Mechanical Design DME3051

14. Rolling-Element Bearings

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HANYANG UNIVERSITY

14 Rolling-Element Bearings

Comparison of Alternative Means for Supporting Rotating Shafts

Sliding Bearings

- Low friction and wear only with full-film lubrication (complete surface separation)
- External pressurization equipment is required to eliminate friction during start-up
- Suited for applications with high rotating speeds
- Require more axial space around the shaft

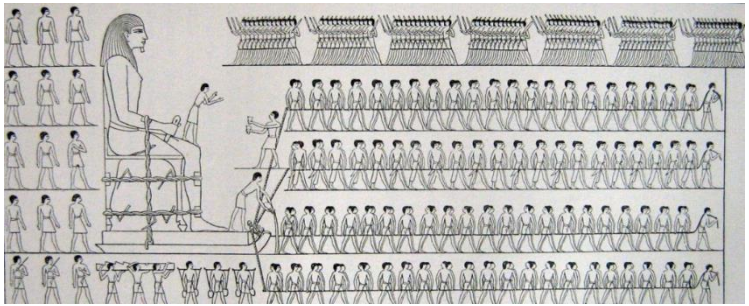
〈Figure 14.1 Sliding bearings〉

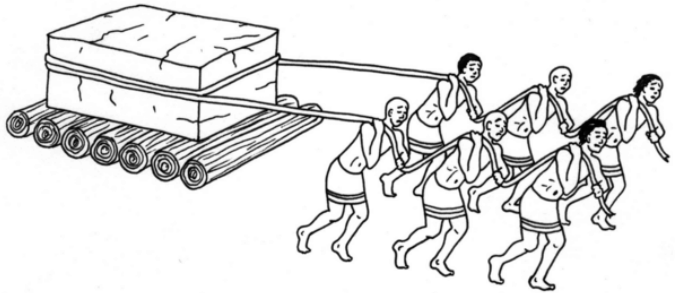
Rolling-Element Bearings

- Low starting fiction
- Suited for applications with high starting loads
- Require more radial space around the shaft
- With normal operating loads, typical frictional coefficients: 0.001 or 0.002

〈Figure 14.2 Rolling element bearings〉

History of Rolling-Element Bearings



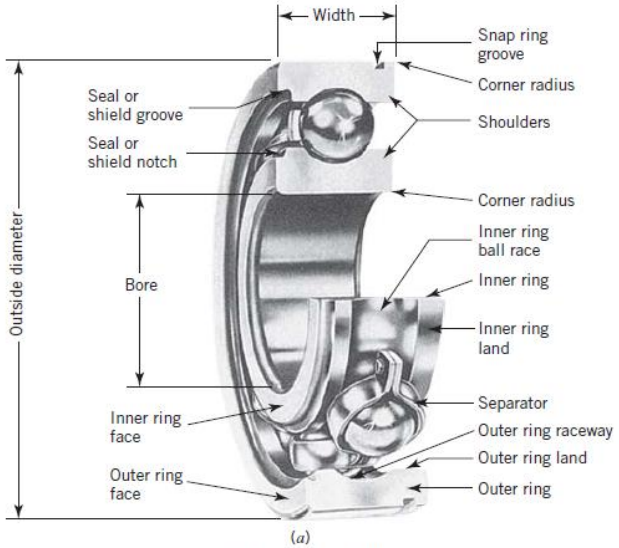


〈Figure 14.3 History of rolling-element bearings〉

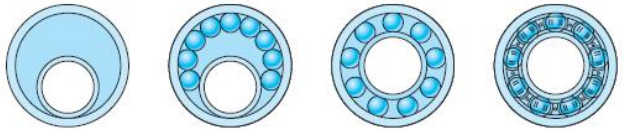
Rolling-Element Bearings

- The Ancient Egyptians are often credited with using roller bearings, often made out of tree trunks that act as rollers under sledges carrying an object.
- The first recorded use of rolling elements to overcome sliding friction was by Egyptian construction workers, to move heavy stone slabs, probably before 200 B.C.
- The tomb contains a schematic drawing of the transportation scene of a colossal statue of himself being transported on a sledge using water as lubrication.
- Egyptologists had originally thought the pouring of the water was simply a ritual, but engineers have since confirmed the transportation technique as feasible.
- It is understood that the water served to increase the stiffness of the sand in order to reduce the force needed to move the statue.

Rolling-Element Bearing



(a)
Construction and nomenclature

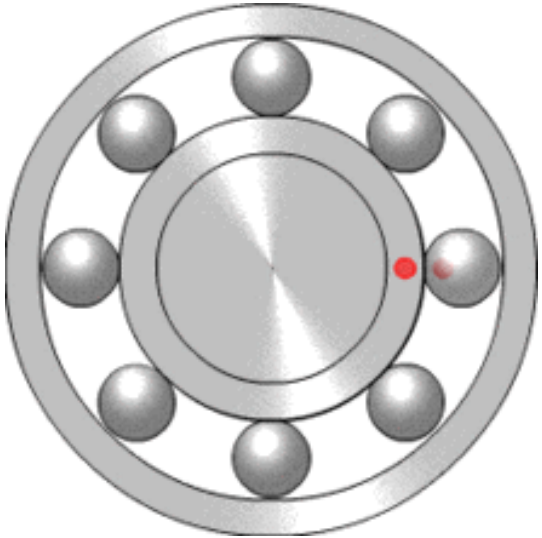


(b)
Steps in assembly

(c)
Contact surface geometry

〈Figure 14.4 Radial ball bearing (deep-groove or "Conrad" type). (Courtesy New Departure-Hyatt Bearing Division, General Motors Corporation.)〉

Rolling-Element Bearing



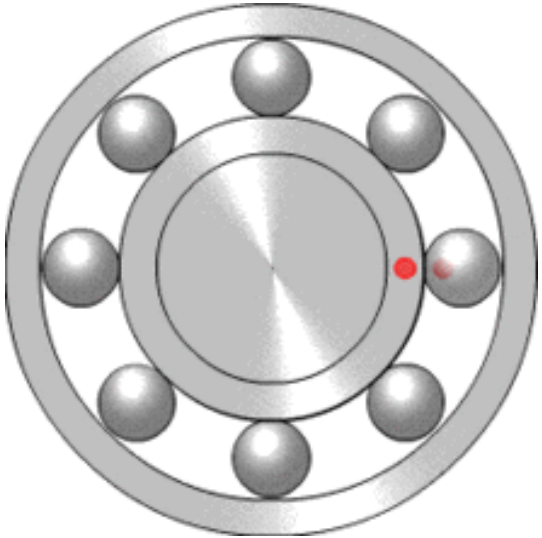
〈Figure 14.5 Ball bearing〉

Rolling-Element Bearings

- Rolling-element bearings are either ball bearings or roller bearings.
- In general, ball bearings are capable of higher speeds, and roller bearings can carry greater loads.
- Ball or roller: Rolling elements

