Chapter 11

Rolling-Contact Bearings
11-1. bearing Types

Function:
• Carry load in one or several directions while allowing frictionless motion in other directions

I. Ball Bearings
II. Roller Bearings
III. Journal Bearing
Rolling Bearing types

- Ball bearing
- Tapered roller bearing
- Thrust bearing
- Needle roller bearing
Load is transferred through elements in rolling contact rather than sliding contact.
Types of ball bearings

(a) Deep groove
(b) Filling notch
(c) Angular contact
(d) Shielded
(e) Sealed

(f) External
(g) Double row
(h) Self-aligning
(i) Thrust
(j) Self-aligning thrust
Types of Roller Bearings

a. Straight roller
b. Spherical roller, thrust
c. Tapered roller, thrust
d. Needle
e. Tapered roller
f. Steep-angle tapered roller
Ball vs. Roller Bearings

- Roller bearings are stiffer and have a higher load capacity that comparably sized ball bearings. This is due to the type of contact, line contact for rollers vs. point contact for balls.

- Ball bearings have a lower friction. This also is a function of contact type.

- Ball bearings can often be operated at higher speeds.

- Most ball bearings can take modest axial load for “free”. Only tapered rollers can take axial loads.

- Ball bearings are less expensive than roller bearings.
• Straight roller bearings will carry greater radial load due to increased contact area. However, they require nearly perfect raceways and rollers to maintain alignment.

• Spherical-roller thrust bearings are useful where heavy loads and misalignment occur.

• Needle bearings very useful when radial space is limited.

• Tapered roller bearings combine the advantages of ball and straight roller bearings, since they can take radial and/or thrust load and have high load-carrying capacity.
Radial bearings

Tapered roller bearings

Single direction thrust bearings
Ex: Types of Roller Bearings

- Tapered Roller Bearing
- Spherical Roller Bearings
- Needle Bearings
- Double Deep Groove
- Thrust Bearings
• Angular contact ball bearing
  – Increased thrust load due to increase in lateral contact area between ball and race

Model 70000C (α = 15°)
Model 70000AC (α = 25°)
Model 70000B (α = 40°)
Design Considerations

Bearings are selected from catalogs, before referring to catalogs you should know the followings:

- Bearing load – radial, thrust (axial) or both

- Bearing life and reliability
- Bearing speed (rpm)
- Space limitation
- Accuracy
11-2 Bearing Life

Common measures of bearing life are:

• No. of revs of inner ring (with outer ring stationery) until first evidence of fatigue.

• No. of hours of use at a standard speed until first evidence of fatigue. The ANTI-Friction Bearing Manufacturer’s Association (AFBMA) sanctions the term rating life and defines it as the number of revs (or hours at constant speed) that 90% of a group of bearings will achieve before fatigue failure occurs. -Synonymous with minimum life, $L_{10}$ life and $B_{10}$ life

• Median life is the 50$^{th}$ percentile life of a group of bearings. 
  Median life = 4 to 5 times $L_{10}$ life

-Life – number of revolutions (or hours of operation at design speed) of the inner race that a certain percentage of the bearings will survive at a known load.
SKF rates bearings for 1 million revs, so that $L_{10}\text{life}$ is:

$$60L_R n_R = 10^6 \text{revs.}$$

In Catalog the $60L_R n_R$ product produces a familiar number.

Timken uses $90(10^6)$ revs.

$L_{10}\text{ Life}$ - 10% of the bearings tested fail before a rated number of revolutions of the inner race at the rated load.
A regression equation of form

\[ FL^{1/a} = \text{const.} \]

\(a = 3\) for ball bearings
\(a = 10/3\) for roller rearings (cylindrical and tapered roller)

Reliability
Typical life-failure criterion at different loads (Reliability = 0.9)
A manufacturer may choose a rated cycle value of $10^6$ revs as the rated life corresponding to a basic load rating. This is called the catalog load rating, $C_{10}$, to correspond to the 10th percentile rating life for the particular bearing. Then

$$F_1 L_1^{1/a} = F_2 L_2^{1/a}$$

OR

units of $L$ are revs

$$C_{10} L_{10}^{1/a} = F L^{1/a}$$

$C_{10}$ is the catalog basic dynamic load rating corresponding to $L_R$ hours of life at the speed of $n_R$ rpm.
\[ C_{10} \left( \frac{L_{D}n_{D}60}{L_{R}n_{R}60} \right)^{1/a} = F_{D} \left( \frac{L_{D}n_{D}60}{L_{R}n_{R}60} \right)^{1/a} \]

catalog rating

rating life in hours

rating speed

desired speed, \( r/\text{min} \)

desired life, hours

desired radial load, lb or kN

Solving for \( C_{10} \) gives

\[ C_{10} = F_{D} \left( \frac{L_{D}n_{D}60}{L_{R}n_{R}60} \right)^{1/a} \]

