The University of Jordan
School of Engineering

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Mechanical Engineering	Machine Deisgn II	0904436	Fall 2022-2023

Rolling-Contact Bearings

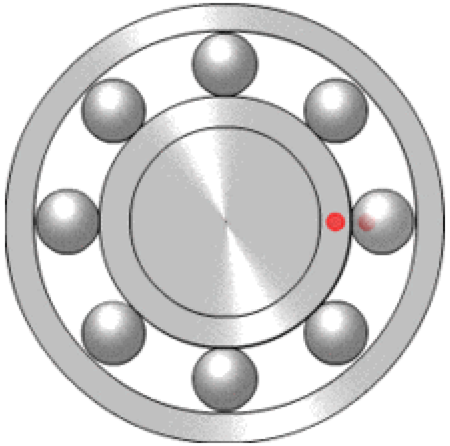
Introduction

A bearing is a device to allow constrained relative motion between two or more parts, typically rotation or linear movement.

Bearings may be classified broadly according to the motions they allow and according to their principle of operation as well as by the directions of applied loads they can handle.

There are many types of bearings, with varying shape, material, lubrication, principal of operation, and so on.

For example, rolling-element bearings use spheres or drums rolling between the parts to reduce friction; reduced friction allows tighter tolerances and thus higher precision than a plain bearing, and reduced wear extends the time over which the machine stays accurate.



Introduction

Plain bearings are commonly made of varying types of metal or plastic depending on the load, how corrosive or dirty the environment is, and so on.

Bearing friction and life may be altered dramatically by the type and application of lubricants.

A lubricant may improve bearing friction and life, but for food processing a bearing may be lubricated by an inferior food-safe lubricant to avoid food contamination; in other situations a bearing may be run without lubricant because continuous lubrication is not feasible, and lubricants attract dirt that damages the bearings.




Introduction

There are at least six common principles of operation for bearings:

- plain bearing, also known by the specific styles: bushings, journal bearings, sleeve bearings, rifle bearings.
- rolling-element bearings such as ball bearings and roller bearings. Also angular contact bearing: designed for combination radial and axial loading.
- jewel bearings, in which the load is carried by rolling the axle slightly off-center.
- fluid bearings, in which the load is carried by a gas or Liquid.
- magnetic bearings, in which the load is carried by a magnetic field.
- flexure bearings, in which the motion is supported by a load element which bends.






Introduction

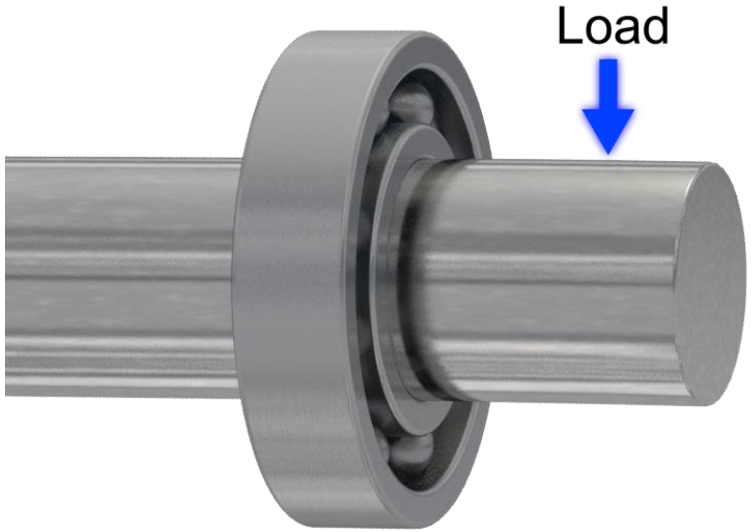
Type	Description	Friction	Stiffness†	Speed	Life	Notes
Plain bearing	Rubbing surfaces, usually with lubricant; some bearings use pumped lubrication and behave similarly to fluid bearings.	Depends on materials and construction, PTFE has coefficient of friction ~0.05-0.35, depending upon fillers added	Good, provided wear is low, but some slack is normally present	Low to very high	Moderate (depends on lubrication)	Widely used, relatively high friction, suffers from stiction in some applications. Depending upon the application, lifetime can be higher or lower than rolling element bearings.
Rolling element bearing	Ball or rollers are used to prevent or minimise rubbing	Rolling coefficient of friction with steel can be ~0.005 (adding resistance due to seals, packed grease, preload and misalignment can increase friction to as much as 0.125)	Good, but some slack is usually present	Moderate to high (often requires cooling)	Moderate to high (depends on lubrication, often requires maintenance)	Used for higher moment loads than plain bearings with lower friction
Jewel bearing	Off-center bearing rolls in seating	Low	Low due to flexing	Low	Adequate (requires maintenance)	Mainly used in low-load, high precision work such as clocks. Jewel bearings may be very small.
Fluid bearing	Fluid is forced between two faces and held in by edge seal	Zero friction at zero speed, low	Very high	Very high (usually limited to a few hundred feet per second at/by seal)	Virtually infinite in some applications, may wear at startup/shutdown in some cases. Often negligible maintenance.	Can fail quickly due to grit or dust or other contaminants. Maintenance free in continuous use. Can handle very large loads with low friction.
Magnetic bearings	Faces of bearing are kept separate by magnets (electromagnets or eddy currents)	Zero friction at zero speed, but constant power for levitation, eddy currents are often induced when movement occurs, but may be negligible if magnetic field is quasi-static	Low	No practical limit	Indefinite. Maintenance free. (with electromagnets)	Active magnetic bearings (AMB) need considerable power. Electrodynamic bearings (EDB) does not require external power.
Flexure bearing	Material flexes to give and constrain movement	Very low	Low	Very high.	Very high or low depending on materials and strain in application. Usually maintenance free.	Limited range of movement, no backlash, extremely smooth motion

†Stiffness is the amount that the gap varies when the load on the bearing changes, it is distinct from the friction of the bearing.