〈Figure 14.6 Types of rolling elements〉

Rolling-Element Bearing

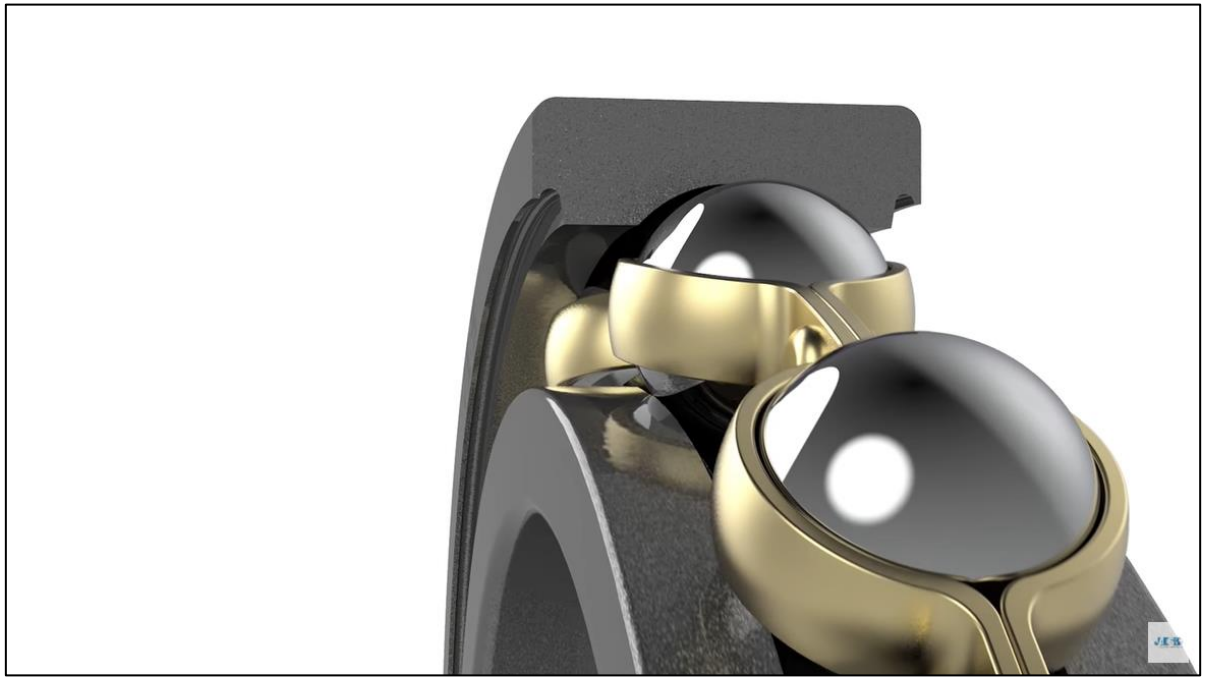


〈Figure 14.5 Ball bearing〉

Rolling-Element Bearings

- Rolling-element bearings have the advantage of a good tradeoff between cost, size, weight, carrying capacity, durability, accuracy, friction, and so on
- Other bearing designs are often better on one specific attribute, but worse in most other attributes, although fluid bearings can sometimes simultaneously outperform on carrying capacity, durability, accuracy, friction, rotation rate and sometimes cost
- Only plain bearings are used as widely as rolling-element bearings.

Rolling-Element Bearing



Rolling-Element Bearing Types

- **Roller Types**
  - Ball Bearings
  - Roller Bearings
- **Ball Bearings**
  - Radial Ball Bearings
  - Thrust Ball Bearings
  - Angular Contact Ball Bearings
- **Roller Bearings**
  - Cylindrical Roller Bearings
  - Spherical Roller Bearings
  - Tapered Roller Bearings
  - Needle Roller Bearings

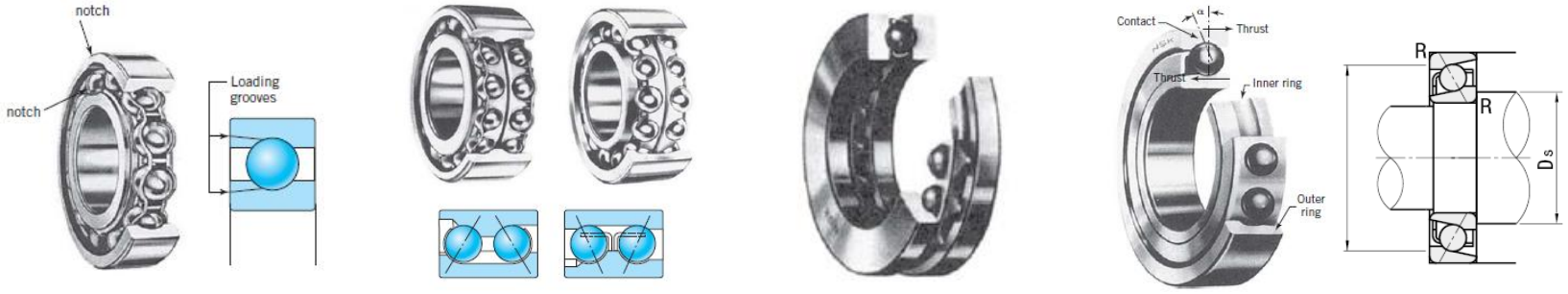
〈Figure 14.7 Ball bearings〉

〈Figure 14.8 Roller bearings〉

Rolling-Element Bearing Types

Ball Bearings

- Radial ball bearings with *notches* or *loading grooves* are assembled with races and balls (20 - 40% greater load capacity than deep groove type/Sharply reduction in thrust capacity)
- Double row ball bearings incorporate a pair of angular contact ball bearings into a single unit
- Angular contact ball bearings support radial and thrust load both (Thrust load capacity in one direction only)



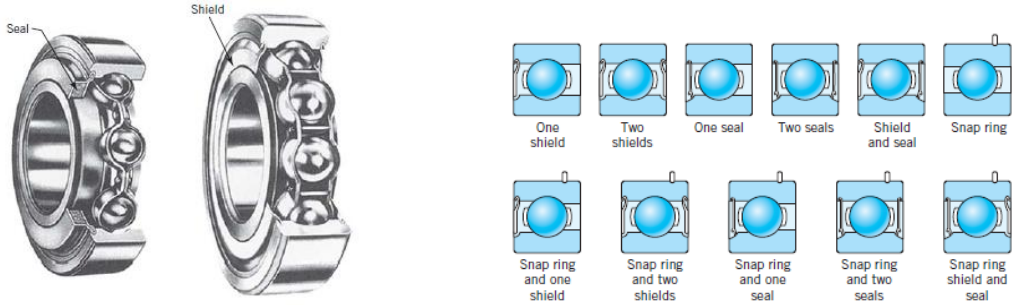
(a) Filling notch (b) Double row type (c) Thrust (d) Angular contact type

〈Figure 14.9 Ball bearings (a) Filling notch (loading groove) type (b) Double row type (c) Thrust (d) Angular contact type〉

Rolling-Element Bearing Types

Ball Bearings

- Generally, ball bearings are non-separable (two races, balls, and retainer are installed as an assembly)
- Shields are close-fitting and non-rubbing thin washers that protect the bearing against foreign particles and help retain lubricant
- Seals have rubbing contact and provide greater lubricant retention and protection against contamination (Following frictional drag)



