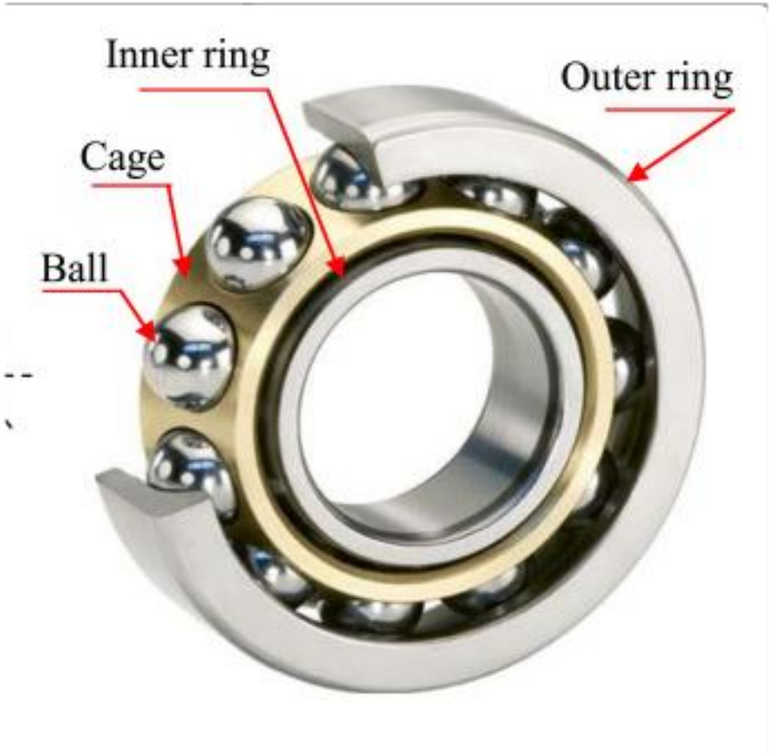
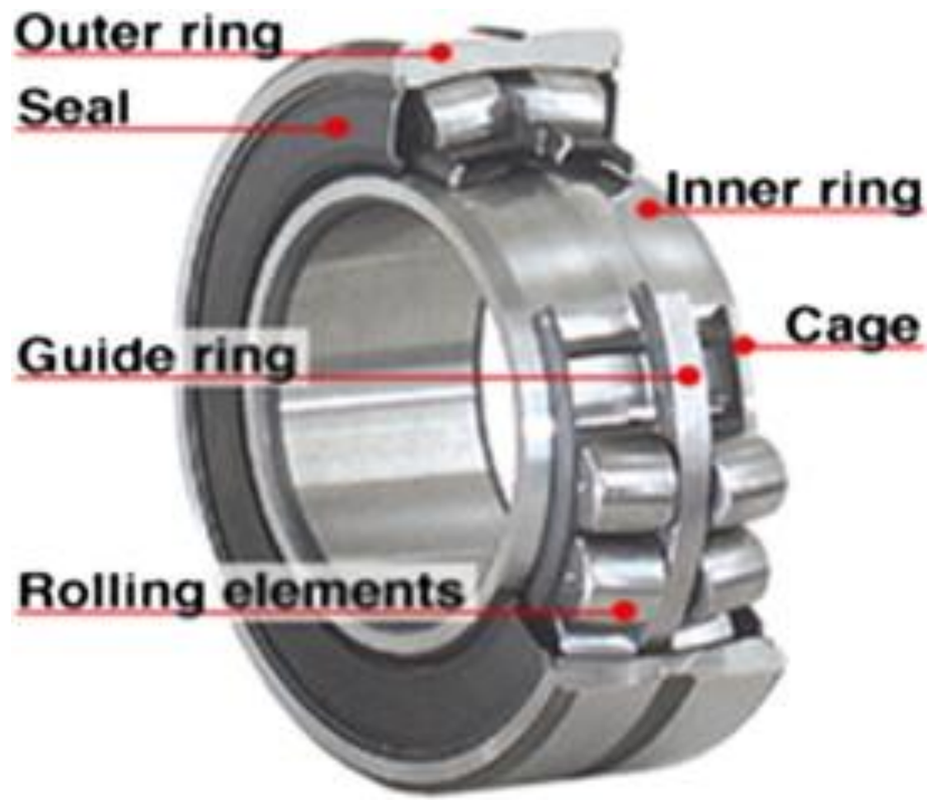
# ROLLING CONTACT BEARINGS

- Bearing Nomenclature and Definitions
- Bearing Types
- Bearing Life
- Combined Radial and Thrust Loading
- Selection of Radial and Cylindrical Roller Bearings

