Rolling Contact Bearings

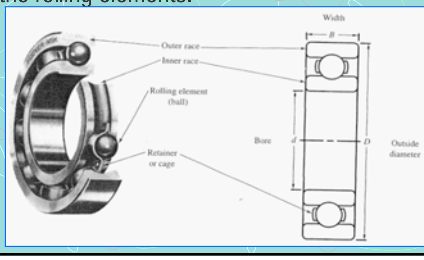
Chapter 14

Rolling Contact Bearings

- The purpose of a bearing is to support a load while permitting relative motion between two elements of a machine.
- The term rolling contact bearings refers to the wide variety of bearings that use spherical balls or some other type of roller between the stationary and the moving elements.
- The most common type of bearing supports a rotating shaft, resisting purely radial loads or a combination of radial and axial (thrust) loads.

Rolling Contact Bearings con't

- The components of a typical rolling contact bearing are the inner race, the outer race, and the rolling elements.



Types of Rolling Contact Bearings

- Radial loads act toward the center of the bearing along a radius.
- Such loads are typical of those created by power transmission elements on shafts such as spur gears, V-belt drives, and chain drives.
- Thrust loads are those that act parallel to the axis of the shaft.

Types of Rolling Contact Bearings

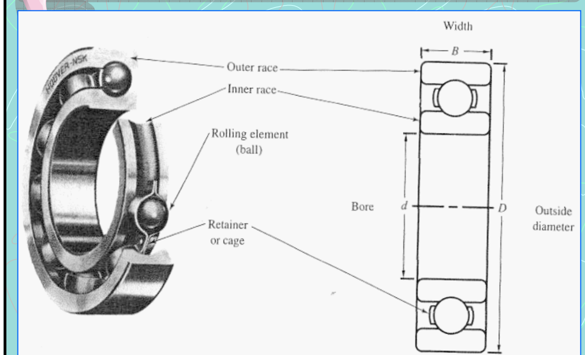
- The axial components of the forces on helical gears, worms and wormgears, and bevel gears are thrust loads.
- Misalignment refers to the angular deviation of the axis of the shaft at the bearing from the true axis of the bearing itself.

TABLE 14–1 Comparison of bearing types

Bearing type	Radial load capacity	Thrust load capacity	Misalignment capability
Single-row, deep-groove ball	Good	Fair	Fair
Double-row, deep-groove ball	Excellent	Good	Fair
Angular contact	Good	Excellent	Poor
Cylindrical roller	Excellent	Poor	Fair
Needle	Excellent	Poor	Poor
Spherical roller	Excellent	Fair/good	Excellent
Tapered roller	Excellent	Excellent	Poor

Single-Row, Deep Groove Ball Bearing

- The single-row, deep groove ball bearing is what most people think of when the term ball bearing is used.
- The inner race is typically pressed on the shaft at the bearing seat with a slight interference fit to ensure that it rotates with the shaft.
- The spherical rolling elements, or balls, roll in a deep groove in both the inner and outer races.
- The spacing of the balls is maintained by retainers, or cages.



Double-Row, Deep-Groove Ball Bearing

- Adding a second row of balls increases the radial load-carrying capacity of the deep-groove type of bearing compared with the single-row design because more balls share the load.

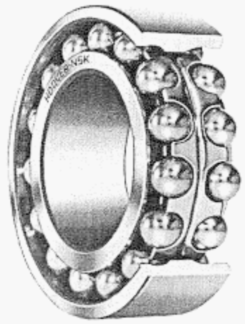


FIGURE14–2 Double-row, deep-groove ball bearing (NSK Corporation, Ann Arbor, MI)

Angular Contact Ball Bearing

- One side of each race in an angular contact bearing is higher to allow the accommodation of greater thrust loads compared with the standard single-row, deep-groove bearing.