〈Figure 14.10 Bearings with seals and shields. (Courtesy New Departure-Hyatt Bearing Division, General Motors Corporation.)〉

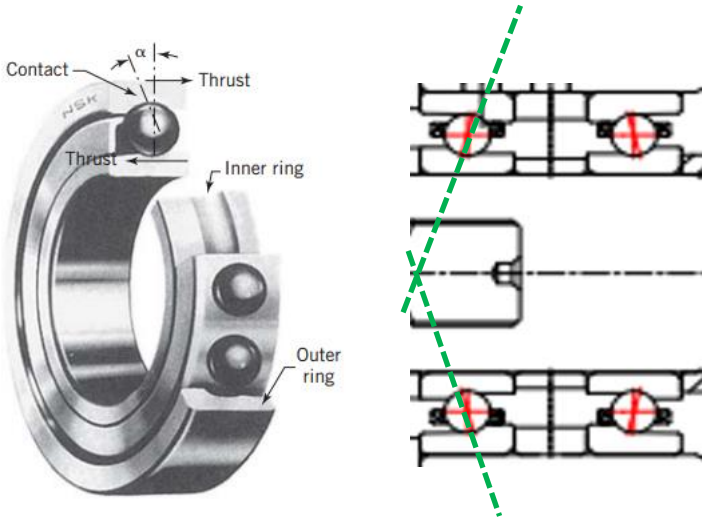
Rolling-Element Bearing Types

〈Figure 14.11 Deep groove ball bearings〉

Deep Groove Ball Bearings

- There is enough space between the balls that if they're all pushed over to one side, the inner ring can be pushed to the opposite side, into the space left by moving the balls
- This increases the space on the side where the balls are, letting them be removed
- The bearing cage usually keeps the balls evenly spaced so this doesn't happen by accident
- These bearings are assembled by placing the inner ring into an eccentric position relative to the outer ring, with the two rings in contact at one point, resulting in a large gap opposite the point of contact

Rolling-Element Bearing Types

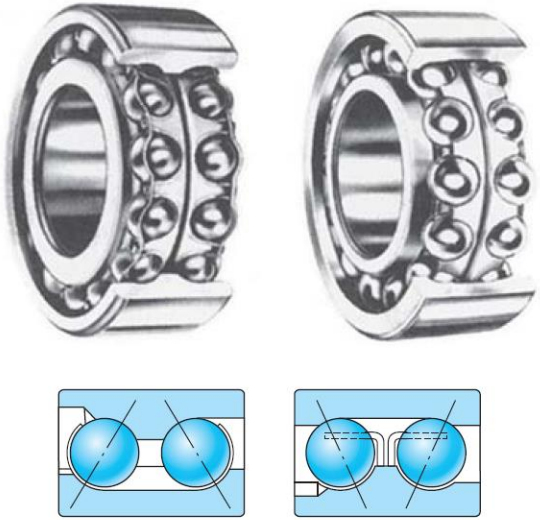


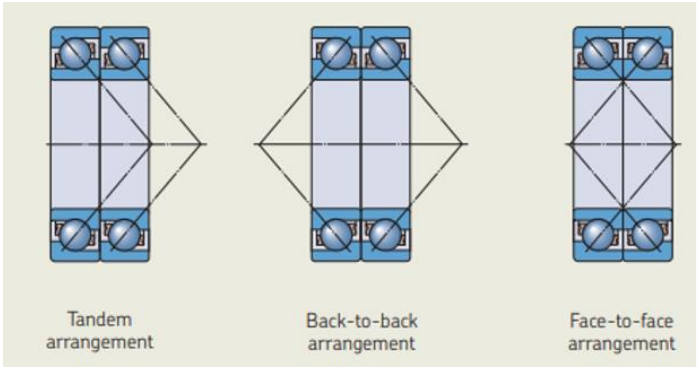
〈Figure 14.12 Angular contact ball bearings〉

Angular Contact Ball Bearings

- Angular-contact bearings have substantial thrust capacity in one direction only
- They are commonly installed in pairs, with each taking thrust in one direction

Rolling-Element Bearing Types





〈Figure 14.13 Double-row type angular contact ball bearings〉

Angular Contact Ball Bearings

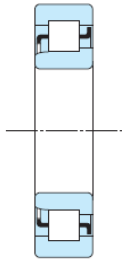
- The double-row ball bearing incorporates a pair of angular-contact bearings into a single unit
- Tandem arrangement
- Back-to-back arrangement
- Face-to-face arrangement

Rolling-Element Bearing Types

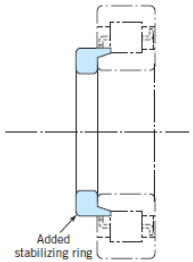
Cylindrical Roller Bearings

- In contrast with ball bearings, roller bearings are usually made the rings (races) can be separated
- (a) One ring has no flanges; hence, no thrust loads can be carried
- (b) Inner ring has one flange, permitting small thrust loads in one direction
- (c) Inner ring has an integral flange on one side and a removable flange on the other side so that light thrust can be taken in either direction

(a) Non-locating



(b) One-direction locating



(c) Two-direction locating

(d) Thrust

〈Figure 14.4 Four basic types of cylindrical roller bearings. (a) Non-locating (b) One-direction locating (c) Two-direction locating (d) Thrust〉

Rolling-Element Bearing Types

Spherical Roller Bearings

- The single-row type has little thrust capacity
- The double-row bearings carry thrust load up to about 30% of its radial load
- The spherical roller bearing with angular contact thrust carry large thrust loads in one direction

(a) Single-row convex

(b) Double-row convex

(c) Thrust

〈Figure 14.15 Three types of spherical roller bearings. (a) Courtesy McGill Manufacturing Company, Inc., Bearing Division, Valparaiso, Indiana, (b) (c) Courtesy Hoover-NSK Bearings Company〉

Rolling-Element Bearing Types

Tapered Roller Bearings

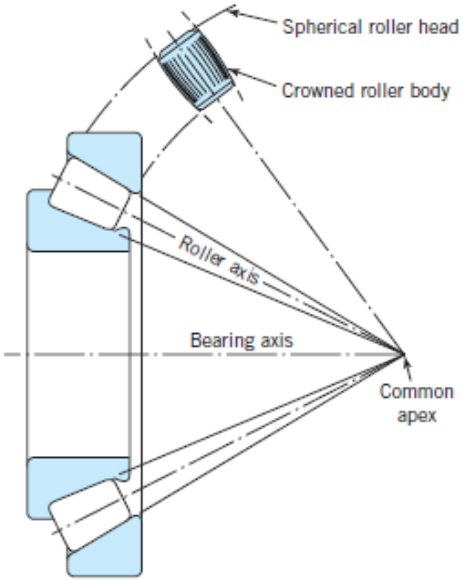
- Conical elements of the rollers and races intersect at a common apex on the centerline of rotation
- Single row type is often used for wheel bearings
- Double and four row roller types are used singly to heavy load applications