# Images of Rolling Contact Bearing



# Images of Rolling Contact Bearing Cont'd

# Nomenclature of a Ball Bearing

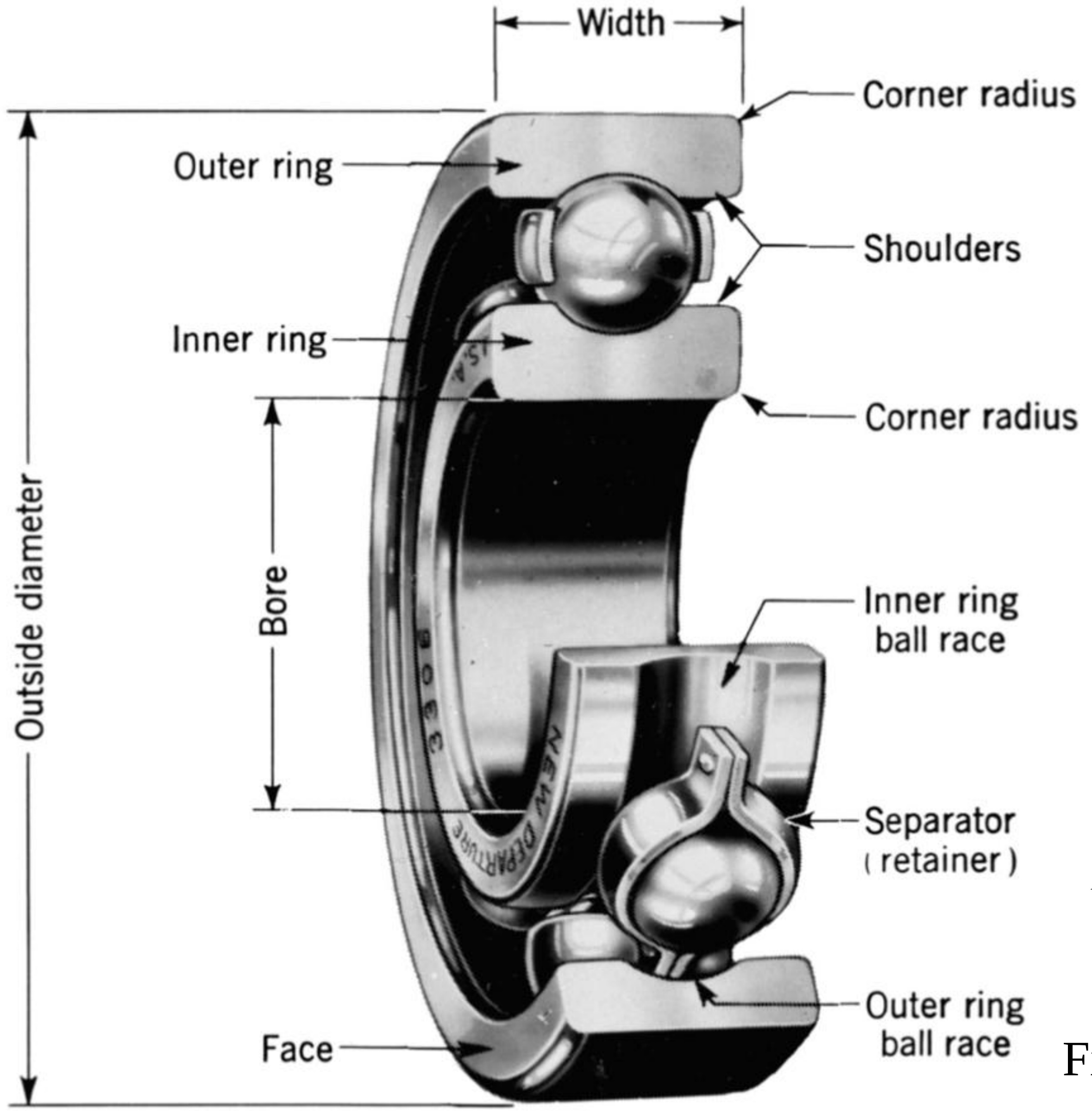



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Fig. 11–1

# Types of Ball Bearings

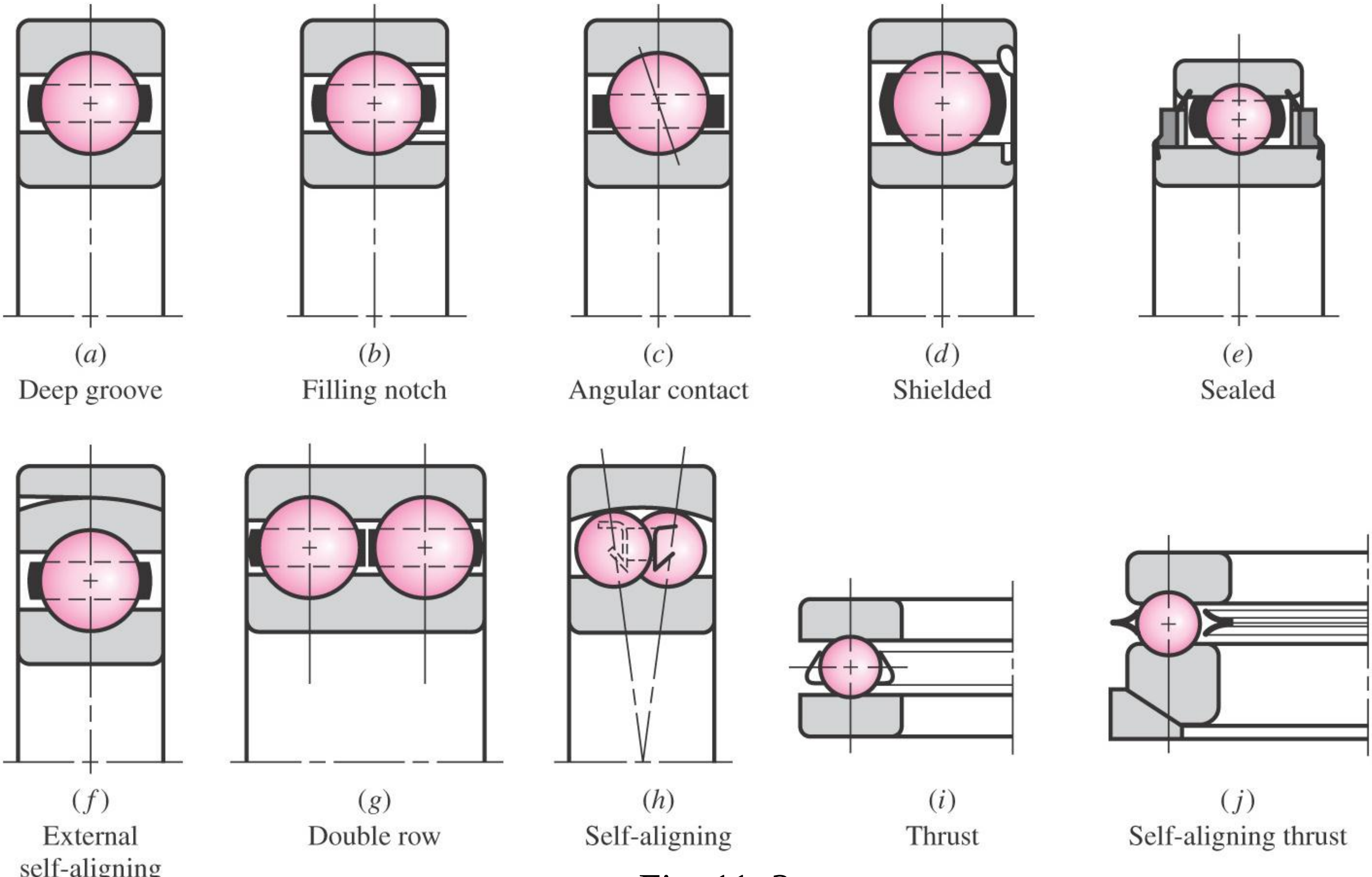
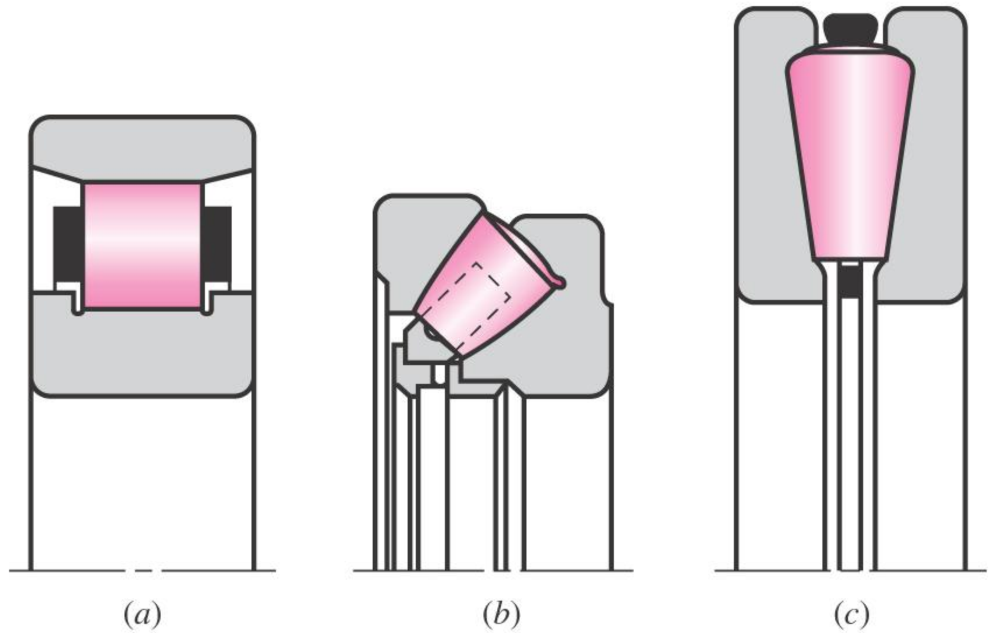



Fig. 11–2

# Types of Roller Bearings




Straight Cylindrical    Spherical Roller, thrust    Tapered roller, thrust

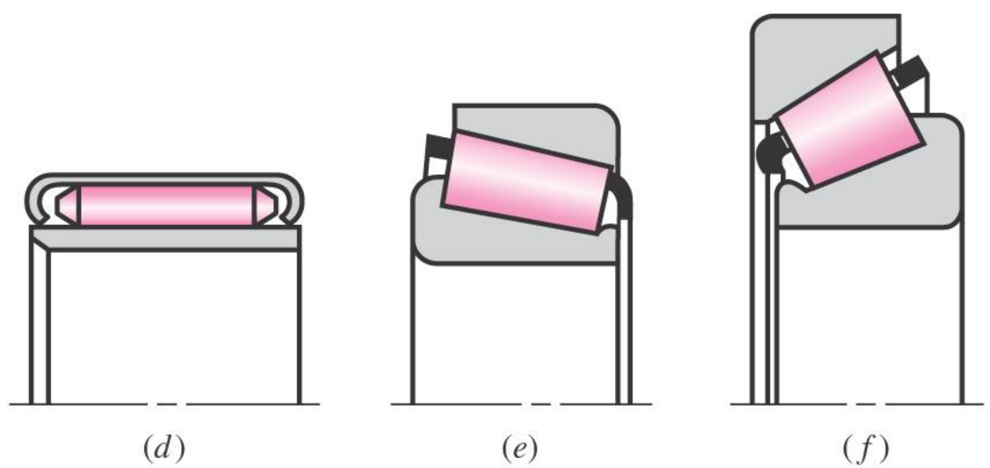



Fig. 11–3

Needle    Tapered roller    Steep-angle tapered roller

# Bearing Life Definitions

- ***Bearing Failure:*** Spalling or pitting of an area of 0.01 in$^2$
- ***Life***: Number of revolutions (or hours @ given speed) required for failure.
  - For one bearing
- ***Rating Life***: *Life* required for 10% of sample to fail **(Reliability of 90%)**
  - For a group of bearings
  - Also called *Minimum Life* or $L_{10}$ *Life*
- ***Median Life***: Average life required for 50% of sample to fail.
  - For many groups of bearings
  - Also called *Average Life* or *Average Median Life*
  - *Median Life* is typically 4 or 5 times the $L_{10}$ *Life*

# Load Rating Definitions

- ***Catalog Load Rating, $C_{10}$*:** Constant radial load that causes 10% of a group of bearings to fail at the **bearing manufacturer's rating life.**
  - Depends on type, geometry, accuracy of fabrication, and material of bearing
  - Also called Basic Dynamic Load Rating, and Basic Dynamic Capacity
- ***Basic Load Rating, C*:** A catalog load rating based on a rating life of $10^6$ revolutions of the inner ring.
  - The radial load that would be necessary to cause failure at such a low life is unrealistically high.
  - The Basic Load Rating is a reference value.

# Load Rating Definitions

- ***Static Load Rating, $C_o$:***
Static radial load which corresponds to a permanent deformation of rolling element and race at the most heavily stressed contact of 0.0001*d*.
  - *d* = diameter of roller
  - Used to check for permanent deformation
  - **Used in combining radial and thrust loads into an equivalent radial load**
- ***Equivalent Radial Load, $F_e$:***
Constant stationary load applied to bearing with rotating inner ring which gives the same life as actual load and rotation conditions.