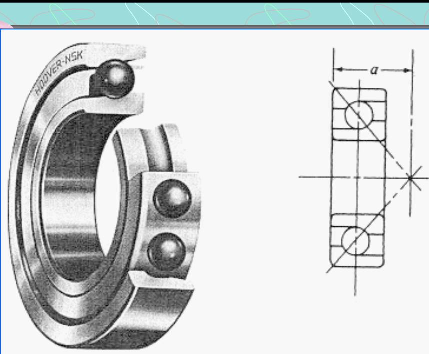
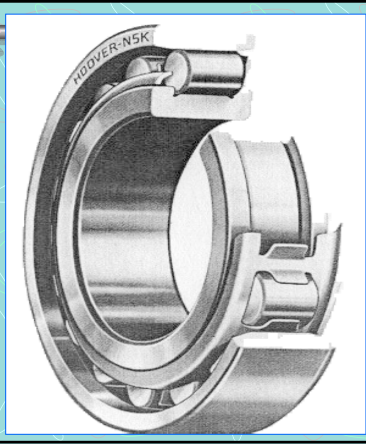


FIGURE 14–3 Angular contact ball bearing (NSK Corporation, Ann Arbor, MI)

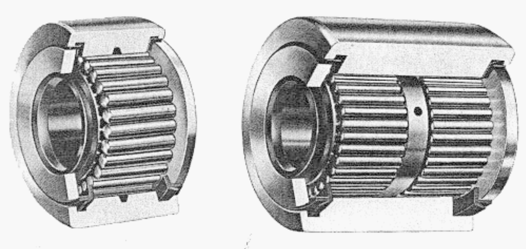
Cylindrical Roller Bearing

- Replacing the spherical balls with cylindrical rollers with corresponding changes in the design of the races, gives a greater radial load capacity.
- The resulting contact stress levels are lower than for equivalent-sized ball bearings, allowing smaller bearings to carry a given load or a given-size bearing to carry a higher load.
- Thrust load capacity is poor because any thrust load would be applied to the side of the rollers, causing rubbing, not true rolling motion.



Needle Bearing

- Needle bearings are actually roller bearings, but they have much smaller-diameter rollers.
- A smaller radial space is typically required for needle bearings to carry a given load than for any other type of rolling contact bearing.
- This makes it easier to design them into many types of equipment and components such as pumps, universal joints, precision instruments, and household appliances.



(a) Single- and double-row needle bearings

Spherical Roller Bearing

- The spherical roller bearing is one form of self-aligning bearing, so called because there is actual relative rotation of the outer race relative to the rollers and the inner race when angular misalignments occur.

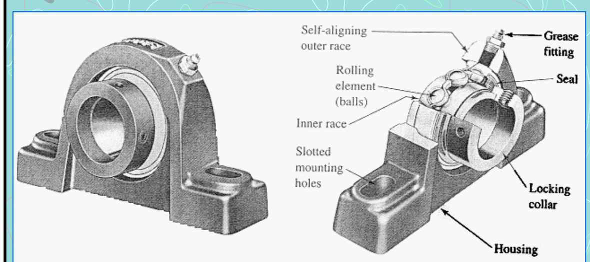
Tapered Roller Bearing

- Tapered roller bearings are designed to take substantial thrust loads along with high radial loads, resulting in excellent ratings on both.
- They are often used in wheel bearings for vehicles and mobile equipment and in heavy-duty machinery having inherently high thrust loads.

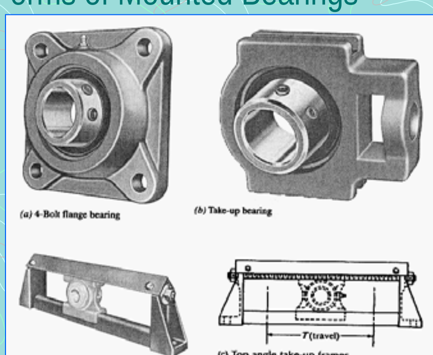
Mounted Bearings

- Mounted bearings rather than unmounted bearings are chosen for heavy machines and special machines produced in small quantities.
- The mounted bearings provide a means of attaching the bearing unit directly to the frame of the machine with bolts rather than inserting it into a machined recess in a housing as is required in unmounted bearings.