Introduction

Common motions permitted by bearings are:

- axial rotation e.g. shaft rotation
- linear motion e.g. drawer
- spherical rotation e.g. ball and socket joint
- hinge motion e.g. door, elbow, knee



Introduction

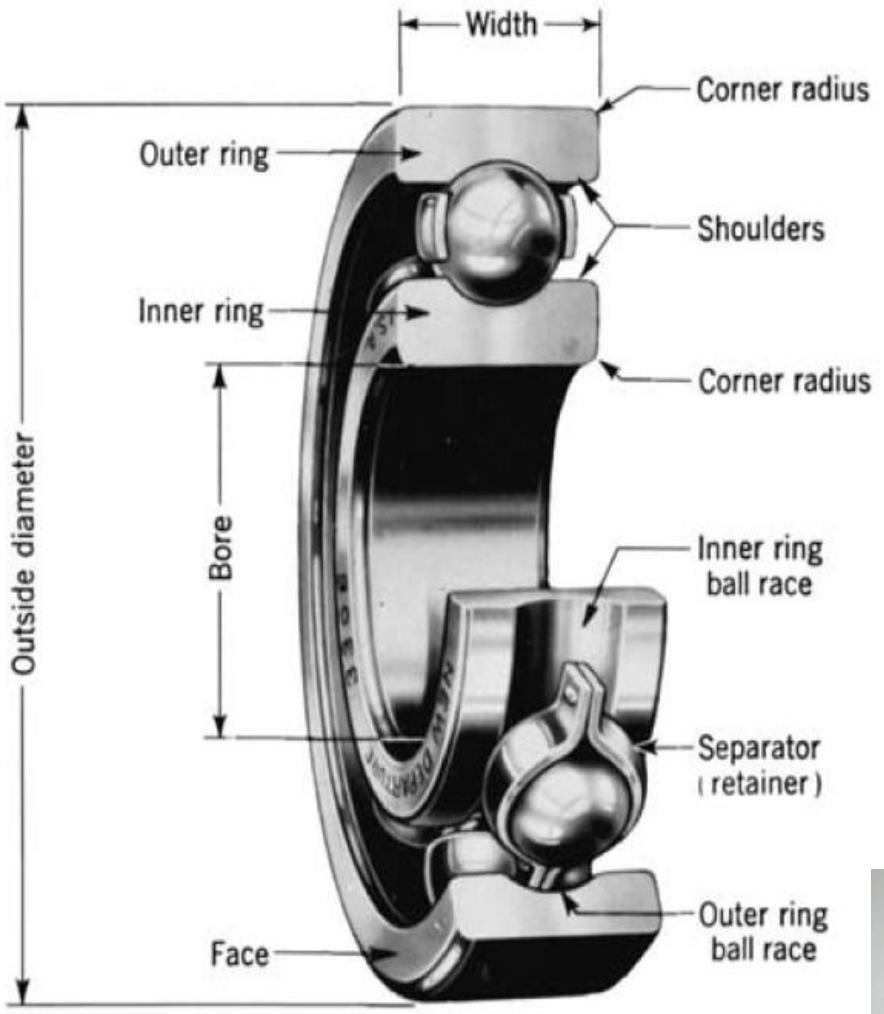
Bearings are manufactured to take pure radial loads, pure thrust loads, or a combination of the two kinds of loads.

