20. Ball and Roller Bearings

Objectives
• Recognize the different types of rolling contact bearings and applications where they may be suitable.
• Calculate equivalent load on Conrad-type ball bearings and relationship of this load to expected lifetime of the bearing.
• Factor in effect of thrust loading on the equivalent radial load in calculating the life of a bearing.
• Understand principles of roller bearings, tapered roller bearings, thrust bearings, and needle bearings.
• Select appropriate type of bearings and their sizes for the design being undertaken.

Introduction to Bearings

- Ball Bearings
  – Radial and Thrust loads
- Roller Bearings
  – Radial and Thrust loads
- Needle Bearings
  – Only radial loads

Ball Bearings

- Terminology
  – Outer ring, which contains the outer raceway
  – Inner ring, which contains the inner raceway
  – Complement of balls
  – Two-piece separator (also called cage or retainer)

Ball Bearing assembly

Ball Bearings

Single-row Ball Bearing Terminology

Ball Bearings
Ball Bearing nomenclature

- Width
- Corner radius
- Outside diameter
- Bore

Ball Bearings

See the difference in the curvature of the ball and the race.

Life of Antifriction Bearings

- They are subjected to repeated stress cycles and are likely to fail by fatigue.
- \( B_{10} \) or \( L_{10} \) life is defined as the number of hours that 90% of the bearings tested will exceed.
- The probability of failure is 10% at the \( L_{10} \) life.
- Average life is the number of hours that 50% of the bearings exceed.

Life of Antifriction Bearings

Relative life

Fig. 20.1 Typical bearing failure curve

- The expected life of the bearing is
- \( L = T \times n \times 60 \)
- \( T = \) Hours of operation
- \( n = \) revolutions per minute
Life of Bearings

- The life of the bearing decreases with an increase in the load.
  \[
  L_d = \left( \frac{C_d}{P_d} \right)^k
  \]
  \(k = 3\) for ball bearings
  \(k = 10/3\) for roller bearings
- \(L_d\) = desired life
- \(L_c\) = life from the table (manufacturers catalog)
- \(C_d\) = dynamic rating from manufacturer
- \(P_d\) = design load

\(k = 3\) for ball bearings
\(k = 10/3\) for roller bearings

The equations can be rewritten as depending upon the variable to be calculated

\[
C_d = P_d \left( \frac{L_d}{L_c} \right)^{1/k}
\]

\[
L_d = L_c \left( \frac{C_d}{P_d} \right)^k
\]

Example Problem 20-1: Life Expectancy of Ball Bearings

- Table 12-1 lists the basic dynamic load for bearing number 6208 as 5050 pounds.
- What would the expected life be for the bearing if it were subjected to a radial load of 2400 pounds?
- If the shaft turns at 1750 rpm, how many hours would bearing last based on \(L_{10}\) design life?

\[
T = \frac{9.3 \times 10^6 \text{ rev}}{1750 \text{ rev/min}} \times \frac{1 \text{ hr}}{60 \text{ min}} = 88 \text{ hrs}
\]

Example Problem 20-2: Life Expectancy of Ball Bearings

- For conditions in the previous example problem, if an \(L_{10}\) life of 200 hours is needed, select a bearing from Table 20-1 to meet criterion.
Example Problem 20-2: Life Expectancy of Ball Bearings

- Bearing number 6211 has a dynamic load rating of 7500 pounds.
- This bearing would be acceptable.
- If bearing bore is too large, a heavier series could be substituted.

\[ L = \frac{500 \text{ rpm} \times 5000 \text{ hr}}{10^6 \text{ hr}} = 2.5 \times 10^3 \text{ revolutions} \]

\[ C_L = R \left( \frac{T}{C_r} \right)^{\frac{1}{3}} \]

\[ C_J = 2400 \text{ lb} \left( \frac{2}{3} \right)^{\frac{1}{3}} \]

