Bearings Types

- Plain
- Rolling Element
  - Ball
  - Roller
- Jewel
  - Precision
- Fluidic/Journal
  - Hydrodynamic
- Fluidic/Air
  - Hydrostatic
- Magnetic
- Other?

Drawing of Leonardo da Vinci (1452-1519)
Study of a balls in a bearing
Some Basic Bearings

- Ball thrust
- Needle
- Roller thrust
- Plain
- Spherical roller
- Tapered Roller
- Self-aligning
- Ball
Nomenclature of a Ball Bearing

Fig. 11–1
Types of Ball Bearings

(a) Deep groove
(b) Filling notch
(c) Angular contact
(d) Shielded
(e) Sealed
(f) External self-aligning
(g) Double row
(h) Self-aligning
(i) Thrust
(j) Self-aligning thrust

Fig. 11–2
For Even Greater Loads, Use Rollers

Types of Roller Bearings

(a) Straight Cylindrical
(b) Spherical Roller, thrust
(c) Tapered roller, thrust
(d) Needle
(e) Tapered roller
(f) Steep-angle tapered roller

Fig. 11–3
Some Common Bearing Mounting Configurations

Fig. 11–20

Fig. 11–21
Some Common Bearing Mounting Configurations

Fig. 11–22
Some Common Bearing Mounting Configurations

Fig. 11–23

Shigley’s Mechanical Engineering Design
Duplexing

- When maximum stiffness and resistance to shaft misalignment is desired, pairs of angular-contact bearings can be used in an arrangement called *duplexing*.
- Duplex bearings have rings ground with an offset.
- When pairs are clamped together, a preload is established.
Duplexing Arrangements

- Three common duplexing arrangements:
  (a) DF mounting – Face to face, good for radial and thrust loads from either direction
  (b) DB mounting – Back to back, same as DF, but with greater alignment stiffness
  (c) DT mounting – Tandem, good for thrust only in one direction

Fig. 11–24
Preferred Fits

- **Rotating ring** usually requires a **press** fit
- **Stationary ring** usually best with a **push** fit
- Allows stationary ring to creep, bringing new portions into the load-bearing zone to equalize wear
Preloading

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

Fig. 11–25
Alignment

- Catalogs will specify alignment requirements for specific bearings.
- Typical maximum ranges for shaft slopes at bearing locations:

<table>
<thead>
<tr>
<th>Bearing Type</th>
<th>Alignment Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tapered roller</td>
<td>0.0005–0.0012 rad</td>
</tr>
<tr>
<td>Cylindrical roller</td>
<td>0.0008–0.0012 rad</td>
</tr>
<tr>
<td>Deep-groove ball</td>
<td>0.001–0.003 rad</td>
</tr>
<tr>
<td>Spherical ball</td>
<td>0.026–0.052 rad</td>
</tr>
<tr>
<td>Self-align ball</td>
<td>0.026–0.052 rad</td>
</tr>
</tbody>
</table>
Enclosures

- Common shaft seals to exclude dirt and retain lubricant

(a) Felt seal  
(b) Commercial seal  
(c) Labyrinth seal

Fig. 11–26
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.
- **Rating Life**: Life required for 10% of sample to fail.
  - For a group of bearings
  - Also called *Minimum Life* or *L\(_{10}\)* Life
- **Median Life**: Average life 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, not an actual load.
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/ball
  - 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,

\[ FL^{1/a} = \text{constant} \quad (11-1) \]

- \( a = 3 \) for ball bearings
- \( a = 10/3 \) for roller bearing (cylindrical and tapered roller)
Load-Life Relationship

- Applying Eq. (11–1) to two load-life conditions,
  \[ F_1 L_1^{1/a} = F_2 L_2^{1/a} \]  
  \[ (11–2) \]

- Denoting condition 1 with \( R \) for catalog rating conditions, and condition 2 with \( D \) for the desired design conditions,
  \[ F_R L_R^{1/a} = F_D L_D^{1/a} \]  
  \[ (a) \]

- The units of \( L \) are revolutions. If life \( L \) is given in hours at a given speed \( n \) in rev/min, applying a conversion of 60 min/h,
  \[ L = 60 \ L n \]  
  \[ (b) \]

- Solving Eq. (a) for \( F_R \), which is just another notation for the catalog load rating,
  \[ C_{10} = F_R = F_D \left( \frac{L_D}{L_R} \right)^{1/a} = F_D \left( \frac{L_D n_D 60}{L_R n_R 60} \right)^{1/a} \]  
  \[ (11–3) \]
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 typically used to find a suitable bearing in the catalog.