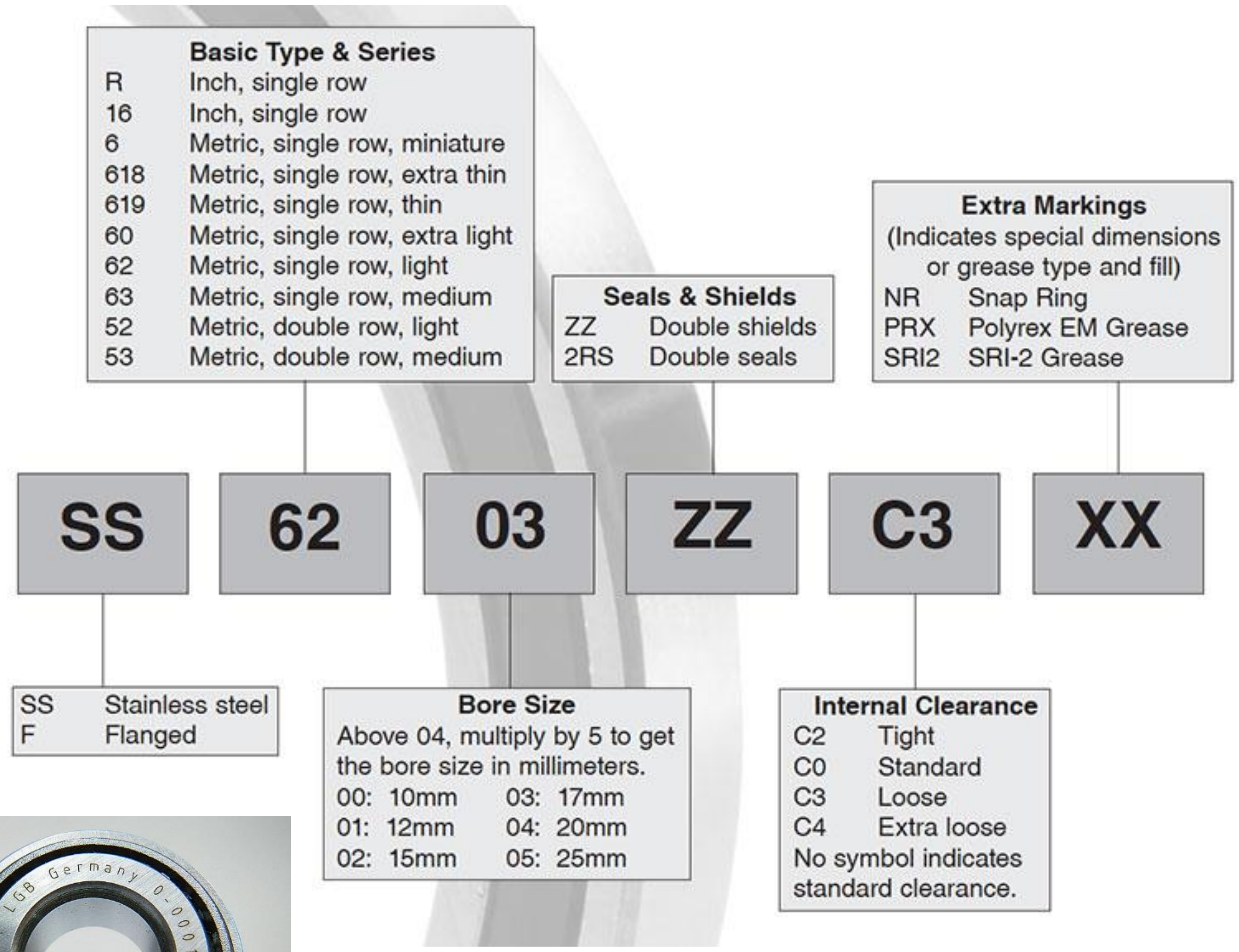
The nomenclature of a ball bearing is illustrated in Fig. 11–1, which also shows the four essential parts of a bearing: These are:

1. the outer ring,
2. the inner ring,
3. the balls or rolling elements, and
4. the separator.

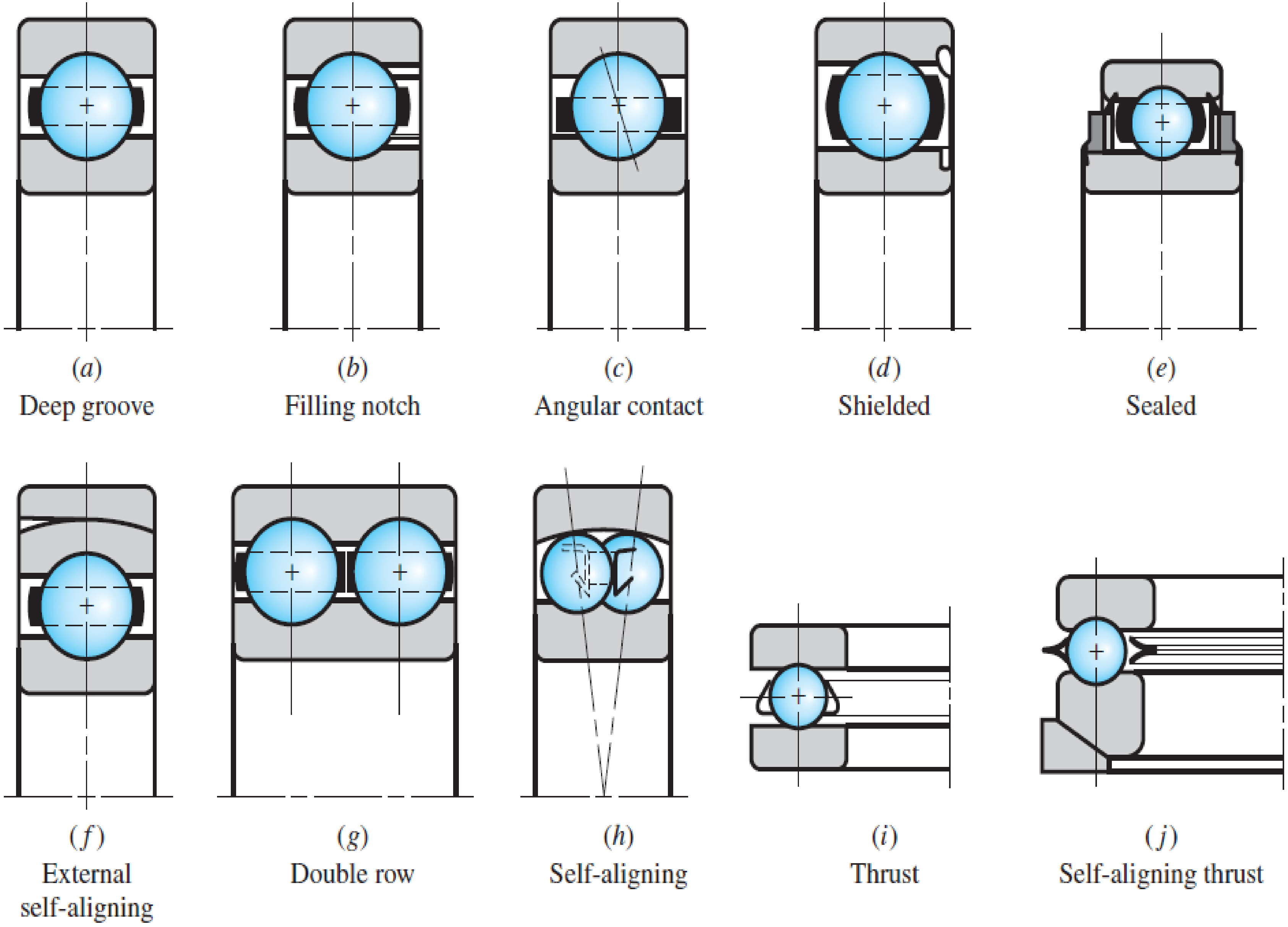
In low-priced bearings, the separator is sometimes omitted, but it has the important function of separating the elements so that rubbing contact will not occur.