(a) Single-row

(b) Double-row

(c) Four-row

〈Figure 14.16 Tapered roller bearings. (Courtesy The Torrington Company.) (a) Single-row (b) Double-row (c) Four-row〉



〈Figure 14.11 Tapered roller bearings geometry〉

Rolling-Element Bearing Types

Needle Roller Bearings

- Needle bearings have for a given radial space the highest load capacity of all rolling-element bearings
- (a) Drawn-cup caged type
- (b) Full complement aircraft type
- (c) Full-complement drawn-cup type
- (d) Thrust

(a) Drawn-cup caged

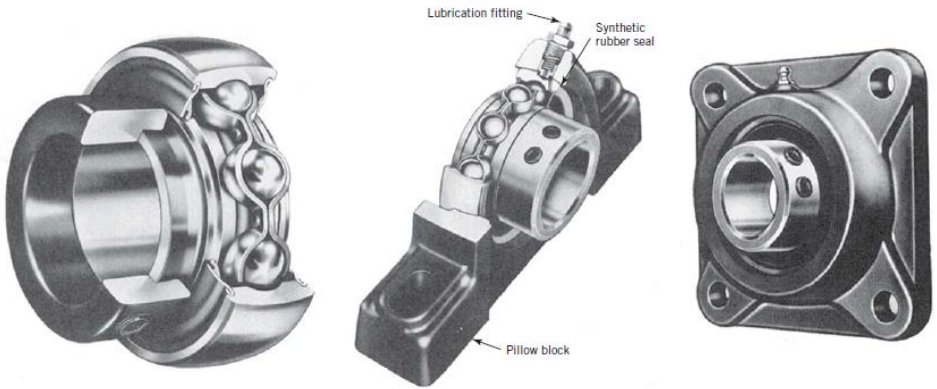
(b) Full complement aircraft

(c) Full-complement drawn-cup

(d) Thrust

〈Figure 14.17 Four types of needle roller bearings. (a) Drawn-cup caged (b) Full complement aircraft (c) Full-complement drawn-cup (d) Thrust〉

Rolling-Element Bearing Types



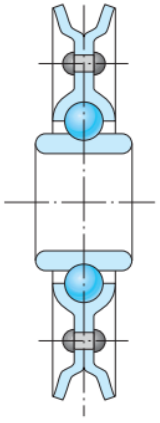
(a) Adapter bearing (b) Pillow block mounting (c) Flange bearing

〈Figure 14.18 Sample of rolling element bearings〉

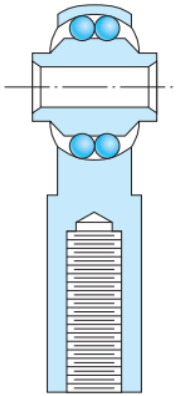
Rolling Element Bearing Applications

- (a) The adapter bearing can be economically mounted on commercial steel shafting without machining a bearing seat
- (b) The pillow block mounting is a common arrangement used to support a rotating shaft parallel to a flat surface
- (c) The flange bearing support a rotating shaft perpendicular to a flat surface

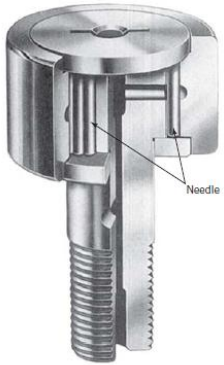
Rolling-Element Bearing Types



(d) Idler sheave



(e) Rod end bearing



(f) Needle bearing can follower

〈Figure 14.18 Sample of rolling element bearings〉

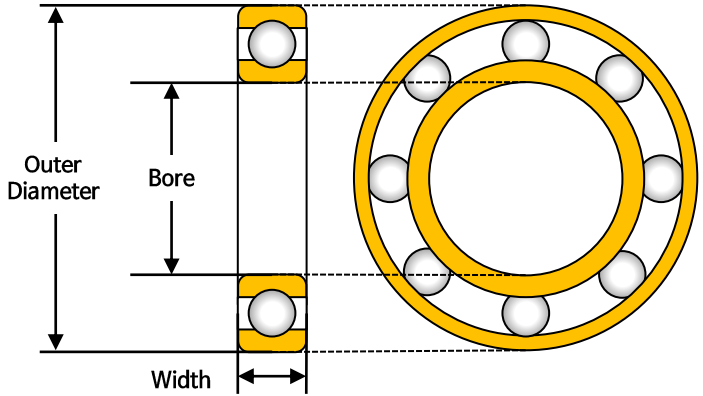
Rolling Element Bearing Applications

- (d) The idler sheave has an inexpensive unground ball bearing built with the outer race sized and contoured to accommodate a belt.
- (e) The rod end bearing is used for aircraft controls and miscellaneous machinery and mechanism applications.
- (f) The needle bearing cam follower has a heavy outer ring to withstand high cam contact forces

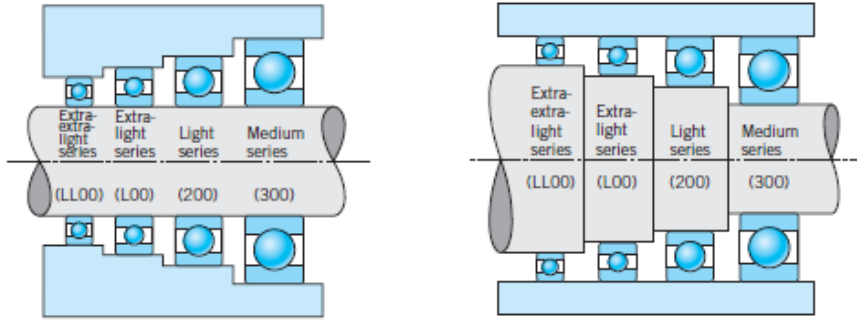
Design of Rolling-Element Bearings

Ball Bearings Design

- A radius only a trifle larger than that of the ball gives a relatively large area of contact and low contact stress
- Sliding and in turn friction and wear due to various contact area from the axis
- Thus, the radius selection is a compromise between providing load supporting area and accepting sliding friction



〈Figure 14.19 Outer diameter and bore of ball bearings〉



(a) Relative proportions of bearings with same bore dimension

(b) Relative proportions of bearings with same outside diameter

〈Figure 14.20 Relative proportions of bearings of different series〉

Design of Rolling-Element Bearings

Ball Bearings Design

- Selection of the material: High carbon chrome steel (SAE 52100) since 1920. Roller bearing components are often made of carburized alloy steel.
- Design of the rings: Ring and ball deflection, rotating speed , and lubricant properties combine to determined local stress distribution in the contact area.
- Manufacturing tolerance: For example, tolerances on bearing bores between 35 and 50 *mm* range from +0.0000 *inch* to −0.00005 *inch* for ABEC grade 1 to +0.00000 *inch* to −0.00010 *inch* for ABEC grade 9.

ABEC Grade

- Annular Bearing Engineers' Committee of the Anti-Friction Bearing Manufacturers Association, AFBMA (ABEC - 1, 3, 5, 7, and 9)
- ABEC classifications relate to eccentricity of bearings
- ABEC 1: 0.0075 *mm* / ABEC 3: 0.0050 *mm* / ABEC 5: 0.0035 *mm* / ABEC 7: 0.0025 *mm* / ABEC 9: 0.0012 *mm*

Design of Rolling-Element Bearings

Ceramic vs. Steel Ball Bearings?