- $a = 3$ for ball bearings
- $a = 10/3$ for roller bearings
Load-Life Relationship

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

\[ x_D = \frac{L_D}{L_R} \]
Example 1

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?

Solution

The rating life is \( L_{10} = L_R = \mathcal{L}_R n_R 60 = 10^6 \) revolutions. From Eq. (11–3),

\[
C_{10} = F_D \left( \frac{\mathcal{L}_D n_D 60}{\mathcal{L}_R n_R 60} \right)^{1/\alpha} = 400 \left[ \frac{5000(1725)60}{10^6} \right]^{1/3} = 3211 \text{ lbf} = 14.3 \text{ kN}
\]
Example 11–7

The second shaft on a parallel-shaft 25-hp foundry crane speed reducer contains a helical gear with a pitch diameter of 8.08 in. Helical gears transmit components of force in the tangential, radial, and axial directions (see Chap. 13). The components of the gear force transmitted to the second shaft are shown in Fig. 11–12, at point A. The bearing reactions at C and D, assuming simple-supports, are also shown. A ball bearing is to be selected for location C to accept the thrust, and a cylindrical roller bearing is to be utilized at location D. The life goal of the speed reducer is 10 kh, with

(a) Select the roller bearing for location D.
(b) Select the ball bearing (angular contact) for location C, assuming the inner ring rotates.
Example 11–7

Fig. 11–12
Example 11–7

**Solution**

The torque transmitted is \( T = 595(4.04) = 2404 \text{ lbf} \cdot \text{in}. \) The speed at the rated horsepower, given by Eq. (3–42), p. 116, is

\[
    n_D = \frac{63025H}{T} = \frac{63025(25)}{2404} = 655.4 \text{ rev/min}
\]

The radial load at \( D \) is \( \sqrt{106.6^2 + 297.5^2} = 316.0 \text{ lbf} \), and the radial load at \( C \) is \( \sqrt{356.6^2 + 297.5^2} = 464.4 \text{ lbf} \). The individual bearing reliabilities, if equal, must be at least \( \sqrt[4]{0.96} = 0.98985 \approx 0.99 \). The dimensionless design life for both bearings is

\[
    x_D = \frac{L_D}{L_{10}} = \frac{60S_Dn_D}{L_{10}} = \frac{60(10000)655.4}{10^6} = 393.2
\]

\[
    C_{10} = F_R = F_D \left( \frac{L_D}{L_R} \right)^{1/a}
\]

\[
    C_{10} = 464.4(393.2)^{1/3} = 3402. \text{ lbf}
\]  
For ball bearing @ \( C \)

\[
    C_{10} = 316(393.2)^{3/10} = 1897. \text{ lbf}
\]  
For roller bearing @ \( D \)
Combining Loads
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 $\frac{F_e}{VF_r}$ vs. $\frac{F_a}{VF_r}$ 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
Combined Radial and Thrust Loading

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

\[ F_e = X_i \frac{V F_r}{F_a} + Y_i F_a \quad (11-12) \]

where

- \( i = 1 \) when \( \frac{F_a}{V F_r} \leq e \)
- \( i = 2 \) when \( \frac{F_a}{V F_r} > e \)

- \( X \) and \( Y \) factors depend on geometry and construction of the specific bearing.