Nomenclature of a ball bearing

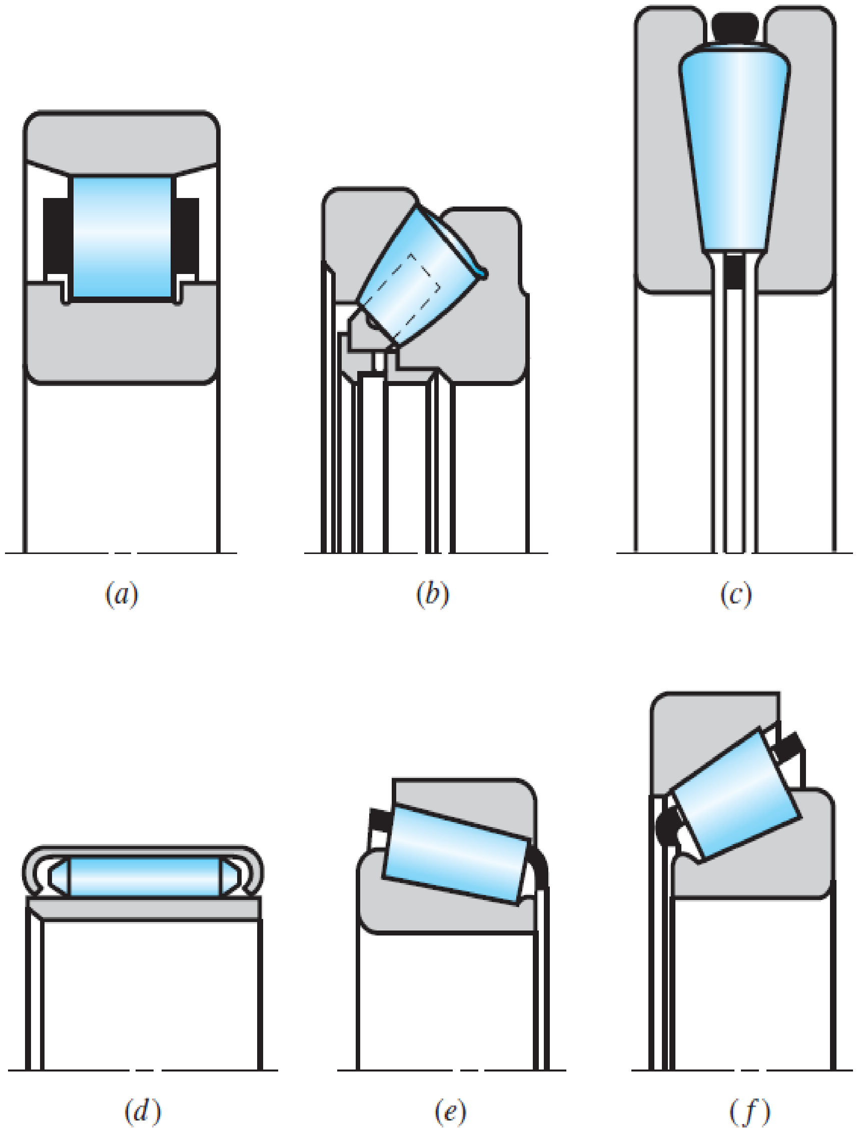




Various types of ball bearings



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. *(Courtesy of The Timken Company.)*

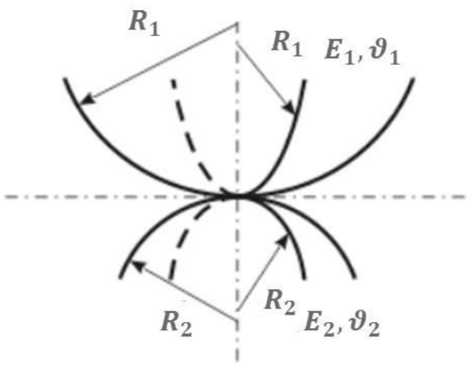
How are bearings made?

https://www.youtube.com/watch?v=b6svVy1lYOA

Bearing Life

When the ball or roller of rolling-contact bearings rolls, contact stresses occur on the inner ring, the rolling element, and on the outer ring.