# Load-Life Relationship

- Nominally identical groups of bearings are tested to the life-failure criterion at different loads.
- A plot of load vs. life on log-log scale is approximately linear.
- Using a regression equation to represent the line,

$$F L^{1/a} = \text{constant} \qquad (11\text{–}1)$$

  - $a$ = 3 for ball bearings
  - $a$ = 10/3 for roller bearings (cylindrical and tapered roller)

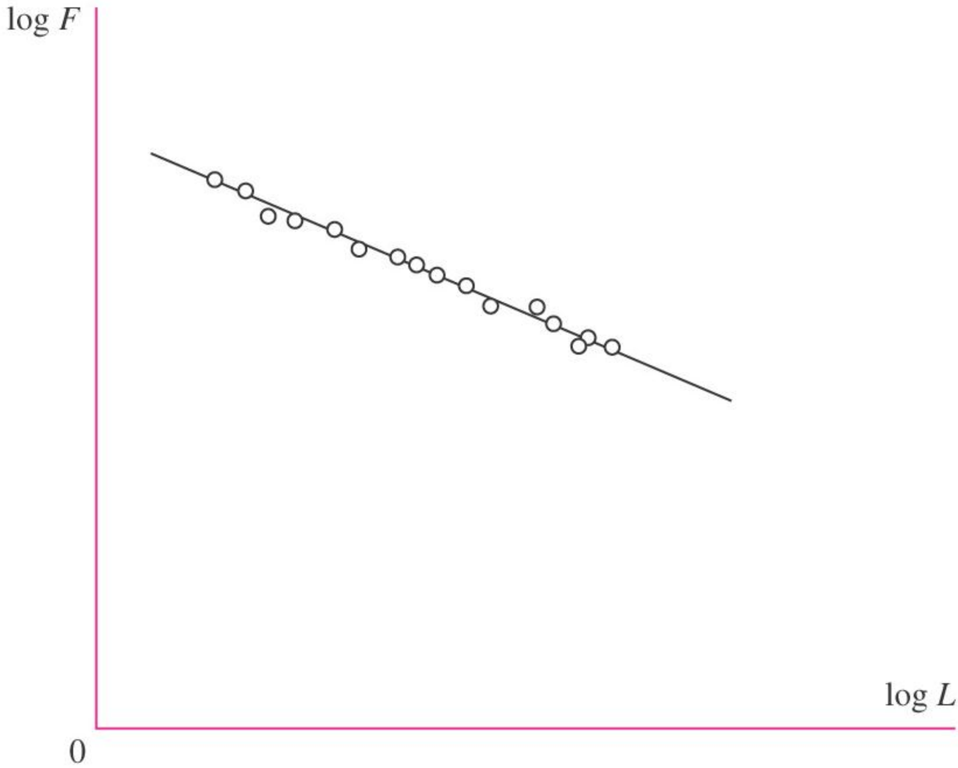



Fig. 11–4

# Load-Life Relationship

- Applying Eq. (11–1) to two load-life conditions,

$$F_1 L_1^{1/a} = F_2 L_2^{1/a} \qquad (11\text{–}2)$$

- Denoting condition 1 with $R$ for catalog rating conditions, and condition 2 with $D$ for the desired design conditions,

$$F_R L_R^{1/a} = F_D L_D^{1/a} \qquad (a)$$

- The units of $L$ are revolutions. If life $\mathcal{L}$ is given in hours at a given speed $n$ in rev/min, applying a conversion of 60 min/h,

$$L = 60\,\mathcal{L} n \qquad (b)$$

- Solving Eq. ($a$) for $F_R$, which is just another notation for the catalog load rating,

$$C_{10} = F_R = F_D \left(\frac{L_D}{L_R}\right)^{1/a} = F_D \left(\frac{\mathcal{L}_D n_D 60}{\mathcal{L}_R n_R 60}\right)^{1/a} \qquad (11\text{–}3)$$

# Load-Life Relationship

$$C_{10} = F_R = F_D \left( \frac{L_D}{L_R} \right)^{1/a} = F_D \left( \frac{\mathcal{L}_D n_D 60}{\mathcal{L}_R n_R 60} \right)^{1/a} \qquad (11\text{–}3)$$

- The desired design load $F_D$ and life $L_D$ come from the problem statement.
- The rated life $L_R$ will be stated by the specific bearing manufacturer. Many catalogs rate at $L_R = 10^6$ revolutions.
- **The catalog load rating $C_{10}$ is used to find a suitable bearing in the catalog.**

# Load-Life Relationship

- It is often convenient to define a dimensionless *multiple of rating life*

$$x_D = L_D / L_R$$

# Dimension-Series Code

- ABMA standardized *dimension-series code* represents the relative size of the boundary dimensions of the bearing cross section for metric bearings.
- Two digit series number
- First digit designates the width series
- Second digit designates the diameter series
- Specific dimensions are tabulated in catalogs under a specific series

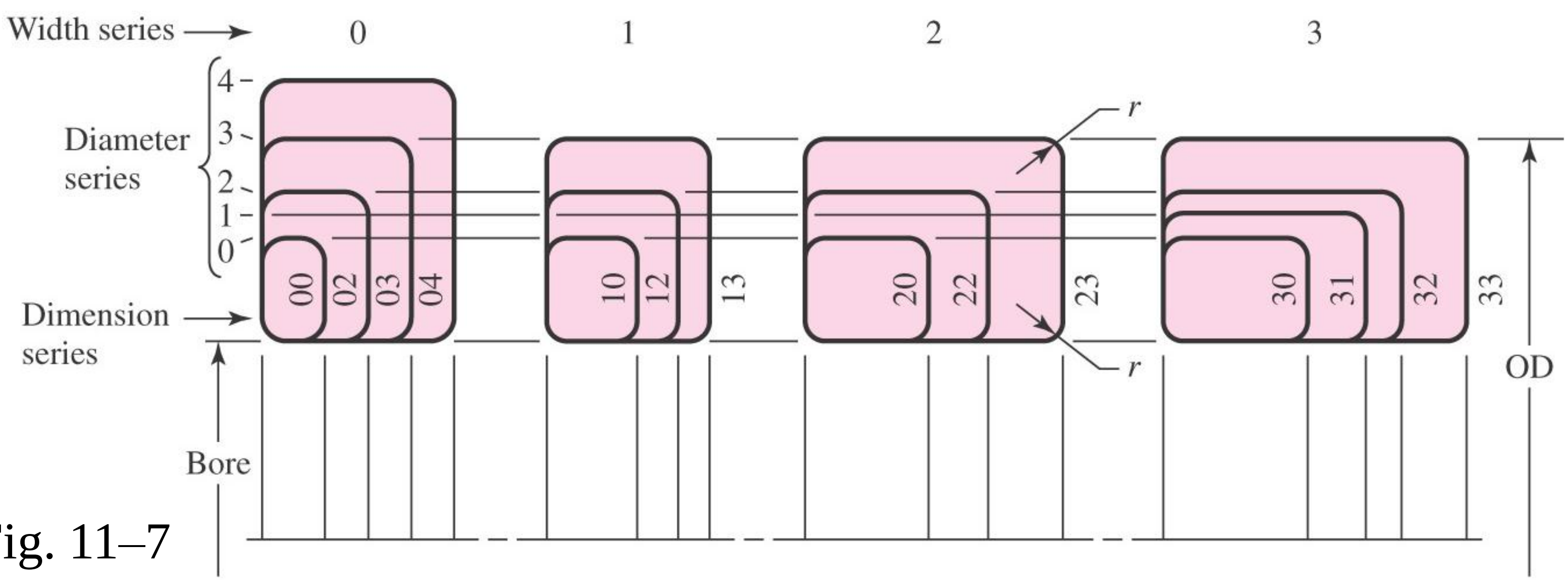



Fig. 11–7

# Representative Catalog Data for Ball Bearings (Table 11–2)

Dimensions and Load Ratings for Single-Row 02-Series Deep-Groove and Angular-Contact Ball Bearings

| Bore, mm | OD, mm | Width, mm | Fillet Radius, mm | Shoulder Diameter, mm | | Load Ratings, kN | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | | Deep Groove | | Angular Contact | |
| | | | | $d_S$ | $d_H$ | $C_{10}$ | $C_0$ | $C_{10}$ | $C_0$ |
| 10 | 30 | 9 | 0.6 | 12.5 | 27 | 5.07 | 2.24 | 4.94 | 2.12 |
| 12 | 32 | 10 | 0.6 | 14.5 | 28 | 6.89 | 3.10 | 7.02 | 3.05 |
| 15 | 35 | 11 | 0.6 | 17.5 | 31 | 7.80 | 3.55 | 8.06 | 3.65 |
| 17 | 40 | 12 | 0.6 | 19.5 | 34 | 9.56 | 4.50 | 9.95 | 4.75 |
| 20 | 47 | 14 | 1.0 | 25 | 41 | 12.7 | 6.20 | 13.3 | 6.55 |
| 25 | 52 | 15 | 1.0 | 30 | 47 | 14.0 | 6.95 | 14.8 | 7.65 |
| 30 | 62 | 16 | 1.0 | 35 | 55 | 19.5 | 10.0 | 20.3 | 11.0 |
| 35 | 72 | 17 | 1.0 | 41 | 65 | 25.5 | 13.7 | 27.0 | 15.0 |
| 40 | 80 | 18 | 1.0 | 46 | 72 | 30.7 | 16.6 | 31.9 | 18.6 |
| 45 | 85 | 19 | 1.0 | 52 | 77 | 33.2 | 18.6 | 35.8 | 21.2 |
| 50 | 90 | 20 | 1.0 | 56 | 82 | 35.1 | 19.6 | 37.7 | 22.8 |
| 55 | 100 | 21 | 1.5 | 63 | 90 | 43.6 | 25.0 | 46.2 | 28.5 |
| 60 | 110 | 22 | 1.5 | 70 | 99 | 47.5 | 28.0 | 55.9 | 35.5 |
| 65 | 120 | 23 | 1.5 | 74 | 109 | 55.9 | 34.0 | 63.7 | 41.5 |
| 70 | 125 | 24 | 1.5 | 79 | 114 | 61.8 | 37.5 | 68.9 | 45.5 |
| 75 | 130 | 25 | 1.5 | 86 | 119 | 66.3 | 40.5 | 71.5 | 49.0 |
| 80 | 140 | 26 | 2.0 | 93 | 127 | 70.2 | 45.0 | 80.6 | 55.0 |
| 85 | 150 | 28 | 2.0 | 99 | 136 | 83.2 | 53.0 | 90.4 | 63.0 |
| 90 | 160 | 30 | 2.0 | 104 | 146 | 95.6 | 62.0 | 106 | 73.5 |
| 95 | 170 | 32 | 2.0 | 110 | 156 | 108 | 69.5 | 121 | 85.0 |