- Ball bearings can be made from many different materials, [stainless steel, chrome steel, and ceramic (silicon nitride (Si3N4)]
- A hybrid ball bearing is a bearing with ceramic balls and races of metal
- Ceramics such as silicon nitride are now regularly used in such applications due to their low density (40% of steel)
- These materials significantly reduce centrifugal force and function well in high temperature environments.
- They also tend to wear in a similar way to bearing steel—rather than cracking or shattering like glass or porcelain.

〈Figure 14.21 Hybrid ball bearings with ceramic balls and metal races〉

Design of Rolling-Element Bearings

〈Figure 14.21 Hybrid ball bearings with ceramic balls and metal races〉

Ceramic vs. Steel Ball Bearings?

- While ceramic hybrid bearings use ceramic balls in place of steel ones, they are constructed with steel inner and outer rings; hence the hybrid designation
- While the ceramic material itself is stronger than steel, it is also stiffer, which results in increased stresses on the rings, and hence decreased load capacity
- Ceramic balls are electrically insulating, which can prevent 'arcing' failures if current should be passed through the bearing
- Ceramic balls can also be effective in environments where lubrication may not be available (such as in space applications).

Design of Rolling-Element Bearings

〈Figure 14.21 Hybrid ball bearings with ceramic balls and metal races〉

Advantages of Ceramic Balls

Lighter
- The ceramic balls are lighter than the steel balls.
- Reduction in force outward against the outer race

Harder
- The ceramic balls are harder than the steel balls.
- Run 10 times longer than the steel ball bearings

Smoother
- The ceramic balls are smoother surface properties than the steel balls.
- Reduction in friction between the balls and the bearings races

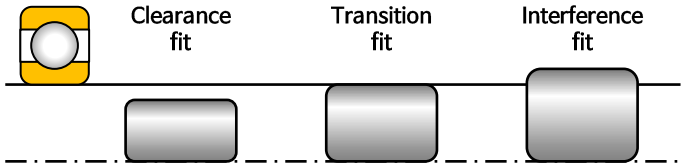
Thermal
- The ceramic balls have better thermal properties than the steel balls.
- The ceramic ball will not heat up like the steep balls

Lubrication
- The ceramic balls are impervious to oxidation, chemicals, and require less lubricant

Fitting of Rolling-Element Bearings

Fitting of Rolling Element Bearings

- Normal practice is to fit the stationary ring with the rotating raceway with enough interference to prevent relative motion during operation
- Recommended fits depend on bearing type, size, and tolerance grade
- Proper fits and tolerances are influenced by the radial stiffness of the shaft and housing, and sometimes by thermal expansion
- Too tight fit causes internal interference that shortens the bearing life



〈Figure 14.22 Fitting of rolling element bearing classifications〉

Type of Fits

Clearance Fit
- Loose joints
- Movable design
- Hydraulic machines

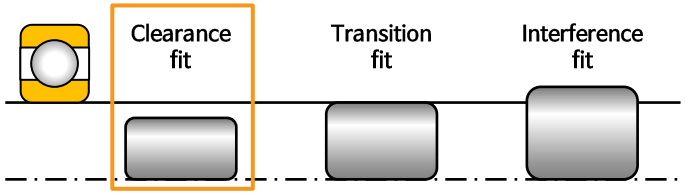
Transition Fit
- Accurate location
- Small clearance
- Precision manufacturing

Interference Fit
- Called press/friction fit
- Negative clearance

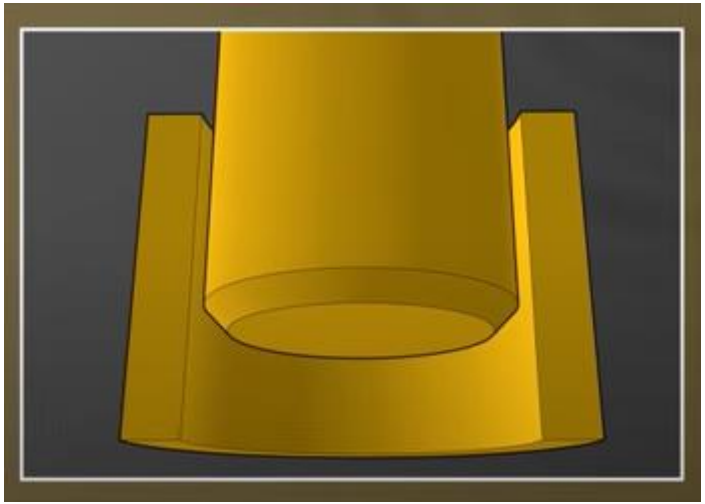
Fitting of Rolling-Element Bearings

Clearance Fit

- The maximum limit of the shaft is less than the minimum limit of the bore diameter
- Loose joints
- Movable design
- Hydraulic machines



〈Figure 14.22 Fitting of rolling element bearing classifications〉

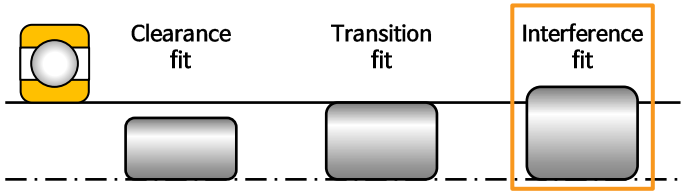


〈Figure 14.23 Clearance fit〉

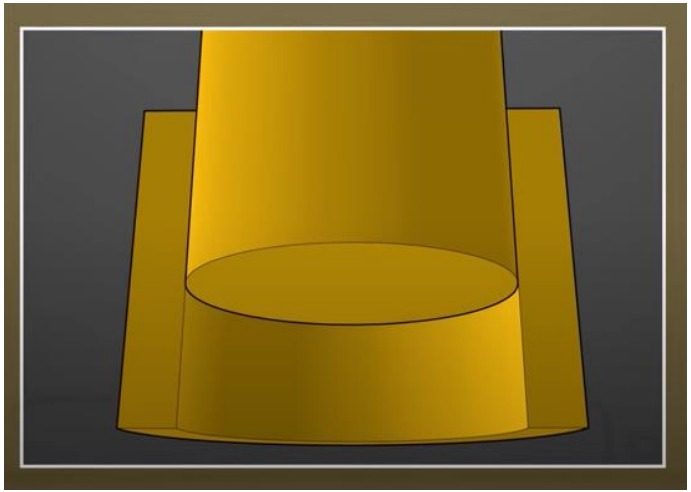
Fitting of Rolling-Element Bearings

Interference Fit

- Guarantees the shaft and bore will interfere at every point within their tolerance zone
- Expansion or shrinkage by temperature
- Called press fit
- Called friction fit
- Negative clearance