Because the curvature of the contacting elements in the axial direction is different from that in the radial direction, the equations for these stresses are more involved than in the Hertz equations.



$$P_{mean} = \frac{F}{\pi a^2}, P_{max} = \frac{4}{\pi P_{mean}}$$

$$a = \sqrt[\frac{1}{3}]{\frac{3FR}{E'}} \qquad \frac{1}{R} = \frac{2}{R_1} + \frac{2}{R_2}$$

If a bearing is clean and properly lubricated, is mounted and sealed against the entrance of dust and dirt, is maintained in this condition, and is operated at reasonable temperatures, then metal fatigue will be the only cause of failure.

Bearing Life

Inasmuch as metal fatigue implies many millions of stress applications successfully endured, we need a quantitative life measure.

Common life measures are:

- Number of revolutions of the inner ring (outer ring stationary) until the first tangible evidence of fatigue.
- Number of hours of use at a standard angular speed until the first tangible evidence of fatigue.

It is important to realize, as in all fatigue, life as defined above is a stochastic variable and, as such, has both a distribution and associated statistical parameters.

The life measure of an individual bearing is defined as the total number of revolutions (or hours at a constant speed) of bearing operation until the failure criterion is developed.

Bearing Life

The American Bearing Manufacturers Association (ABMA) standard states that the failure criterion is the first evidence of fatigue.

The fatigue criterion used by the Timken Company laboratories is the spalling or pitting of an area of 0.01 in^2.

Timken also observes that the useful life of the bearing may extend considerably beyond this point.

This is an operational definition of fatigue failure in rolling bearings.

Bearing Life

The *rating life* is a term sanctioned by the ABMA and used by most manufacturers.

The rating life of a group of nominally identical ball or roller bearings is defined as the number of revolutions (or hours at a constant speed) that 90 percent of a group of bearings will achieve or exceed before the failure criterion develops.

The terms *minimum life,* L_{10} *life,* and B_{10} *life* are also used as synonyms for rating life.

The rating life is the 10th percentile location of the bearing group's revolutions-to-failure distribution.

Bearing Life

Median life is the 50th percentile life of a group of bearings.

When many groups of bearings are tested, the median life is between 4 and 5 times the L_{10} life.

Each bearing manufacturer will choose a specific rating life for which load ratings of its bearings are reported. The most commonly used rating life is 10^6 revolutions.

The Timken Company is a well-known exception, rating its bearings at 3 000 hours at 500 rev/min, which is $90(10^6)$ revolutions.

These levels of rating life are actually quite low for today's bearings, but since rating life is an arbitrary reference point, the traditional values have generally been maintained.

Bearing Load Life at Rated Reliability

When nominally identical groups are tested to the life-failure criterion at different loads, the data are plotted on a graph as depicted in Fig. 11–4 using a log-log transformation.

To establish a single point, load F_1 and the rating life of group one $(L_{10})_1$ are the coordinates that are logarithmically transformed.

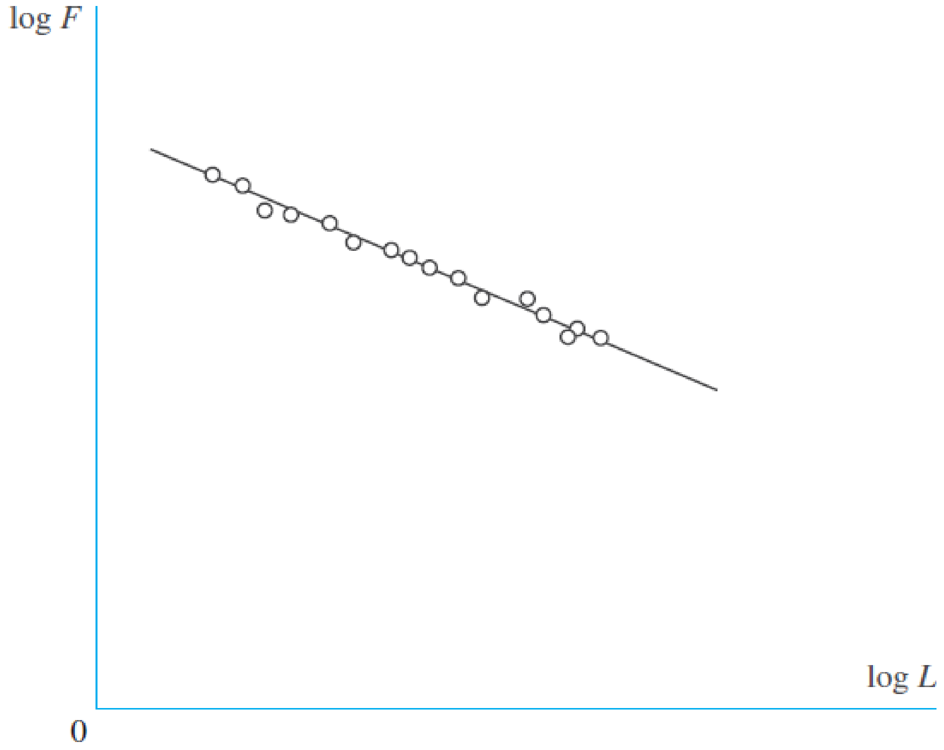


Figure 11–4

Typical bearing load-life log-log curve.