**Example Problem 20-3: Ball Bearing Selection**

- To select bearing, assume thrust factor of \( Y = 1.6 \) (average of table):
  \[ P = 0.56 R + Y F_t \]  
  \( P = 0.56 \times 1200 \text{ lb} + 1.6 \times 500 \text{ lb} \)
  \[ P = 1472 \text{ lb} \]

- Find life:
  \[ L = \frac{1500 \text{ rpm} \times 5000 \text{ hr} \times 60 \text{ min}}{10^6 \text{ hr}} = 450 \times 10^6 \text{ revolutions} \]

**Equivalent combined radial load**

- For combined radial and thrust loads
  \[ P = V \times R + Y F_t \]
- \( R \) = actual radial load (lb)
- \( F_t \) = actual thrust load (lb)
- \( X \) = radial factor (usually 0.56)
- \( V \) = 1.0 for inner race rotating
  = 1.2 for outer race rotating
- Thrust factor \( Y \) is obtained from Table 20.2

**Example Problem 20-3: Ball Bearing Selection**

- Select a bearing from Table 20-1 to meet following criteria:
  - \( R = 1200 \text{ pounds} \)
  - \( F_t = 500 \text{ pounds} \)
  - \( n = 1500 \text{ rpm} \) - shaft rotates
  - \( L_{10} = 5000 \text{ hours} \)

- Adjust rating for life:
  \[ C_L = P \left( \frac{L}{C} \right)^{\frac{1}{3}} \]

\[ C_J = 1472 \text{ lb} \left( \frac{450}{9700} \right)^{\frac{1}{3}} \]

\[ C_l = 11280 \text{ lb} \]

- From Table 20-1:
  Bearing number 6215 C \( d = 11400 \)
  \( C_r = 9700 \)

- Verify assumption for \( Y \):
  \[ \frac{F_t}{C_r} = \frac{500}{950} = 0.515 \]

- Interpolate to find factor:
  \[ Y = \frac{(0.56 - 0.515) + 1.71}{0.56 - 0.515 + (0.99 - 1.71)} = 1.74 \]
Example Problem 20-3: Ball Bearing Selection (cont'd.)

- Verify:
  \[ P = 56R + Y F_L \]
  \[ P = 56(1200) + 1.76(500) \]
  \[ P = 1550 \text{ lb} \]

  \[ C_L = \frac{500}{d}^{1/3} \]
  \[ C_L = 1550 \text{ lb} \]
  \[ C_L = 11,875 \text{ lb} \]

  - This is not acceptable.
  - Try next larger size bearing. Try bearing number 6216.

  \[ \frac{P}{C_L} = \frac{500}{10,500} = 0.048 \]

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Example Problem 20-4: Life Expectancy of Ball Bearings

- Estimate life for a 6200 series bearing that has an inside diameter of 30 mm on a stationary shaft where outside race rotates.

  - There is a radial load of 1,000 pounds and a thrust load of 300 pounds.

- Find thrust factor as bearing is known:

  \[ F_T = \text{from Table 20-2: (20-7)} \]

  \[ \frac{F}{C_T} = \frac{300}{106.28} = 0.119 \]

  \[ F_T = 1.19 \]

  \[ P = F X R + Y F_L \]
  \[ P = 1.2(1560) + 1.41(300) \]
  \[ P = 1095 \text{ lb} \]

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Example Problem 20-4: Life Expectancy of Ball Bearings (cont'd.)

- Interpolate from Table 20-2:

  \[ Y = \frac{17 - 129}{17 - 11} \]
  \[ Y = 1.41 \]

  \[ P = F X R + Y F_L \]
  \[ P = 1095 \text{ lb} \]

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Static strength capacity

- It is defined as the maximum load that can be applied without bearing damage when neither race is moving.
- The permanent deformation does not exceed 0.0001 in. per in. of diameter of the rolling element.

