bearing</td>
<td><img src="angular_bearing.png" alt="Diagram" /></td>
</tr>
</tbody>
</table>

- 98% reliability
- $L = 5000 \text{ hr}$ life
- Light-moderate impact
- $F_T = 3 \text{ kN}$

**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$)(1000 \text{ rev/min})(60 \text{ min/hr}) = 3 \times 10^8$ 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),
   \[ C_{req} = F_e K_a \left( L/K_r L_R \right)^{0.3} = F_e (1.5)(300/(0.33)(90))^{0.3} = 3.00 \ F_e. \]
   (a)
6. For $F_t = 1.5 \ \text{kN}$, $F_t/F_r = 0.5$.
7. For the radial bearing, Eq. (14.3) gives $F_e = (3.0)(1 + 1.115(0.15)) = 3.50 \ \text{kN}$.
8. The required value of rated capacity for the application, $C_{req} = 3(3.50) = 10.5 \ \text{kN}$.
9. Select bearing No. 211.
10. For the angular bearing, Eq. (14.4) gives $F_e = F_r = 3.0 \ \text{kN}$.
11. $C_{req} = (3)(3.0) = 9 \ \text{kN}$.
12. Select 40 mm bore bearing No. 208.
   (b)
13. For $F_t = 3.0 \ \text{kN}$, $F_t/F_r = 1.0$.
14. For the radial bearing, Eq. (14.3) gives $F_e = (3.0)(1 + 1.115(0.65)) = 5.17 \ \text{kN}$.
15. $C_{req} = (3)(5.17) = 15.52 \ \text{kN}$.
16. Select bearing No. 213.
17. For the angular bearing, Eq. (14.4) gives $F_e = (3.0)(1.0 + 0.870(0.32)) = 3.84 \ \text{kN}$.
18. $C_{req} = (3)(3.84) = 11.51 \ \text{kN}$.
19. Select bearing No. 211.
SOLUTION (14.19)

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:

Radial Bearing
\[ F_r = 5 \text{ kN}, \ F_t = 1 \text{ kN} \]
98% reliability
L = 5000 hr life
light-moderate impact
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 \( F_d/F_r = 1/5 = 0.20 \), 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. \( L = 5000 \text{ hours} = \frac{5000 \text{ hours}}{\text{min}} \times \frac{1000 \text{ rev}}{\text{min}} \times \frac{60 \text{ min}}{\text{hour}} = 3 \times 10^8 \text{ rev} \)
5. For the radial bearing with \( F_e = F_r = 5 \text{ kN}, K_a = 1.5, L = 3 \times 10^8 \text{ rev}, K_r = 0.33 \) and \( L_R = 90 \times 10^6 \text{ rev} \), 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 \( C_{req} = 15.02 \text{ kN} \) 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 (14.20D)

**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:**

![Diagram](image)

**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.
   
   \[ \Sigma \text{Torque} = 0: \quad R_h(75) - 1200(\cos 20)(60) = 0 \]
   
   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:**
   
   \[ \Sigma M_h = 0: \quad 901.6(210) + 1200(\cos 20)(520) - B_h(420) = 0 \]
Hence, \( B_h = 1846.9 \) N
\[
[\Sigma F_h = 0]: \quad 901.6 + 1200(\cos 20) - 1846.9 - A_h = 0
\]
Hence, \( A_h = 182.3 \) N

**Vertical forces:**
\[
[\Sigma M_a = 0]: \quad 4(300)(210) - 1200(\sin 20)(520) - B_v(420) = 0
\]
Hence, \( B_v = 91.9 \) N
\[
[\Sigma F_v = 0]: \quad -A_v - 91.9 + 4(300) - 1200(\sin 20) = 0
\]
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), \( C_{req} = F_e K_a (L/K_i L_R)^{0.3} \)
   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.
   \[
   L = \frac{350 \text{ rev}}{\text{min}} \left| \frac{60 \text{ min}}{1 \text{ hr}} \right| \left| \frac{30,000 \text{ hr}}{1} \right| = 630 \times 10^6 \text{ rev}
   \]
   \[
   C_{req} = 1849(1.1) \left[ \frac{630 \times 10^6}{(1)(90 \times 10^6)} \right]^{0.3} = 3646 \) N

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 (14.21D)

**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:**

[Diagram showing a chain idler sprocket with labeled dimensions and forces]
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.
   \[
   [\Sigma M_a = 0]: \quad 1200(2.50) - B(1.75) = 0 \\
   \text{Hence, } B = 1714.3 \text{ lb} \\
   [\Sigma F_h = 0]: \quad 1200 + 1714.3 + A_h = 0 \\
   \text{Hence, } A = -514.3 \text{ lb}
   \]

2. The bearing radial loads are:
   Bearing A: \quad F_r = 514.3 \text{ lb} \\
   Bearing B: \quad F_r = 1714.3 \text{ 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), \( C_{req} = F_c K_a (L/K_f L_R)^{0.3} \)
   where \( F_c = F_r = 1714.3 \text{ lb} \)
   Also, \( K_a = 1.1 \) (Table 14.3, favorable gearing) and \( K_f = 1.0 \) for 90% reliability.

   \[
   L = \frac{350 \text{ rev}}{\text{min}} \times \frac{60 \text{ min}}{1 \text{ hr}} \times \frac{30,000 \text{ hr}}{1} = 630 \times 10^6 \text{ rev}
   \]

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

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

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