Bearing Load Life at Rated Reliability

The reliability associated with this point, and all other points, is 0.90. Thus we gain a glimpse of the load-life function at 0.90 reliability. Using a regression equation of the form:

$$FL^{1/a} = \text{constant} \tag{11-1}$$

the result of many tests for various kinds of bearings result in

- *a* = 3 for ball bearings
- *a* = 10/3 for roller bearings (cylindrical and tapered roller)

A *catalog load rating* is defined as the radial load that causes 10 percent of a group of bearings to fail at the bearing manufacturer's rating life.

We shall denote the catalog load rating as C_{10}. The catalog load rating is often referred to as a *Basic Dynamic Load Rating,* or sometimes just Basic Load Rating, if the manufacturer's rating life is 10^6 revolutions.

Bearing Load Life at Rated Reliability

The radial load that would be necessary to cause failure at such a low life would be unrealistically high.

Consequently, *the Basic Load Rating should be viewed as a reference value*, and not as an actual load to be achieved by a bearing.

In selecting a bearing for a given application, it is necessary to relate the desired load and life requirements to the published catalog load rating corresponding to the catalog rating life. From Eq. (11–1) we can write:

$$F_1 L_1^{1/a} = F_2 L_2^{1/a} \qquad (11\text{–}2)$$

where the subscripts 1 and 2 can refer to any set of load and life conditions.

Bearing Load Life at Rated Reliability

Letting F_1 and L_1 correlate with the catalog load rating and rating life, and F_2 and L_2 correlate with desired load and life for the application, we can express Eq. (11–2) as:

$$F_R L_R^{1/a} = F_D L_D^{1/a} \qquad (a)$$

where the units of L_R and L_D are revolutions, and the subscripts R and D stand for Rated and Desired.

It is sometimes convenient to express the life in hours at a given speed. Accordingly, any life L in revolutions can be expressed as:

$$L = 60\,\mathcal{L} n \qquad (b)$$

where $\mathcal{L}$ is in hours, n is in rev/min, and 60 min/h is the appropriate conversion factor.

Bearing Load Life at Rated Reliability

Incorporating Eq. (*b*) into Eq. (*a*),

$$L = 60\,\mathcal{L}n \quad \rightarrow \quad F_R L_R^{1/a} = F_D L_D^{1/a}$$

$$F_R(\mathcal{L}_R n_R 60)^{1/a} = F_D(\mathcal{L}_D n_D 60)^{1/a} \qquad (c)$$

- F_R: catalog rating, lbf or kN
- $\mathcal{L}_R$: rating life in hours
- n_R: rating speed, rev/min
- F_D: desired radial load, lbf or kN
- $\mathcal{L}_D$: desired life, hours
- n_D: desired speed, rev/min

Bearing Load Life at Rated Reliability

Solving Eq. (*c*) for F_R, and noting that it is simply an alternate notation for the catalog load rating C_{10}, we obtain an expression for a catalog load rating as a function of the desired load, desired life, and catalog rating life.

$$C_{10} = F_R = F_D \left(\frac{L_D}{L_R} \right)^{1/a} = F_D \left(\frac{\mathcal{L}_D n_D 60}{\mathcal{L}_R n_R 60} \right)^{1/a} \qquad (11\text{–}3)$$

It is sometimes convenient to define $x_D = L_D/L_R$ as a dimensionless *multiple of rating life.*