# Representative Catalog Data for Cylindrical Roller Bearings (Table 11–3)

| | 02-Series | | | | 03-Series | | | |
|---|---|---|---|---|---|---|---|---|
| Bore, mm | OD, mm | Width, mm | Load Rating, kN $C_{10}$ | $C_0$ | OD, mm | Width, mm | Load Rating, kN $C_{10}$ | $C_0$ |
| 25 | 52 | 15 | 16.8 | 8.8 | 62 | 17 | 28.6 | 15.0 |
| 30 | 62 | 16 | 22.4 | 12.0 | 72 | 19 | 36.9 | 20.0 |
| 35 | 72 | 17 | 31.9 | 17.6 | 80 | 21 | 44.6 | 27.1 |
| 40 | 80 | 18 | 41.8 | 24.0 | 90 | 23 | 56.1 | 32.5 |
| 45 | 85 | 19 | 44.0 | 25.5 | 100 | 25 | 72.1 | 45.4 |
| 50 | 90 | 20 | 45.7 | 27.5 | 110 | 27 | 88.0 | 52.0 |
| 55 | 100 | 21 | 56.1 | 34.0 | 120 | 29 | 102 | 67.2 |
| 60 | 110 | 22 | 64.4 | 43.1 | 130 | 31 | 123 | 76.5 |
| 65 | 120 | 23 | 76.5 | 51.2 | 140 | 33 | 138 | 85.0 |
| 70 | 125 | 24 | 79.2 | 51.2 | 150 | 35 | 151 | 102 |
| 75 | 130 | 25 | 93.1 | 63.2 | 160 | 37 | 183 | 125 |
| 80 | 140 | 26 | 106 | 69.4 | 170 | 39 | 190 | 125 |
| 85 | 150 | 28 | 119 | 78.3 | 180 | 41 | 212 | 149 |
| 90 | 160 | 30 | 142 | 100 | 190 | 43 | 242 | 160 |
| 95 | 170 | 32 | 165 | 112 | 200 | 45 | 264 | 189 |
| 100 | 180 | 34 | 183 | 125 | 215 | 47 | 303 | 220 |
| 110 | 200 | 38 | 229 | 167 | 240 | 50 | 391 | 304 |
| 120 | 215 | 40 | 260 | 183 | 260 | 55 | 457 | 340 |
| 130 | 230 | 40 | 270 | 193 | 280 | 58 | 539 | 408 |
| 140 | 250 | 42 | 319 | 240 | 300 | 62 | 682 | 454 |
| 150 | 270 | 45 | 446 | 260 | 320 | 65 | 781 | 502 |

# Example

Consider SKF, which rates its bearings for 1 million revolutions. If you desire a life of 5000 h at 1725 rev/min with a load of 400 lbf with a reliability of 90 percent, for which catalog rating would you search in an SKF catalog?

# Combined Radial and Thrust Loading

- When ball bearings carry both an axial thrust load $F_a$ and a radial load $F_r$, **an *equivalent radial load* $F_e$ that does the same damage is used.**
- A plot of $F_e/(VF_r)$ vs. $F_a/(VF_r)$ is obtained experimentally.
- $V$ is a rotation factor to account for the difference in ball rotations for outer ring rotation vs. inner ring rotation.
  - $V = 1$ for inner ring rotation
  - $V = 1.2$ for outer ring rotation
- ***Set $F_D = F_e$***

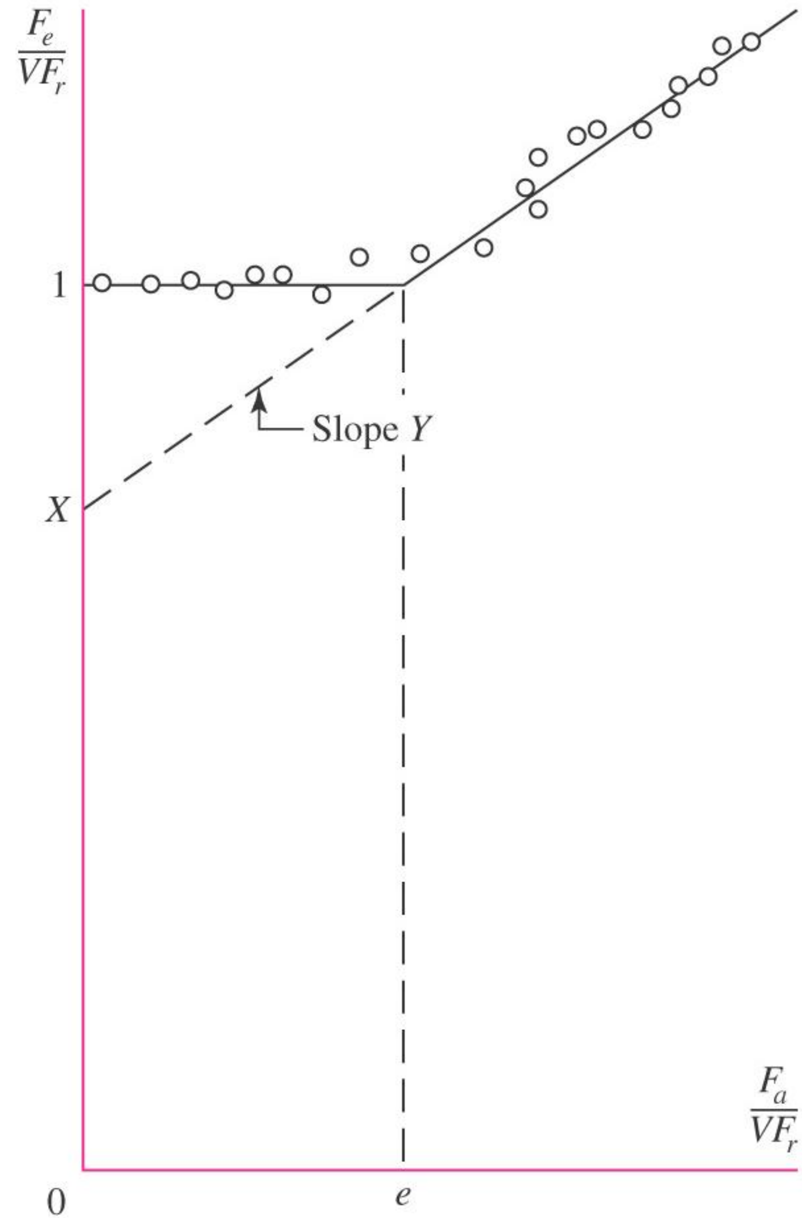



Fig. 11–6

# Combined Radial and Thrust Loading

- The data can be approximated by two straight lines

$$\frac{F_e}{VF_r} = 1 \qquad \text{when } \frac{F_a}{VF_r} \le e$$

$$\frac{F_e}{VF_r} = X + Y\frac{F_a}{VF_r} \qquad \text{when } \frac{F_a}{VF_r} > e$$

- $X$ is the ordinate intercept and $Y$ is the slope
- **Basically indicates that $F_e$ equals $F_r$ for smaller ratios of $F_a/F_r$, then begins to rise when $F_a/F_r$ exceeds some amount $e$**

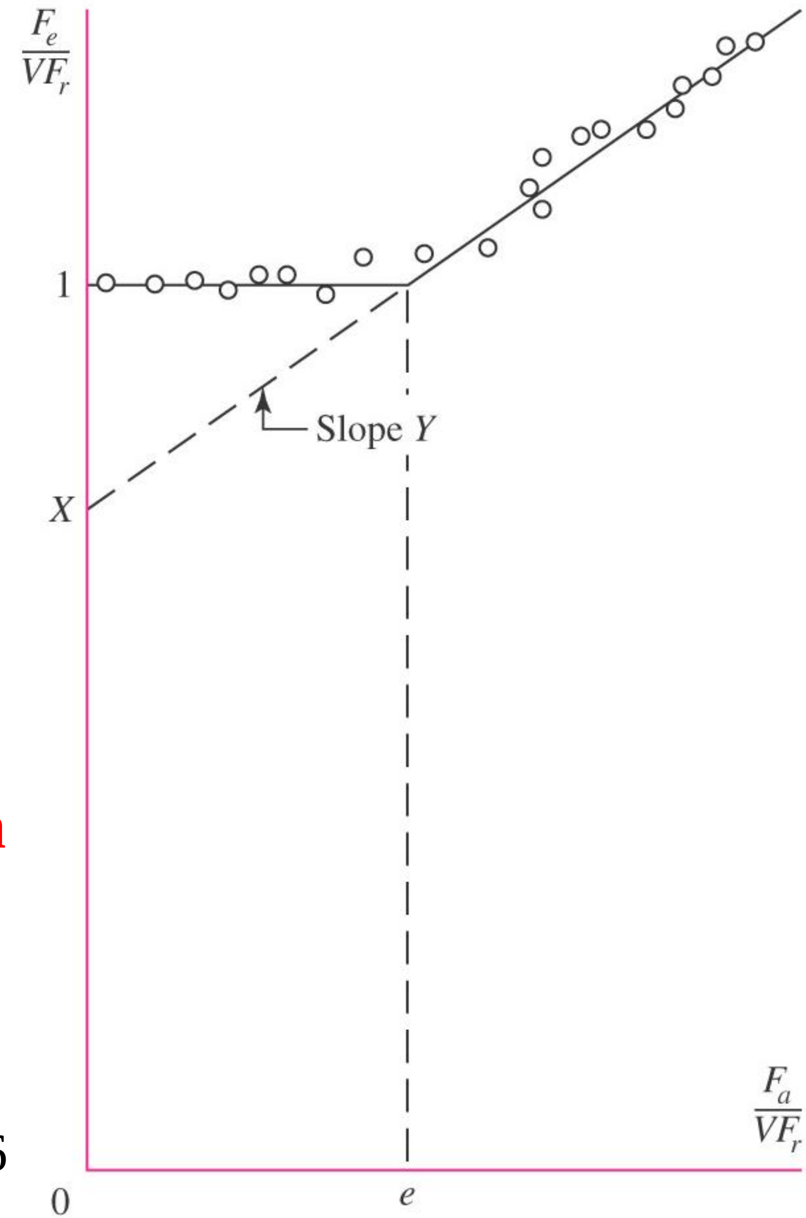



Fig. 11–6

# Combined Radial and Thrust Loading

- It is common to express the two equations as a single equation

$$F_e = X_i V F_r + Y_i F_a \qquad (11\text{–}12)$$

where

$$i = 1 \text{ when } F_a/(VF_r) \le e$$

$$i = 2 \text{ when } F_a/(VF_r) > e$$

- *X* and *Y* factors depend on geometry and construction of the specific bearing.