Ball Bearing Pillow Block



Forms of Mounted Bearings



Bearing Materials

- The load on a rolling contact bearing is exerted on a small area.
- The resulting contact stresses are quite high, regardless of the type of bearing.
- Contact stresses of approximately 300,000 psi are not uncommon in commercially available bearings.
- To withstand such high stresses, the balls, rollers, and races are made from a very hard, high-strength steel or ceramic.

Bearing Materials con't

- The most widely used bearing material is AISI 52100 steel.
- Impurities are carefully minimized to obtain a very clean steel.
- The material is through-hardened to the range of 58 – 65 on the Rockwell C scale to give it the ability to resist high contact stress.

Load/Life Relationship

- Despite using steels with very high strength, all bearings have a finite life and will eventually fail due to fatigue because of the high contact stresses.
- But, obviously, the lighter the load, the longer the life, and vice versa.
- The relationship between load, P, and life, L, for the rolling contact bearings can be stated as:
  - $L_2 / L_1 = (P_1 / P_2)^k$
  - Where k = 3.00 for ball bearings or 3.33 for roller bearings

TABLE 14–3 Bearing selection data for single-row, deep-groove, Conrad-type ball bearings

A. *Series 6200*

Bearing number	Nominal bearing dimensions							Preferred shoulder diameter		Bearing weight	Basic static load rating, C_o	Basic dynamic load rating, C
	d		D		B		r*	Shaft	Housing			
	mm	in	mm	in	mm	in	in	in	in	lb	lb	lb
6200	10	0.3937	30	1.1811	9	0.3543	0.024	0.500	0.984	0.07	520	885
6201	12	0.4724	32	1.2598	10	0.3937	0.024	0.578	1.063	0.08	675	1180
6202	15	0.5906	35	1.3780	11	0.4331	0.024	0.703	1.181	0.10	790	1320
6203	17	0.6693	40	1.5748	12	0.4724	0.024	0.787	1.380	0.14	1010	1660
6204	20	0.7874	47	1.8504	14	0.5512	0.039	0.969	1.614	0.23	1400	2210
6205	25	0.9843	52	2.0472	15	0.5906	0.039	1.172	1.811	0.29	1610	2430
6206	30	1.1811	62	2.4409	16	0.6299	0.039	1.406	2.205	0.44	2320	3350
6207	35	1.3780	72	2.8346	17	0.6693	0.039	1.614	2.559	0.64	3150	4450
6208	40	1.5748	80	3.1496	18	0.7087	0.039	1.811	2.874	0.82	3650	5050
6209	45	1.7717	85	3.3465	19	0.7480	0.039	2.008	3.071	0.89	4150	5650
6210	50	1.9685	90	3.5433	20	0.7874	0.039	2.205	3.268	1.02	4650	6050
6211	55	2.1654	100	3.9370	21	0.8268	0.059	2.441	3.602	1.36	5850	7500

Load/Life Relationship con't

- Standard bearings are available in several classes, typically extra-light, light, medium, and heavy classes.
- The designs differ in the size and number of load-carrying elements (balls or rollers) in the bearing.
- The bearing number usually indicates the class and size of the bore of the bearing.

Load/Life Relationship con't

- The number preceding the last two digits indicates the class.
- For example, several manufacturers use series 100 to indicate extra-light, 200 for light, 300 for medium, and 400 for heavy-duty classes.
- Inch-type bearings are available with bores ranging from 0.125 through 15.000 in.
- Considering load-carrying capacity first, the data reported for each bearing design will include a basic dynamic load rating, C, and a basic static load rating, C_0.

Load/Life Relationship con't

- The basic static load rating is the load that the bearing can withstand without permanent deformation of any component.
- To understand the basic dynamic load rating, it is necessary first to discuss the concept of the rated life of a bearing.
- Fatigue occurs over a large number of cycles of loading; for a bearing, that would be a large number of revolutions.
- Also, fatigue is a statistical phenomenon with considerable spread of the actual life of a group of bearings of a given design.