Sample Bearing Catalogue

Principal dimensions			Basic load ratings		Allowable load limit	Speed ratings		Mass	Designation
			Dynamic	Static		Grease	Oil		
d_b	d_a	b_w	C	C_0	w_{all}				
mm			N		N			kg	
in.			lbf		lbf	rpm		lbm	—
15	**35**	**11**	**12 500**	**10 200**	**1 200**	**18 000**	**22 000**	**0.047**	NU 202 EC
0.5906	1.3780	0.4331	2 810	2 290	274			0.10	
	42	**13**	**19 400**	**15 300**	**1 860**	**16 000**	**19 000**	**0.086**	NU 302 EC
	1.6535	0.5118	4 360	3 440	418			0.19	
20	**47**	**14**	**25 100**	**22 000**	**2 750**	**13 000**	**16 000**	**0.11**	NU 204 EC
0.7874	1.8504	0.5512	5 640	4 950	618			0.24	
	52	**15**	**30 800**	**26 000**	**3 250**	**12 000**	**15 000**	**0.15**	NU 304 EC
	2.0472	0.5906	6 920	5 850	731			0.33	
25	**52**	**15**	**28 600**	**27 000**	**3 350**	**11 000**	**14 000**	**0.13**	NU 205 EC
0.9843	2.0472	0.5906	6 430	6 070	753			0.29	
	62	**17**	**40 200**	**36 500**	**4 550**	**9 500**	**12 000**	**0.24**	NU 305 EC
	2.4409	0.6693	9 040	8 210	1 020			0.53	
30	**62**	**16**	**38 000**	**36 500**	**4 450**	**9 500**	**12 000**	**0.20**	NU 206 EC
1.811	2.4409	0.6299	8 540	8 210	1 020			0.44	
	72	**19**	**51 200**	**48 000**	**6 200**	**9 000**	**11 000**	**0.36**	NU 306 EC
	2.8346	0.7480	11 500	10 800	1 390			0.79	
35	**72**	**17**	**48 400**	**48 000**	**6 100**	**8 500**	**10 000**	**0.30**	NU 207 EC
1.3780	2.8346	0.6693	10 900	10 800	1 370			0.66	
	80	**21**	**64 400**	**63 000**	**8 150**	**8 000**	**9 500**	**0.48**	NU 307 EC
	3.1496	0.8268	14 500	14 200	1 830			1.05	
40	**80**	**18**	**53 900**	**53 000**	**6 700**	**7 500**	**9 000**	**0.37**	NU 208 EC
1.5748	3.1496	0.7087	12 100	11 900	1 510			0.82	
	90	**23**	**80 900**	**78 000**	**10 200**	**6 700**	**8 000**	**0.65**	NU 308 EC
	3.5433	0.9055	18 200	17 500	2 290			1.05	
45	**85**	**19**	**60 500**	**64 000**	**8 150**	**6 700**	**8 000**	**0.43**	NU 209 EC
1.7717	3.3465	0.7480	13 600	14 400	1 830			0.95	
	100	**25**	**99 000**	**100 000**	**12 900**	**6 300**	**7 500**	**0.90**	NU 309 EC
	3.9370	0.9843	22 300	22 500	2 900			2.00	
50	**90**	**20**	**64 400**	**69 500**	**8 800**	**6 300**	**7 500**	**0.48**	NU 210 EC
1.9685	3.5433	0.7874	14 500	15 600	1 980			1.05	
	110	**27**	**110 000**	**112 000**	**15 000**	**5 000**	**6 000**	**1.15**	NU 310 EC
	4.3307	1.0630	24 700	25 200	3 370			2.55	

Example 01

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?

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

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

Example 01

Dimensions and Load Ratings for Single-Row 02-Series Deep-Groove and Angular-Contact Ball Bearings

Bore, mm	OD, mm	Width, mm	Fillet Radius, mm	Shoulder Diameter, mm d_S	d_H	Load Ratings, kN Deep Groove C_{10}	C_0	Angular Contact C_{10}	C_0
10	30	9	0.6	12.5	27	5.07	2.24	4.94	2.12
12	32	10	0.6	14.5	28	6.89	3.10	7.02	3.05
15	35	11	0.6	17.5	31	7.80	3.55	8.06	3.65
17	40	12	0.6	19.5	34	9.56	4.50	9.95	4.75
20	47	14	1.0	25	41	12.7	6.20	13.3	6.55
25	52	15	1.0	30	47	14.0	6.95	14.8	7.65
30	62	16	1.0	35	55	19.5	10.0	20.3	11.0
35	72	17	1.0	41	65	25.5	13.7	27.0	15.0
40	80	18	1.0	46	72	30.7	16.6	31.9	18.6
45	85	19	1.0	52	77	33.2	18.6	35.8	21.2
50	90	20	1.0	56	82	35.1	19.6	37.7	22.8
55	100	21	1.5	63	90	43.6	25.0	46.2	28.5
60	110	22	1.5	70	99	47.5	28.0	55.9	35.5
65	120	23	1.5	74	109	55.9	34.0	63.7	41.5
70	125	24	1.5	79	114	61.8	37.5	68.9	45.5

Combined Radial and Thrust Loading

A ball bearing is capable of resisting radial loading and a thrust loading. Furthermore, these can be combined.

Consider F_a and F_r to be the axial thrust and radial loads, respectively, and F_e to be the *equivalent radial load* that does the same damage as the combined radial and thrust loads together.

A rotation factor V is defined such that $V = 1$ when the inner ring rotates and $V = 1.2$ when the outer ring rotates.

Self-aligning bearings are an exception: they have $V = 1$ for rotation of either ring. Straight or cylindrical roller bearings will take no axial load, or very little.

Combined Radial and Thrust Loading

Two dimensionless groups can now be formed: $F_e/(VF_r)$ and $F_a/(VF_r)$.

When these two dimensionless groups are plotted as in Fig. 11–6, the data fall in a gentle curve that is well approximated by two straight-line segments.

The abscissa e is defined by the intersection of the two lines.