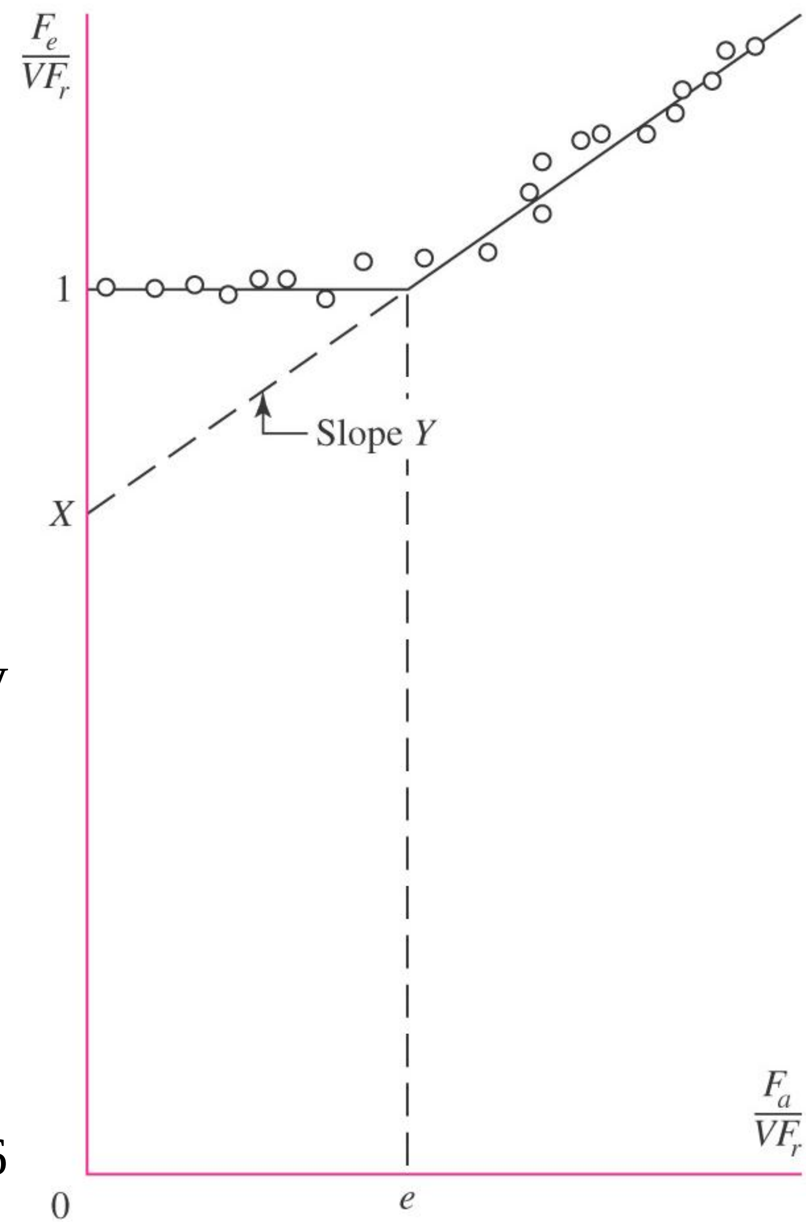



Fig. 11–6

# Equivalent Radial Load Factors for Ball Bearings

$$F_e = X_i V F_r + Y_i F_a \qquad (11\text{–}12)$$

- ***X* and *Y* for specific bearing obtained from bearing catalog.**
- Table 11–1 gives representative values in a manner common to many catalogs.

Table 11–1

| $F_a/C_0$ | $e$ | $F_a/(VF_r) \le e$ $X_1$ | $Y_1$ | $F_a/(VF_r) > e$ $X_2$ | $Y_2$ |
|---|---|---|---|---|---|
| 0.014* | 0.19 | 1.00 | 0 | 0.56 | 2.30 |
| 0.021 | 0.21 | 1.00 | 0 | 0.56 | 2.15 |
| 0.028 | 0.22 | 1.00 | 0 | 0.56 | 1.99 |
| 0.042 | 0.24 | 1.00 | 0 | 0.56 | 1.85 |
| 0.056 | 0.26 | 1.00 | 0 | 0.56 | 1.71 |
| 0.070 | 0.27 | 1.00 | 0 | 0.56 | 1.63 |
| 0.084 | 0.28 | 1.00 | 0 | 0.56 | 1.55 |
| 0.110 | 0.30 | 1.00 | 0 | 0.56 | 1.45 |
| 0.17 | 0.34 | 1.00 | 0 | 0.56 | 1.31 |
| 0.28 | 0.38 | 1.00 | 0 | 0.56 | 1.15 |
| 0.42 | 0.42 | 1.00 | 0 | 0.56 | 1.04 |
| 0.56 | 0.44 | 1.00 | 0 | 0.56 | 1.00 |

# Equivalent Radial Load Factors for Ball Bearings

$$F_e = X_i V F_r + Y_i F_a \qquad (11\text{–}9)$$

Table 11–1

| | | $F_a/(VF_r) \le e$ | | $F_a/(VF_r) > e$ | |
|---|---|---|---|---|---|
| $F_a/C_0$ | $e$ | $X_1$ | $Y_1$ | $X_2$ | $Y_2$ |
| 0.014* | 0.19 | 1.00 | 0 | 0.56 | 2.30 |
| 0.021 | 0.21 | 1.00 | 0 | 0.56 | 2.15 |
| 0.028 | 0.22 | 1.00 | 0 | 0.56 | 1.99 |
| 0.042 | 0.24 | 1.00 | 0 | 0.56 | 1.85 |
| 0.056 | 0.26 | 1.00 | 0 | 0.56 | 1.71 |
| 0.070 | 0.27 | 1.00 | 0 | 0.56 | 1.63 |
| 0.084 | 0.28 | 1.00 | 0 | 0.56 | 1.55 |
| 0.110 | 0.30 | 1.00 | 0 | 0.56 | 1.45 |
| 0.17 | 0.34 | 1.00 | 0 | 0.56 | 1.31 |
| 0.28 | 0.38 | 1.00 | 0 | 0.56 | 1.15 |
| 0.42 | 0.42 | 1.00 | 0 | 0.56 | 1.04 |
| 0.56 | 0.44 | 1.00 | 0 | 0.56 | 1.00 |

- ***X* and *Y* are functions of *e*, which is a function of $F_a/C_0$.**
- **$C_0$ is the *basic static load rating*, which is tabulated in the catalog.**

# Example 2

An SKF 6210 angular-contact ball bearing has an axial load $F_a$ of 400 lbf and a radial load $F_r$ of 500 lbf applied with the outer ring stationary. The basic static load rating $C_0$ is 4450 lbf and the basic load rating $C_{10}$ is 7900 lbf. Estimate the $\mathcal{L}_{10}$ life at a speed of 720 rev/min.

## Solution

$V = 1$ and $F_a/C_0 = 400/4450 = 0.090$. Interpolate for $e$ in Table 11–1:

| $F_a/C_0$ | $e$ | |
|---|---|---|
| 0.084 | 0.28 | |
| 0.090 | $e$ | from which $e = 0.285$ |
| 0.110 | 0.30 | |

# Example 2 (continued)

$F_a/(VF_r) = 400/[(1)500] = 0.8 > 0.285$. Thus, interpolate for $Y_2$:

| $F_a/C_0$ | $Y_2$ | |
|---|---|---|
| 0.084 | 1.55 | |
| 0.090 | $Y_2$ | from which $Y_2 = 1.527$ |
| 0.110 | 1.45 | |

From Eq. (11–12),

$$F_e = X_2VF_r + Y_2F_a = 0.56(1)500 + 1.527(400) = 890.8 \text{ lbf}$$

With $\mathcal{L}_D = \mathcal{L}_{10}$ and $F_D = F_e$, solving Eq. (11–3) for $\mathcal{L}_{10}$ gives

$$\mathcal{L}_{10} = \frac{60\mathcal{L}_R n_R}{60 n_D}\left(\frac{C_{10}}{F_e}\right)^a = \frac{10^6}{60(720)}\left(\frac{7900}{890.8}\right)^3 = 16\,150 \text{ h}$$

Answer

# Bearing Life Recommendations (Table 11–4)

| Type of Application | Life, kh |
|---|---|
| Instruments and apparatus for infrequent use | Up to 0.5 |
| Aircraft engines | 0.5–2 |
| Machines for short or intermittent operation where service interruption is of minor importance | 4–8 |
| Machines for intermittent service where reliable operation is of great importance | 8–14 |
| Machines for 8-h service that are not always fully utilized | 14–20 |
| Machines for 8-h service that are fully utilized | 20–30 |
| Machines for continuous 24-h service | 50–60 |
| Machines for continuous 24-h service where reliability is of extreme importance | 100–200 |