\( C_{10} = F_{R} \)
Ex: Select a deep groove ball bearing for a desired life of 5000 hours at 1725 rpm with 90% reliability. The bearing radial load is 400 lb.

\[
C_{10} = F_D \left( \frac{L_D n_D 60}{L_R n_R 60} \right)^{1/a} = 400 \left( \frac{5000(1725)60}{10^6} \right)^{1/3} = 3211 \text{ lb} = 14.3 \text{ kN}
\]

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<th>Bore, (\text{mm})</th>
<th>OD, (\text{mm})</th>
<th>Width, (\text{mm})</th>
<th>Fillet Radius, (\text{mm})</th>
<th>Shoulder Diameter, mm</th>
<th>Load Ratings, kN</th>
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11-4 Bearing Survival: The Reliability-Life Trade-Off

- Constant Load and different Reliability than the rated

The distribution of bearing failure can be best approximated by *two and three parameter Weibull distribution*

life measured is expressed in dimensionless form

\[
x = \frac{L}{L_{10}}
\]

then the reliability, \( R \) is

\[
R = \exp\left[ -\left( \frac{x-x_0}{\theta-x_0} \right)^b \right]
\]

where \( x_0 \) is the guaranteed or minimum life, \( \theta \) is a characteristic parameter corresponding to the 63.2121 percentile, \( b \) is a skewness shape parameter
At constant load, the life measure distribution is as shown in this graph. Such a distribution is right skewed.

\[ R = \exp \left( -\frac{x - x_0}{\theta - x_0} \right)^b \]
11-5 Load-Life-Reliability Trade-Off

\[ F_B x_B^{1/a} = F_D x_D^{1/a} \]

\[ F_B = F_D \left( \frac{x_D}{x_B} \right)^{1/a} \]

\[ R_D = \exp \left[ -\left( \frac{x_B - x_0}{\theta - x_0} \right)^b \right] \]

\[ x_B = x_0 + (\theta - x_0) \left( \ln \frac{1}{R_D} \right)^{1/b} \]
\[ F_B = F_D \left( \frac{x_D}{x_B} \right)^{1/a} = F_D \left[ \frac{x_D}{x_0 + (\theta - x_0)(\ln 1/R_D)^{1/b}} \right]^{1/a} \]

\[ F_B = C_{10} \]

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

- Equation can be written

\[ C_{10} = F_D \left[ \frac{x_D}{x_0 + (\theta - x_0)(1 - R_D)^{1/b}} \right]^{1/a} \Rightarrow R \geq 0.90 \]
Ex: Select a deep groove ball bearing for a desired life of 5000 hours at 1725 rpm with 99% reliability. The bearing radial load is 400 lb.

For 90% reliability \( C_{10} = 14.3 \text{ kN} \)

30 mm Bore deep groove bearing. The Weibull parameters are \( b=1.483, x_0=0.02 \) and \( \theta-x_0=4.439 \)

Use 99% reliability, \( R = .99 \)

\[
F_R = F_D \left\{ \frac{(L_D n_D/L_R n_R)}{0.02 + 4.439[\ln (1/R)]^{1/1.483}} \right\}^{1/a} = 23.7 \text{ kN}
\]

Select a 35 mm bearing instead of 30 mm for 90% reliability.
Shafts generally have two bearings. Often these bearings are different. If the bearing reliability of the shaft with its pair of bearings is to be $R$, then $R$ is related to the individual bearing reliabilities $R_A$ and $R_B$ by

$$R = R_A R_B$$

Ex: If a shaft is assembled with 4 bearings, each having a reliability of 90%, then the reliability of the system is $(0.9)^4 = 0.65 = 65\%$. This points out the need to select bearings with higher than 90% reliability.