〈Figure 14.22 Fitting of rolling element bearing classifications〉

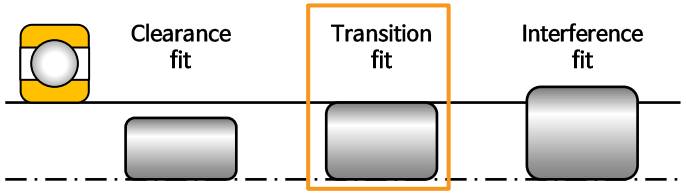


〈Figure 14.24 Interference fit〉

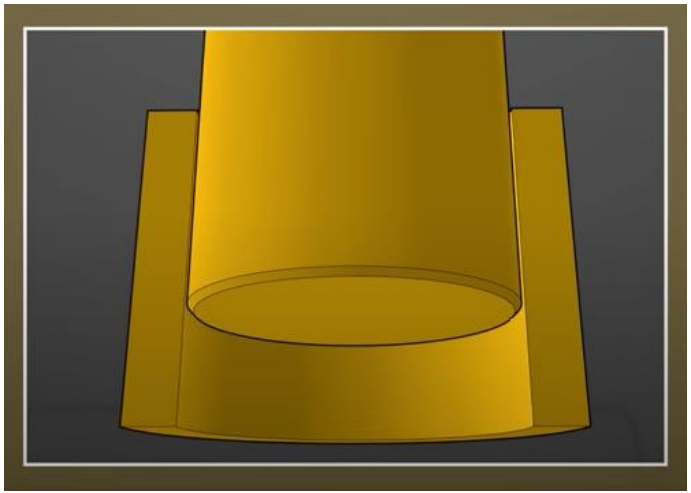
Fitting of Rolling-Element Bearings

Transition Fit

- A combination between the clearance fit and interference fit
- Best used when a shaft must be held in a precise location
- Accurate location
- Small clearance
- Precision manufacturing

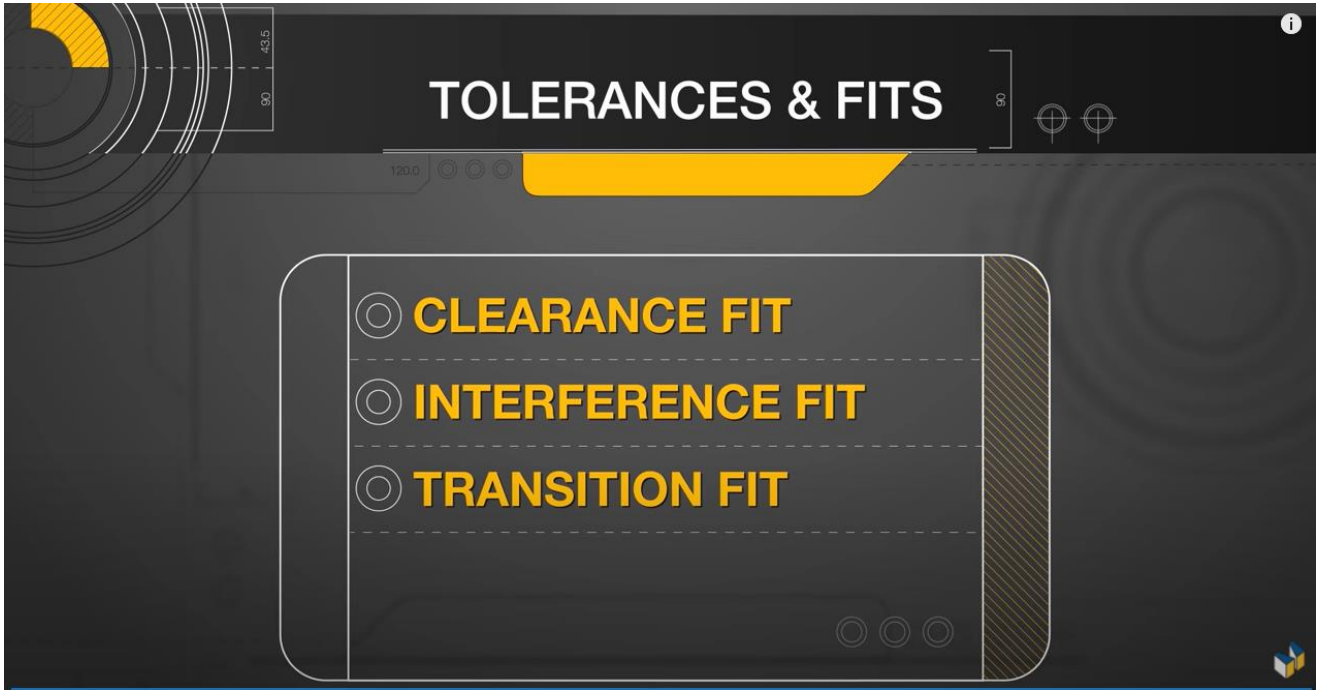


〈Figure 14.22 Fitting of rolling element bearing classifications〉



〈Figure 14.25 Transition fit〉

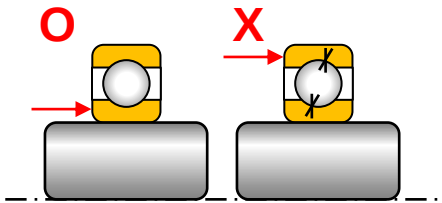
Fitting of Rolling-Element Bearings



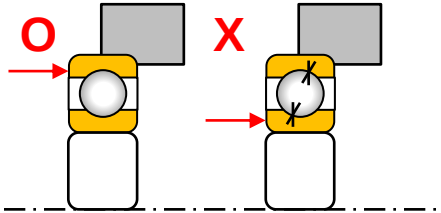
Fitting of Rolling-Element Bearings

Fitting of Rolling Element Bearings

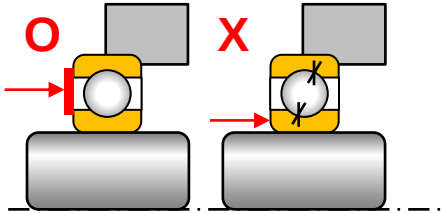
- Bearings installation and removal require forces are applied directly to the bearing raceway
- If forces are transmitted through the bearing, the bearing can be damaged
- Interference fit installations are sometimes facilitated by heating the outer member or by freezing the inner member
- Any heating must not be sufficient to damage the steel or any lubricant



〈Figure 14.26 Mounting on shaft〉



〈Figure 14.27 Mounting on housing〉

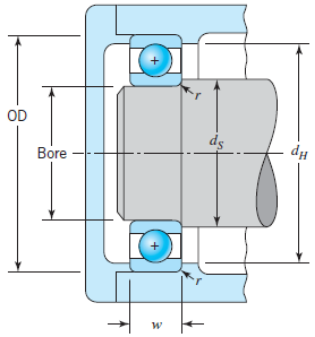


〈Figure 14.28 Mounting on shaft and in housing〉

"Catalogue Information" for Rolling-Element Bearings

Catalogue Dimension Information

- Bearings manufacturer's catalogues identify bearings by number which gives complete dimensional information, load capacities, and furnish details concerning mounting, lubrication, and operation
- For example, No. L08 is an extra-light series bearing with a 40 *mm* bore and 68 *mm* outer diameter