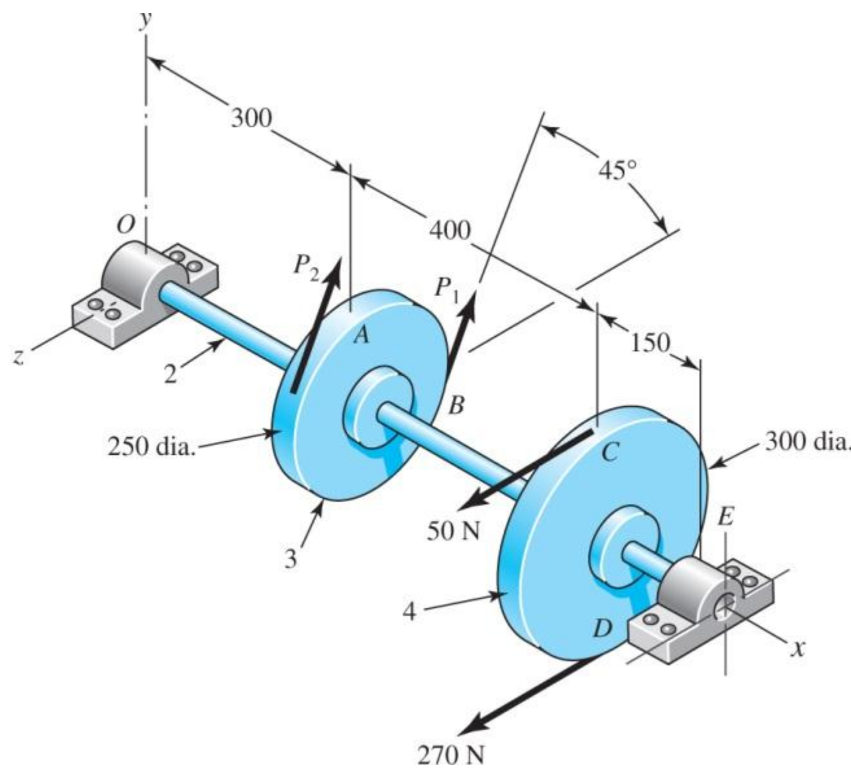
# Recommended Load Application Factors (Table 11–5)

| Type of Application | Load Factor |
|---|---|
| Precision gearing | 1.0–1.1 |
| Commercial gearing | 1.1–1.3 |
| Applications with poor bearing seals | 1.2 |
| Machinery with no impact | 1.0–1.2 |
| Machinery with light impact | 1.2–1.5 |
| Machinery with moderate impact | 1.5–3.0 |

# Assignment 2 - Problem 1

The shaft shown here rotates at 1500 rev/min. The bearings are to have 60kh at a combined reliability of 90%. The belt in the loose side of pulley A is 15 percent of the tension on the tight side. Select deep groove bearings for use at O and E.
Use application factor of unity.

Problem 11–33
Dimensions in millimeters.



# Assignment 2 - Problem 2

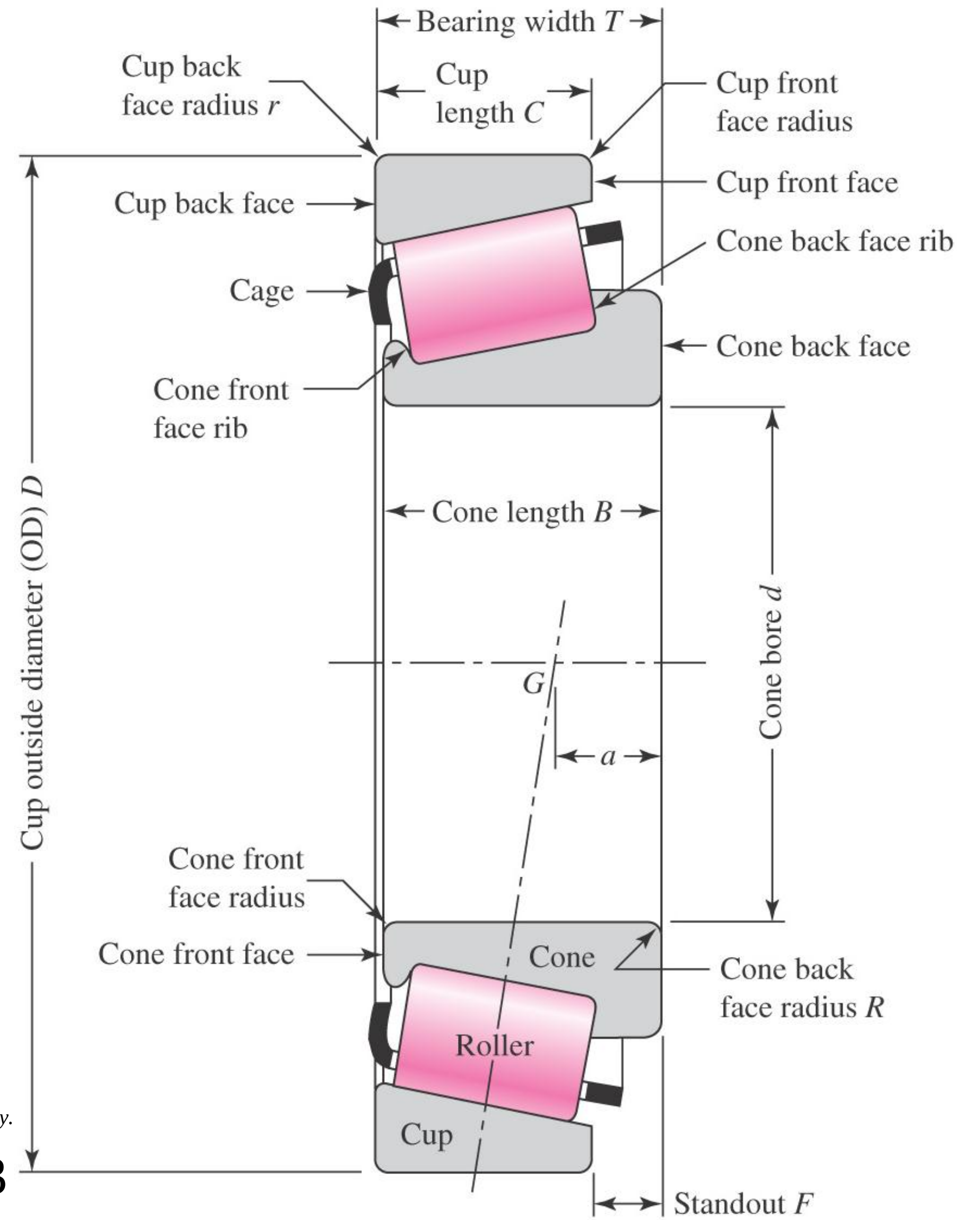
An 02-Series single-row deep groove ball bearing rotating at 400 rev/min is to be selected for the following applications:

Radial Load = 8 kN
Axial Load = 2 kN
Design Life = 10 kh
Desired Reliability = 90%

Specify the smallest bore size that can satisfy the above conditions.

# Tapered Roller Bearings

- Two separable parts
  - Cone assembly
    - Cone (inner ring)
    - Rollers
    - Cage
  - Cup (outer ring)
- Rollers are tapered so virtual apex is on shaft centerline
- Taper allows for pure rolling of angled rollers
- Distance *a* locates the effective axial location for force analysis




Courtesy of The Timken company.

Fig. 11–13

# Tapered Roller Bearings

- Straight roller bearings can carry large radial loads, but no axial load.
- Ball bearings can carry moderate radial loads, and small axial loads.
- Tapered roller bearings rely on roller tipped at an angle to allow them to carry large radial and large axial loads.
- Tapered roller bearings were popularized by the Timken Company.

# Mounting Directions of Tapered Roller Bearings

- Mount pairs in opposite directions to counter the axial loads
- Can be mounted in *direct mounting* or *indirect mounting* configurations
- For the same effective spread $a_e$, direct mounting requires greater geometric spread $a_g$
- For the same geometric spread $a_g$, direct mounting provides smaller effect spread $a_e$