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Some useful facts

- Load carrying capacity is roughly proportional to the diameter of the rolling elements.
- Roller bearings have much greater load-carrying capacity than ball bearings.
- Bearings are subjected to repeated stress cycles with maximum compressive stress of approximately 150,000 psi. This causes fatigue failure.
- Load of a ball bearing is doubled, fatigue life is reduced by a factor of 8.

Some useful facts

- If the load of roller bearing is doubled, the fatigue life is reduced by a factor of 10.
- Deformation is the cause of rolling resistance. Hence, harden all surfaces to about Rc 58.
- Wheel bearing of an automobile is designed for L10 life of 100,000 miles, 10% of the bearing may fail before 100,000 miles are reached.
- For properly loaded bearings force required to pull a load of 1 ton:
  - 1.6 lb for ball bearing
  - 3.0 lb for roller bearing

Type of Rolling Contact Bearings

Maximum capacity Ball Bearings

- Maximum number of balls can be inserted
- Greater radial load carrying capacity

Ball Bearing with shields

- Maximum number of balls can be inserted
- Greater radial load carrying capacity
Angular contact Bearings

- Balls are inserted by thermally expanding the outer ring.
- Can take greater thrust load than the maximum capacity ball bearing from only one direction.

Double row angular contact Bearings

- Takes thrust in both directions.

2-piece inner-ring Ball Bearings

- Large number of balls – higher load-carrying capacity
- Deep ball raceway - Higher thrust load capacity
- Thrust loads from both directions

Advantages
- The maximum complement of balls makes for higher load carrying capacity.
- The very deep ball raceway shoulder makes for high thrust-load capacity.
- Thrust loads can be handled in both directions.
Roller Bearings

- Because of the line contact, they can take greater loads
- They also have more rolling resistance (0.0015 for roller and 0.0008 for ball bearing)
- Types of roller bearings
  - Cylindrical
  - Tapered
  - Spherical

Tapered Roller Bearings

Needle Bearings

- Use large number of small diameter rollers.
- There is no space between rollers (needles). No cage required.
- Drawn cup type is very thin and compact because of the design. Used for lighter loads.

Needle Bearings

- Some types rollers contact directly the shaft (Fig. 4.21) without any inner race. The shaft should be hardened (Rc 58) for proper operation (Fig. 4.22).
- They have large load-capacity/size ratio. It requires very little radial space. One application is the roller type cam follower (Fig. 4.23).
- They have higher coefficient of friction. Typical value is 0.0025 compared to 0.0015 for roller bearings. They have lower max speed limit.
Lubrication of Antifriction Bearings

- Provide a lubricating film between the rolling elements and the separator at the areas of contact
- Dissipate heat caused by deformation of the rolling elements and raceways as well as heat caused by the sliding contact between the rolling elements and the separator
- Prevent corrosion of bearing components
- Aid in preventing dirt and other contamination from entering the critical areas of the bearing where sliding or rolling contact takes place

Advantages

- **Journal bearings or Plain surface bearings**
  - Requires little radial space
  - Run quietly
  - Have a longer life span
  - Are less sensitive to contamination
  - Are less costly
  - Can better sustain shock loads
  - Requires less precise mounting
  - Are available in split halves
Advantages

- **Antifriction bearings**
  - Have less friction
  - Requires no wearing-in period
  - Requires less axial space
  - Can run at higher speeds
  - Have fewer maintenance problems
  - Have fewer lubrication difficulties
  - Allow for considerable misalignment
  - Are easy to replace
  - Allow for greater precision
  - Readily available in large varieties

Summary

- Antifriction bearings operate with rolling contact.
- There are a number of ways in which the balls are loaded into a ball bearing.
- Roller bearings take larger loads than ball bearings because of the line contact.
- Needle bearings requires little space.
- Tapered roller bearings can take axial as well as radial loads.

Summary

- Bearings fail because of fatigue.
- Load capacity of a bearing can be calculated using the supplied formulae.
- Lubrication in bearings serve a number of functions such as dissipating heat, prevent corrosion and forming a film between rolling element and the raceway.
- Pre-mounted bearings are complete bearing assemblies.