〈Figure 14.29 Shaft and housing shoulder dimensions〉

Bearing Basic Number	Bore (mm)	Ball Bearings					Roller Bearings				
		OD (mm)	w (mm)	r^a (mm)	d_S (mm)	d_H (mm)	OD (mm)	w (mm)	r^a (mm)	d_S (mm)	d_H (mm)
L03	17	35	10	0.30	19.8	32.3	35	10	0.64	20.8	32.0
203	17	40	12	0.64	22.4	34.8	40	12	0.64	20.8	36.3
303	17	47	14	1.02	23.6	41.1	47	14	1.02	22.9	41.4
L04	20	42	12	0.64	23.9	38.1	42	12	0.64	24.4	36.8
204	20	47	14	1.02	25.9	41.7	47	14	1.02	25.9	42.7
304	20	52	15	1.02	27.7	45.2	52	15	1.02	25.9	46.2
L05	25	47	12	0.64	29.0	42.9	47	12	0.64	29.2	43.4
205	25	52	15	1.02	30.5	46.7	52	15	1.02	30.5	47.0
305	25	62	17	1.02	33.0	54.9	62	17	1.02	31.5	55.9
L06	30	55	13	1.02	34.8	49.3	47	9	0.38	33.3	43.9
206	30	62	16	1.02	36.8	55.4	62	16	1.02	36.1	56.4
306	30	72	19	1.02	38.4	64.8	72	19	1.52	37.8	64.0

Bearing Basic Number	Bore (mm)	Ball Bearings					Roller Bearings				
		OD (mm)	w (mm)	r^a (mm)	d_S (mm)	d_H (mm)	OD (mm)	w (mm)	r^a (mm)	d_S (mm)	d_H (mm)
L07	35	62	14	1.02	40.1	56.1	55	10	0.64	39.4	50.8
207	35	72	17	1.02	42.4	65.0	72	17	1.02	41.7	65.3
307	35	80	21	1.52	45.2	70.4	80	21	1.52	43.7	71.4
L08	40	68	15	1.02	45.2	62.0	68	15	1.02	45.7	62.7
208	40	80	18	1.02	48.0	72.4	80	18	1.52	47.2	72.9
308	40	90	23	1.52	50.8	80.0	90	23	1.52	49.0	81.3
L09	45	75	16	1.02	50.8	68.6	75	16	1.02	50.8	69.3
209	45	85	19	1.02	52.8	77.5	85	19	1.52	52.8	78.2
309	45	100	25	1.52	57.2	88.9	100	25	2.03	55.9	90.4
L10	50	80	16	1.02	55.6	73.7	72	12	0.64	54.1	68.1
210	50	90	20	1.02	57.7	82.3	90	20	1.52	57.7	82.8
310	50	110	27	2.03	64.3	96.5	110	27	2.03	61.0	99.1

〈Table 14.1 Bearing dimensions catalogue〉

"Catalogue Information" for Rolling-Element Bearings

Catalogue Load Capacity Information

- Rated load capacities
- Constant radial load that 90% of a group of presumably identical bearings can endure for $9X10^7$ *revs* (as 3,000 *hours* of 500 *rpm* operation) without the onset of surface fatigue failures
- Note, rated load capacities given by different bearing manufacturers are not always directly comparable

	Radial Ball, $\alpha = 0°$			Angular Ball, $\alpha = 25°$			Roller		
Bore (mm)	L00 Xlt (kN)	200 lt (kN)	300 med (kN)	L00 Xlt (kN)	200 lt (kN)	300 med (kN)	1000 Xlt (kN)	1200 lt (kN)	1300 med (kN)
10	1.02	1.42	1.90	1.02	1.10	1.88			
12	1.12	1.42	2.46	1.10	1.54	2.05			
15	1.22	1.56	3.05	1.28	1.66	2.85			
17	1.32	2.70	3.75	1.36	2.20	3.55	2.12	3.80	4.90
20	2.25	3.35	5.30	2.20	3.05	5.80	3.30	4.40	6.20
25	2.45	3.65	5.90	2.65	3.25	7.20	3.70	5.50	8.50
30	3.35	5.40	8.80	3.60	6.00	8.80	2.40[a]	8.30	10.0
35	4.20	8.50	10.6	4.75	8.20	11.0	3.10[a]	9.30	13.1
40	4.50	9.40	12.6	4.95	9.90	13.2	7.20	11.1	16.5
45	5.80	9.10	14.8	6.30	10.4	16.4	7.40	12.2	20.9
50	6.10	9.70	15.8	6.60	11.0	19.2	5.10[a]	12.5	24.5

	Radial Ball, $\alpha = 0°$			Angular Ball, $\alpha = 25°$			Roller		
Bore (mm)	L00 Xlt (kN)	200 lt (kN)	300 med (kN)	L00 Xlt (kN)	200 lt (kN)	300 med (kN)	1000 Xlt (kN)	1200 lt (kN)	1300 med (kN)
55	8.20	12.0	18.0	9.00	13.6	21.5	11.3	14.9	27.1
60	8.70	13.6	20.0	9.70	16.4	24.0	12.0	18.9	32.5
65	9.10	16.0	22.0	10.2	19.2	26.5	12.2	21.1	38.3
70	11.6	17.0	24.5	13.4	19.2	29.5		23.6	44.0
75	12.2	17.0	25.5	13.8	20.0	32.5		23.6	45.4
80	14.2	18.4	28.0	16.6	22.5	35.5	17.3	26.2	51.6
85	15.0	22.5	30.0	17.2	26.5	38.5	18.0	30.7	55.2
90	17.2	25.0	32.5	20.0	28.0	41.5		37.4	65.8
95	18.0	27.5	38.0	21.0	31.0	45.5		44.0	65.8
100	18.0	30.5	40.5	21.5	34.5		20.9	48.0	72.9

	Radial Ball, $\alpha = 0°$			Angular Ball, $\alpha = 25°$			Roller		
Bore (mm)	L00 Xlt (kN)	200 lt (kN)	300 med (kN)	L00 Xlt (kN)	200 lt (kN)	300 med (kN)	1000 Xlt (kN)	1200 lt (kN)	1300 med (kN)
105	21.0	32.0	43.5	24.5	37.5			49.8	84.5
110	23.5	35.0	46.0	27.5	41.0	55.0	29.4	54.3	85.4
120	24.5	37.5		28.5	44.5			61.4	100.1
130	29.5	41.0		33.5	48.0	71.0	48.9	69.4	120.1
140	30.5	47.5		35.0	56.0			77.4	131.2
150	34.5			39.0	62.0		58.7	83.6	
160								113.4	
180	47.0			54.0			97.9	140.1	
200								162.4	
220								211.3	
240								258.0	

〈Table 14.2 Bearing rated load capacities, for L_R=9X10^7 , Revolution life with 90% reliability〉