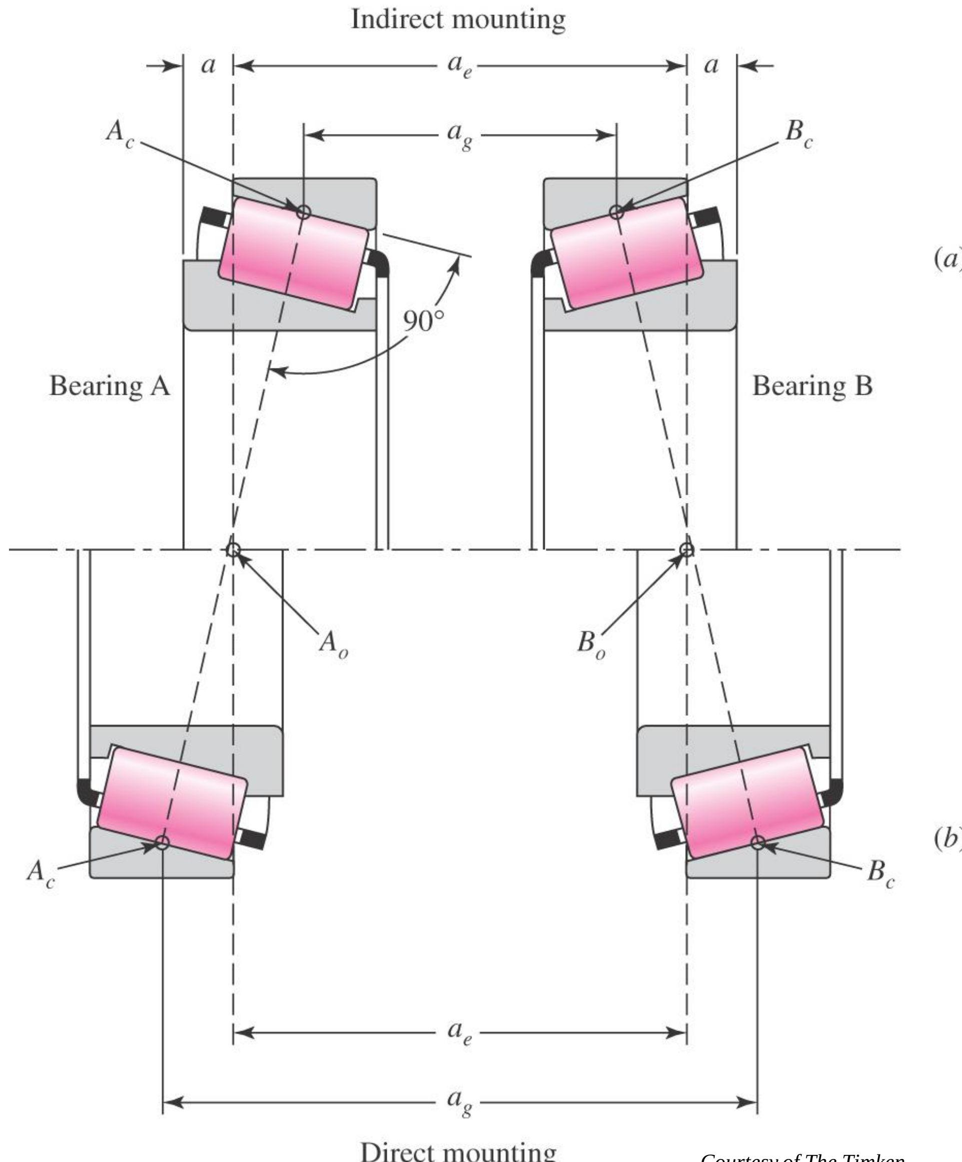



Fig. 11–14

*Courtesy of The Timken Company.*

# Induced Thrust Load

- A radial load induces a thrust reaction due to the roller angle.

$$F_i = \frac{0.47F_r}{K} \qquad (11\text{–}18)$$

- $K$ is ratio of radial load rating to thrust load rating
- $K$ is dependent on specific bearing, and is tabulated in catalog

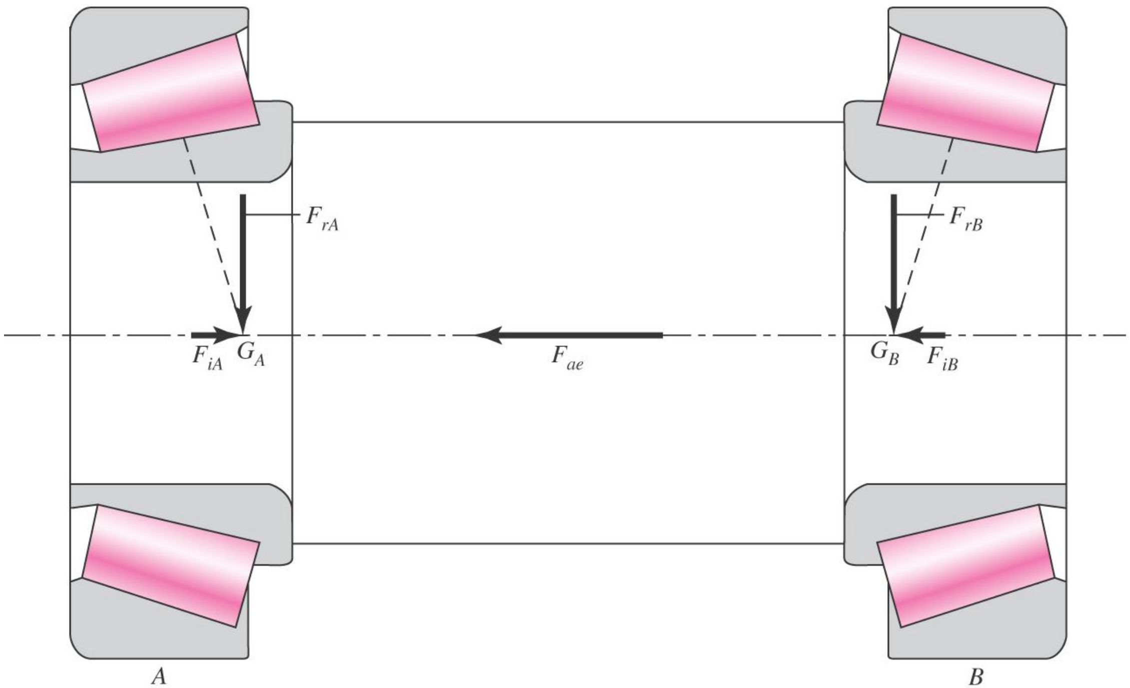



Fig. 11–16

# Equivalent Radial Load

- The equivalent radial load for tapered roller bearings is found in similar form as before,

$$F_e = XVF_r + YF_a$$

- Timken recommends $X = 0.4$ and $Y = K$

$$F_e = 0.4F_r + KF_a$$

- $F_a$ is the net axial load carried by the bearing, including induced thrust load from the other bearing and the external axial load carried by the bearing.
- Only one of the bearings will carry the external axial load

# Bearing Lubrication

- The purposes of bearing lubrication
  - To provide a film of lubricant between the sliding and rolling surfaces
  - To help distribute and dissipate heat
  - To prevent corrosion of the bearing surfaces
  - To protect the parts from the entrance of foreign matter

# Bearing Lubrication

- Either oil or grease may be used, with each having advantages in certain situations.

| Use Grease When | Use Oil When |
|---|---|
| 1. The temperature is not over 200°F. | 1. Speeds are high. |
| 2. The speed is low. | 2. Temperatures are high. |
| 3. Unusual protection is required from the entrance of foreign matter. | 3. Oiltight seals are readily employed. |
| 4. Simple bearing enclosures are desired. | 4. Bearing type is not suitable for grease lubrication. |
| 5. Operation for long periods without attention is desired. | 5. The bearing is lubricated from a central supply which is also used for other machine parts. |