Load/Life Relationship con't

- The rated life is the standard means of reporting the results of many tests of bearings of a given design.
- It represents the life that 90% of the bearings would achieve successfully at a rated load.
- The rated life is typically referred to as the L_{10} life at the rated load.
- The basic dynamic load can be defined as that load to which the bearings can be subjected while achieving a rated life (L10) of 1 million revolutions (rev).

A catalog lists the basic dynamic load rating for a ball bearing to be 7050 lb for a rated life of 1 million rev. What would be the expected L_{10} life of the bearing if it were subjected to a load of 3500 lb?

In Equation (14–1),

$P_1 = C = 7050$ lb (basic dynamic load rating)
$P_2 = P_d = 3500$ lb (design load)
$L_1 = 10^6$ rev (L_{10} life at load C)
$k = 3$ (ball bearing)

Then letting the life, L_2, be called the *design life*, L_d, at the design load,

$$L_2 = L_d = L_1\left(\frac{P_1}{P_2}\right)^k = 10^6\left(\frac{7050}{3500}\right)^{3.00} = 8.17 \times 10^6 \text{ rev}$$

This must be interpreted as the L_{10} life at a load of 3500 lb.

Design Life

- The procedure for computing the required basic dynamic load rating C for a given design load P_d and a given design life L_d.
- If the reported load data in the manufacturer's literature is for 10^6 revolutions:
  - $L_d = (C / P_d)^k (10^6)$
- The required C for a given design load and life would be:
  - $C = P_d (L_d / 10^6)^{1/k}$

Design Life con't

- For a specified design life in hours, and a known speed rotation in rpm, the number of design revolutions for the bearing would be:
  - $L_d = (h)(rpm)(60\ min/hr)$

Bearing Selection

- The selection of a bearing takes into consideration the load capacity and the geometry of the bearing that will ensure that it can be installed conveniently in the machine.

Procedure for Selecting Bearing-Radial Load Only

1. Specify the design load on the bearing, usually called equivalent load. The method of determining the equivalent load when only a radial load, R, is applied takes into account whether the inner or outer race rotates.
   - P = VR; the factor V is called a rotation factor and takes the value of 1.0 if the inner race of the bearing rotates, the usual case. Use V = 1.2 if the outer race rotates.
2. Determine the minimum acceptable diameter of the shaft that will limit the bore size of the bearing.

Procedure for Selecting Bearing-Radial Load Only con't

3. Select the type of bearing, using Table 14-1 as a guide.
4. Specify the design life of the bearing using Table 14-4.
5. Determine the speed factor and the life factor if such tables are available for the selected type of bearing. Use Figure 14-12.
6. Compute the required basic dynamic load rating, C, from Equation 14-1, 14-3, or 14-4.

Procedure for Selecting Bearing-Radial Load Only

7. Identify a set of candidate bearings that have the required basic dynamic load rating.
8. Select the bearing having the most convenient geometry, also considering its cost and availability.
9. Determine mounting conditions, such as shaft seat diameter and tolerance,housing bore diameter and tolerance, means of locating the bearing axially, and special needs such as seals or shields.

Bearing Selection: Radial and Thrust Loads Combined

- When both radial and thrust loads are exerted on a bearing, the equivalent load is the constant radial load that would produce the same rated life for the bearing as the combined loading.
- The method of computing the equivalent load, P:
  - P = VXR + YT
  - Where P = equivalent load
  - V = rotation factor (as defined)
  - R = applied radial load
  - T = applied thrust load
  - X = radial factor
  - Y = thrust factor

Bearing Selection: Radial and Thrust Loads Combined con't

- The values of X and Y vary with the specific design of the bearing and with the magnitude of the thrust load relative to the radial load.
- For relatively small thrust loads, X = 1 and Y = 0, so the equivalent load equation reverts to the form of Equation 14-5 for pure radial loads.
- To indicate the limiting thrust load for which this is the case, manufacturers list a factor called e.