Bearing Selection

DN Value

- Important bearing parameter
- ABEC-1 precision single-row ball bearings run at inner ring surface speeds up to 70 *m/s* and have a life of 3,000 *hours* while carrying 1/3 of the rated load capacity
- This translates to a $1.25X10^6$ *DN* value (bore diameter [*mm*] times [*rpm*])

$$\boldsymbol{DN\ Value} = Bore\ Diameter \times Rotor\ Speed$$

Bearing Selection

Life Requirement

- Ball bearing life varies inversely with approximately the third power of the load by Palmgren
- Rolling element bearing life corresponds to radial load, rated capacity
- Different manufacturers' catalogues use different values of L_R (Some use L_R=10^6 revolutions)

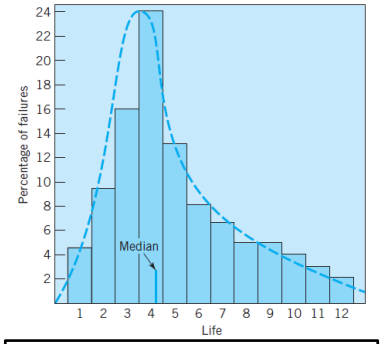
$$L = L_R \left(\frac{C}{F_r}\right)^{3.33}$$

- C : Rated capacity (from Table 14.2)
- L_R : Life corresponding to rated capacity (i.e., 9X10^7 revolutions)
- F_r : Radial load involved in the application
- L : Life corresponding to radial load F_r, or life required by the application

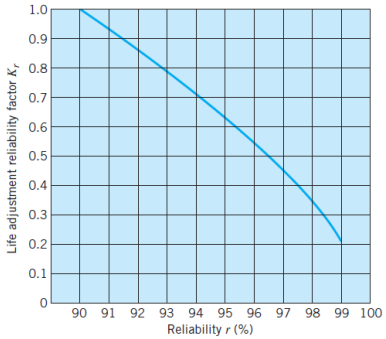
Bearing Selection

Reliability Requirement

- Median life of Rolling element bearings is 4 - 5 times the standard 10% failure fatigue life
- Fatigue life characteristically have a skewed distribution (Fig. 14.30)
- Using the general Weibull equation together with extensive experimental data, the AFBMA has formulated recommended life adjustment reliability factors, K_r (Fig. 14.31)



〈Figure 14.30 General pattern of bearing fatigue life distribution〉



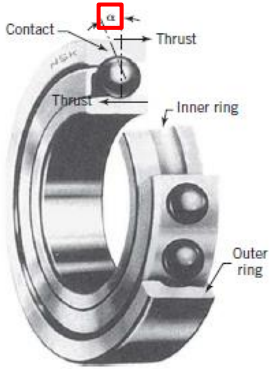
〈Figure 14.31 Reliability factor K_r〉

$$L = K_r L_R \left(\frac{C}{F_r}\right)^{3.33}$$

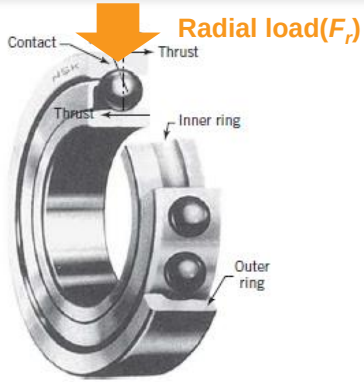
Bearing Selection

Axial Loading

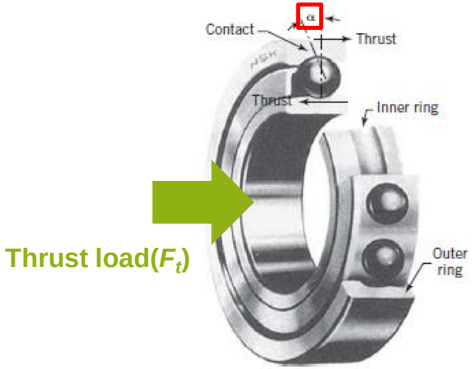
- For ball bearings, any combination of radial load (F_r) and thrust load (F_t) results in approximately the same life as does a pure radial equivalent load (F_e)
- Radial bearings have zero load angle / Standard angular contact ball bearings have 15°, 25°, and 35° load angle
- 25° load angle angular contact ball bearings are covered



〈Figure 14.32 Load angle, α〉



〈Figure 14.33 Radial load〉

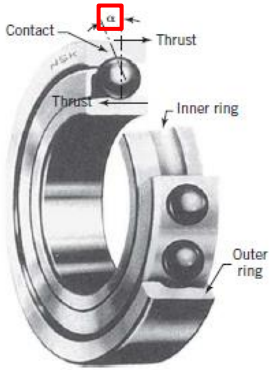


〈Figure 14.34 Thrust load〉

Bearing Selection

Axial Loading

- For ball bearings, any combination of radial load (F_r) and thrust load (F_t) results in approximately the same life as does a pure radial equivalent load (F_e)
- Radial bearings have zero load angle / Standard angular contact ball bearings have 15°, 25°, and 35° load angle
- 25° load angle angular contact ball bearings are covered



〈Figure 14.32 Load angle, α〉

Radial Ball Bearings (α=0°)

$$0 < \frac{F_t}{F_r} < 0.35$$
$$F_e = F_r$$

$$0.35 < \frac{F_t}{F_r} < 10$$
$$F_e = F_r\left[1 + 1.115\left(\frac{F_t}{F_r} - 0.35\right)\right]$$

$$10 < \frac{F_t}{F_r}$$
$$F_e = 1.176F_t$$

Angular Contact Ball Bearings (α=25°)

$$0 < \frac{F_t}{F_r} < 0.68$$
$$F_e = F_r$$

$$0.68 < \frac{F_t}{F_r} < 10$$
$$F_e = F_r\left[1 + 0.87\left(\frac{F_t}{F_r} - 0.68\right)\right]$$

$$10 < \frac{F_t}{F_r}$$
$$F_e = 0.911F_t$$

Bearing Selection

Shock Loading

- The standard bearing rated capacity is for the condition of uniform load without shock
- Shock loading has the effect of increasing the nominal load by an application factor K_a
- Table 14.3 gives representative sample values

Type of Application	Ball Bearing	Roller Bearing
Uniform load, no impact	1.0	1.0
Gearing	1.0–1.3	1.0
Light impact	1.2–1.5	1.0–1.1
Moderate impact	1.5–2.0	1.1–1.5
Heavy impact	2.0–3.0	1.5–2.0

〈Table 14.3 Application factors K_a〉

$$L = K_r L_R \left(\frac{C}{F_e K_a} \right)^{3.33}$$

Summary

Ball Bearings Design

- Bearing configurations: A radius only a trifle larger than that of the ball gives a relatively large area of contact and low contact stress
- Manufacturing tolerance: For example, tolerances on bearing bores between 35 and 50 *mm* range from +0.0000 *inch* to −0.00005 *inch* for ABEC grade 1 to +0.00000 *inch* to −0.00010 *inch* for ABEC grade 9
- Ceramic ball bearings: A hybrid ball bearing is a bearing with ceramic balls and races of metal
- Fitting of rolling element bearings: Clearance fit, Interference fit, and Transition fit
- Rolling element bearings assembly
- Bearing selection: DN Value
- Bearing life requirement: Considering radial and thrust load, reliability factor, shock loading

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