# Some Common Bearing Mounting Configurations

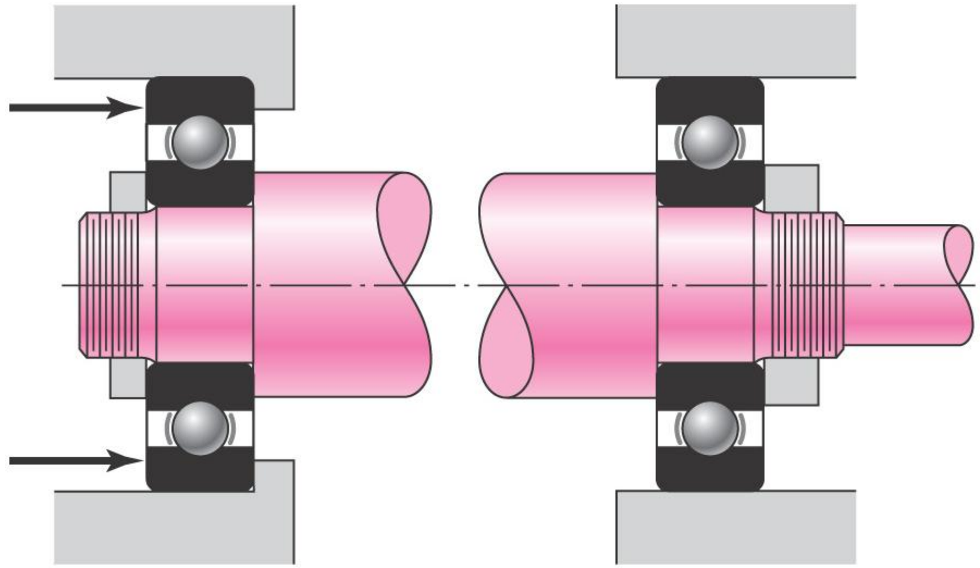


Fig. 11–20

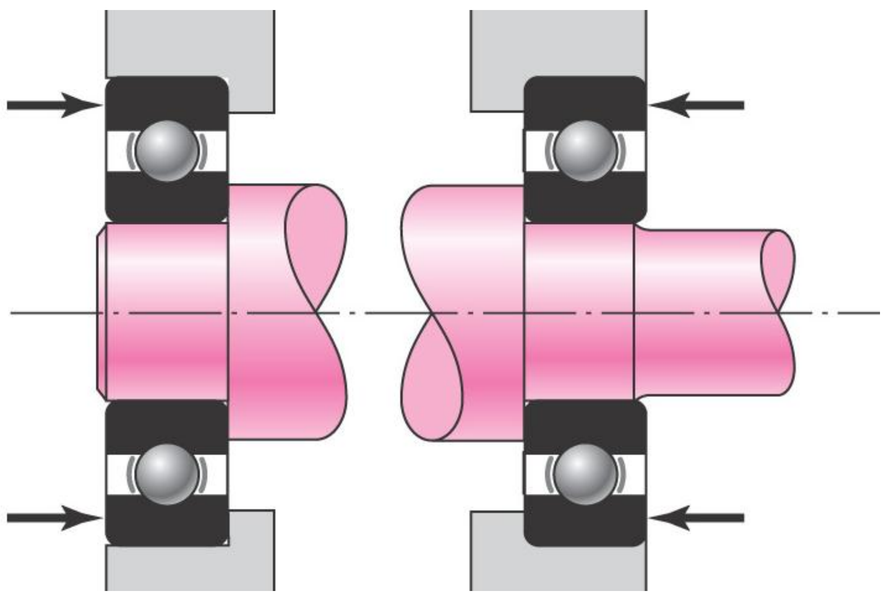
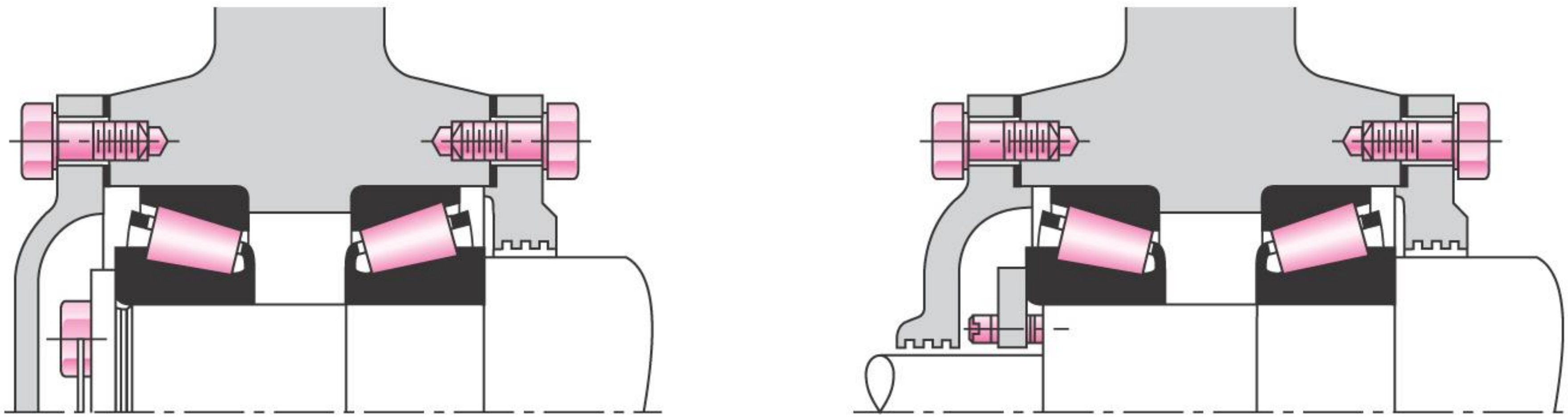


Fig. 11–21

# Some Common Bearing Mounting Configurations



(*a*) (*b*)

Fig. 11–22

*Courtesy of The Timken Company.*

# Some Common Bearing Mounting Configurations

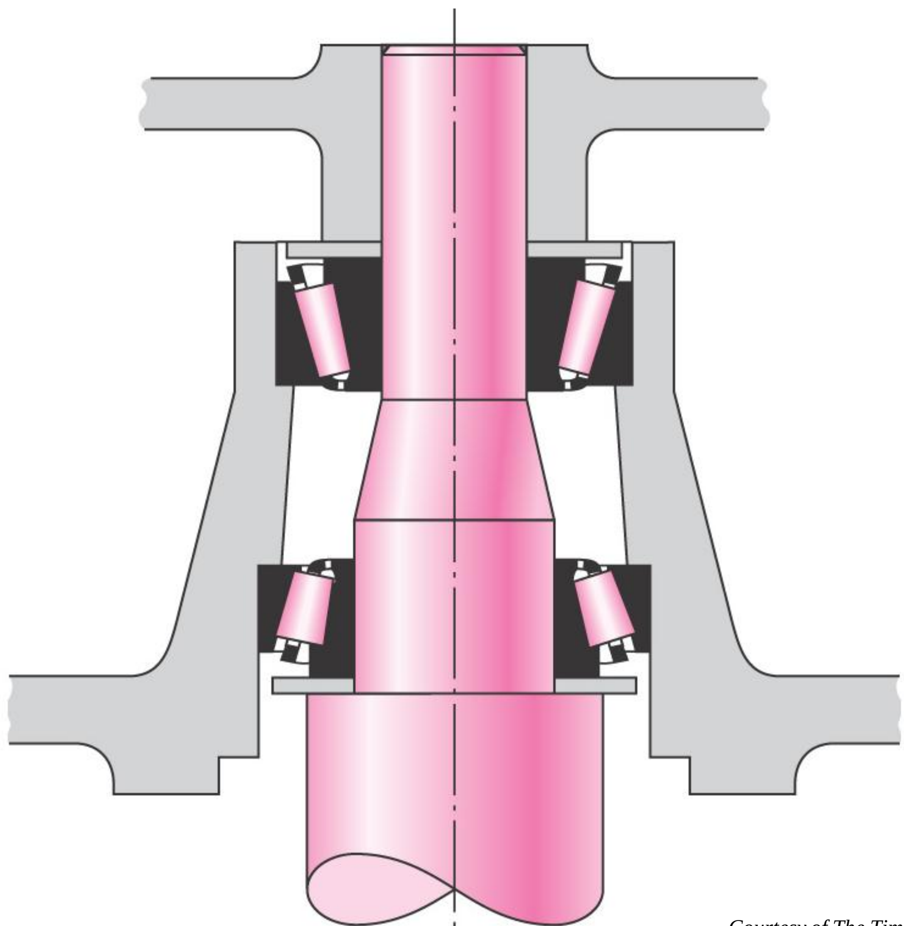

*Courtesy of The Timken Company.*

Fig. 11–23

# Preloading

- Object of preloading
  - Remove internal clearance
  - Increase fatigue life
  - Decrease shaft slope at bearing

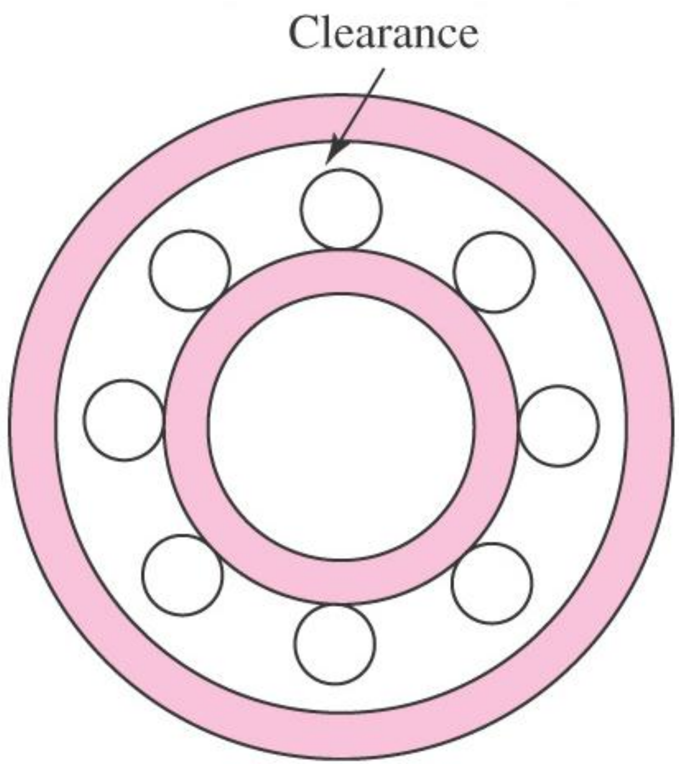



Fig. 11–25

# Enclosures

- Common shaft seals to exclude dirt and retain lubricant

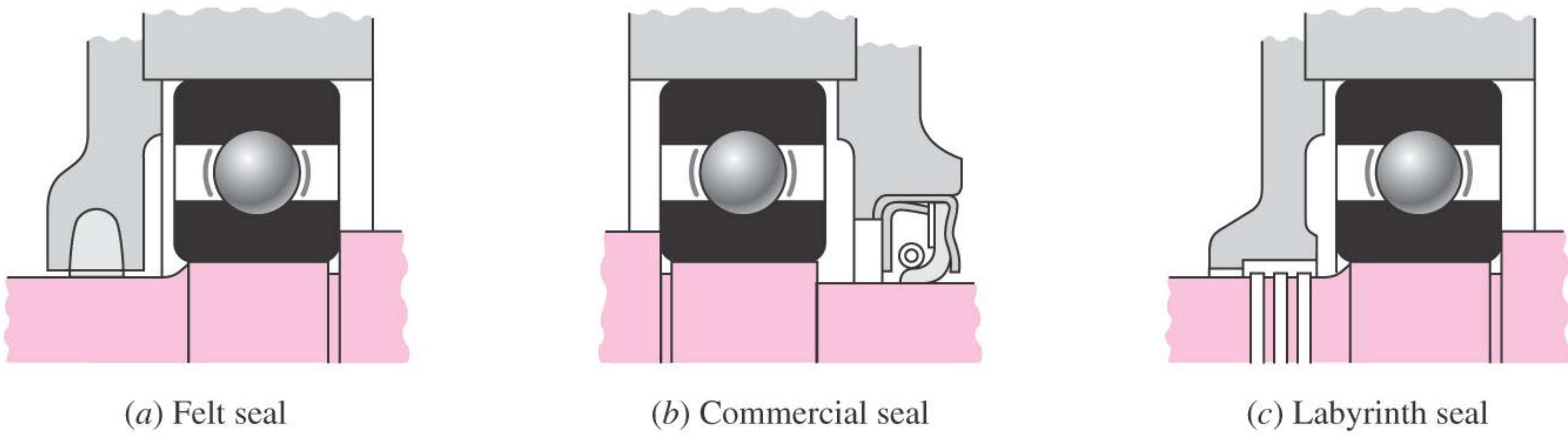



Fig. 11–26

*General Motors Corp. Used with permission, GM Media Archives.*