Bearing Selection: Radial and Thrust Loads Combined con't

- If the ratio T / R > e, Equation 14-6 must be used to compute P.
- If T / R < e, Equation 14-5 is used.
- Table 14-% shows one set of data for a single-row, deep-groove ball bearing.
- Note that both e and Y depend on the ratio T / C_o, where C_o is the static load rating of a particular bearing.
- This presents a difficulty in bearing selection because the value of C_o is not known until the bearing has been selected.
- Therefore, a simple trial-and-error method is applied.

Table 14-5

TABLE 14–5 Radial and thrust factors for single-row, deep-groove ball bearings

e	T/C_o	Y	e	T/C_o	Y
0.19	0.014	2.30	0.34	0.170	1.31
0.22	0.028	1.99	0.38	0.280	1.15
0.26	0.056	1.71	0.42	0.420	1.04
0.28	0.084	1.55	0.44	0.560	1.00
0.30	0.110	1.45			

Note: $X = 0.56$ for all values of Y.

Procedure for Selecting a Bearing-Radial

1. Assume a value of Y from Table 14-5. The value Y = 1.50 is reasonable, being at about the middle of the range of possible values.
2. Compute P = VXR + YT.
3. Compute the required basic dynamic load rating C from Equation 14-1, 14-3, or 14-4.
4. Select a candidate bearing having a value of C at least equal to the required value.
5. For the selected bearing, determine C_o.

Procedure for Selecting a Bearing-Radial con't

6. Compute T / C_o.
7. From Table 14-5, determine e.
8. If T / R > e, then determine Y from Table 14-5.
9. If the new value of Y is different from that assumed in Step 1, repeated the process.
10. If T / R < e, use Equation 14-5 to compute P, and proceed as for a pure radial load.

Select a single-row, deep-groove ball bearing from Table 14–3 to carry a radial load of 1850 lb and a thrust load of 675 lb. The shaft is to rotate at 1150 rpm, and a design life of 20 000 h is desired. The minimum acceptable diameter for the shaft is 3.10 in.

Use the procedure outlined above.

Step 1. Assume $Y = 1.50$.

Step 2. $P = VXR + YT = (1.0)(0.56)(1850) + (1.50)(675) = 2049$ lb.

Step 3. From Figure 14–12, the speed factor $f_N = 0.30$, and the life factor $f_L = 3.41$. Then the required basic dynamic load rating C is

$$C = Pf_L/f_N = 2049(3.41)/(0.30) = 23\,300 \text{ lb}$$

Step 4. From Table 14–3, we could use either bearing number 6222 or 6318. The 6318 has a bore of 3.5433 in and is well suited to this application.

Step 5. For bearing number 6318, $C_o = 22\,500$ lb.

Step 6. $T/C_o = 675/22\,500 = 0.03$.

Step 7. From Table 14–5, $e = 0.22$ (approximately).

Step 8. $T/R = 675/1850 = 0.36$. Because $T/R > e$, we can find $Y = 1.97$ from Table 14–5 by interpolation based on $T/C_o = 0.03$.

Step 9. Recompute $P = (1.0)(0.56)(1850) + (1.97)(675) = 2366$ lb:

$$C = 2366(3.41)/(0.30) = 26\,900 \text{ lb}$$

The bearing number 6318 is not satisfactory at this load. Let's choose bearing number 6320 and repeat the process from Step 5.

Step 5. $C_o = 29\,800$ lb.

Step 6. $T/C_o = 675/29\,800 = 0.023$.

Step 7. $e = 0.20$.

Step 8. $T/R > e$. Then $Y = 2.10$ using $T/C_o = 0.023$.

Step 9. $P = (1.0)(0.56)(1850) + (2.10)(675) = 2454$ lb. Thus,

$$C = 2454(3.41)/(0.30) = 27\,900 \text{ lb}$$

Because bearing number 6320 has a value of $C = 30\,000$ lb, it is satisfactory.