Fig. 11–6
Equivalent Radial Load Factors for Ball Bearings

\[ F_e = X_i VF_r + Y_i F_a \]  

(11–12)

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

<table>
<thead>
<tr>
<th>( F_a/C_0 )</th>
<th>( e )</th>
<th>( F_a/(VF_r) \leq e )</th>
<th>( F_a/(VF_r) &gt; e )</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>( X_1 )</td>
<td>( Y_1 )</td>
</tr>
<tr>
<td>0.014*</td>
<td>0.19</td>
<td>1.00</td>
<td>0</td>
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<tr>
<td>0.021</td>
<td>0.21</td>
<td>1.00</td>
<td>0</td>
</tr>
<tr>
<td>0.028</td>
<td>0.22</td>
<td>1.00</td>
<td>0</td>
</tr>
<tr>
<td>0.042</td>
<td>0.24</td>
<td>1.00</td>
<td>0</td>
</tr>
<tr>
<td>0.056</td>
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<td>1.00</td>
<td>0</td>
</tr>
<tr>
<td>0.070</td>
<td>0.27</td>
<td>1.00</td>
<td>0</td>
</tr>
<tr>
<td>0.084</td>
<td>0.28</td>
<td>1.00</td>
<td>0</td>
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<tr>
<td>0.110</td>
<td>0.30</td>
<td>1.00</td>
<td>0</td>
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<tr>
<td>0.17</td>
<td>0.34</td>
<td>1.00</td>
<td>0</td>
</tr>
<tr>
<td>0.28</td>
<td>0.38</td>
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</tr>
<tr>
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<td>0.42</td>
<td>1.00</td>
<td>0</td>
</tr>
<tr>
<td>0.56</td>
<td>0.44</td>
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<td>0</td>
</tr>
</tbody>
</table>
Equivalent Radial Load Factors for Ball Bearings

\[ F_e = X_i V F_r + Y_i F_a \]  \hspace{1cm} (11–9)

Table 11–1

<table>
<thead>
<tr>
<th>( \frac{F_a}{C_0} )</th>
<th>( e )</th>
<th>( \frac{F_a}{(VF_r)} \leq e )</th>
<th>( \frac{F_a}{(VF_r)} &gt; e )</th>
</tr>
</thead>
<tbody>
<tr>
<td>( F_a/C_0 )</td>
<td>( e )</td>
<td>( X_1 )</td>
<td>( Y_1 )</td>
</tr>
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<td>1.00</td>
<td>0</td>
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<tr>
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<td>0.21</td>
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<tr>
<td>0.56</td>
<td>0.44</td>
<td>1.00</td>
<td>0</td>
</tr>
</tbody>
</table>

- \( X \) 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.
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.
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

Fig. 11–13
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
### Typical Catalog Data (Fig. 11–15)

<table>
<thead>
<tr>
<th>bore</th>
<th>outside diameter</th>
<th>width</th>
<th>rating at 500 rpm for 3000 hours L₁₀</th>
<th>one-row radial load</th>
<th>thrust load</th>
<th>K</th>
<th>a²</th>
<th>eff. load center</th>
<th>part numbers</th>
<th>cone max shaft fillet radius</th>
<th>cup max housing fillet radius</th>
<th>backing shoulder diameters</th>
<th>cup max housing fillet radius</th>
<th>backing shoulder diameters</th>
</tr>
</thead>
<tbody>
<tr>
<td>d</td>
<td>D</td>
<td>T</td>
<td>N lbf</td>
<td>N lbf</td>
<td></td>
<td></td>
<td></td>
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<td></td>
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<td>0.5906</td>
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<td>1.0</td>
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<td>0.5906</td>
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<td>1.14</td>
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<td>30.5</td>
<td>29.0</td>
<td>1.0</td>
<td>13.000</td>
<td>46.0</td>
</tr>
</tbody>
</table>

![SINGLE-ROW STRAIGHT BORE](image-url)
**Induced Thrust Load**

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

\[
F_i = \frac{0.47F_r}{K}
\]  

(11–18)

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

![Fig. 11–16](image-url)
Equivalent Radial Load

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

\[ F_e = X V F_r + Y F_a \]

Timken recommends \( X = 0.4 \) and \( Y = K \)

\[ F_e = 0.4F_r + K F_a \]

\( F_a \) 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.