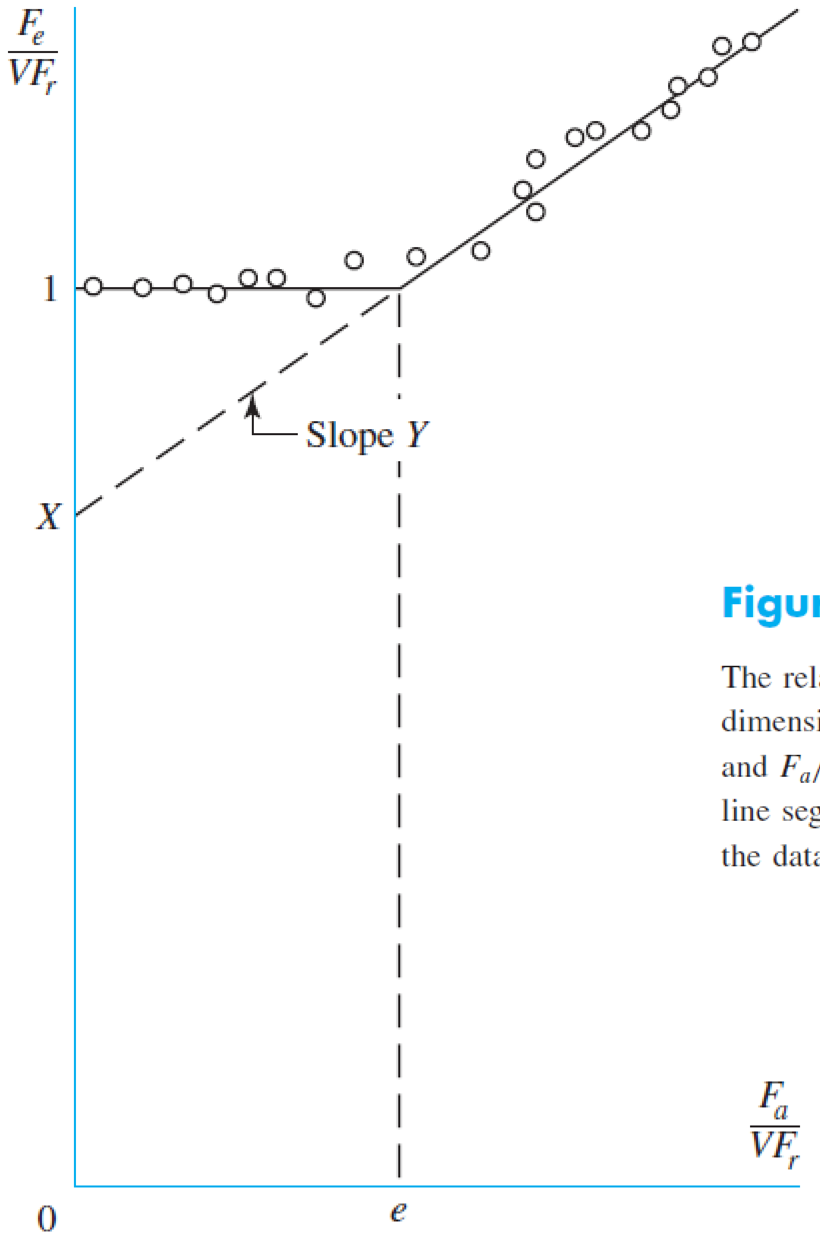


Figure 11–6

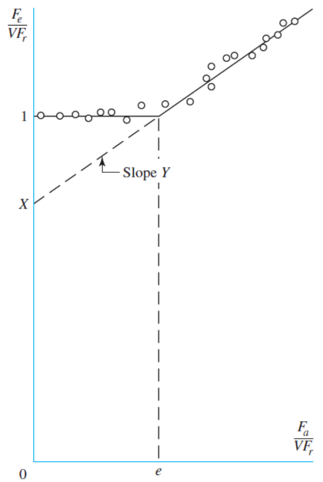
The relationship of dimensionless group $F_e/(VF_r)$ and $F_a/(VF_r)$ and the straight-line segments representing the data.

Combined Radial and Thrust Loading

The equations for the two lines shown in Fig. 11–6 are:

$$\frac{F_e}{VF_r} = 1 \qquad \text{when} \quad \frac{F_a}{VF_r} \le e \qquad (11\text{–}11a)$$

$$\frac{F_e}{VF_r} = X + Y\frac{F_a}{VF_r} \qquad \text{when} \quad \frac{F_a}{VF_r} > e \qquad (11\text{–}11b)$$



where, X is the ordinate intercept and Y is the slope of the line for $F_a/(VF_r) > e$. It is common to express Eqs. (11–11a) and (11–11b) as a single equation,

$$F_e = X_i VF_r + Y_i F_a \qquad (11\text{–}12)$$

where i = 1 when $F_a/(VF_r) \le e$ and i = 2 when $F_a/(VF_r) > e$. The X and Y factors depend upon the geometry and construction of the specific bearing.

Combined Radial and Thrust Loading

Table 11–1 lists representative values of X_1, Y_1, X_2, and Y_2 as a function of e, which in turn is a function of F_a/C_0, where C_0 is the basic static load rating.

Table 11–1

Equivalent Radial Load Factors for Ball Bearings

		$F_a/(VF_r) \le e$		$F_a/(VF_r) > e$	
F_a/C_0	e	X_1	Y_1	X_2	Y_2
0.014*	0.19	1.00	0	0.56	2.30
0.021	0.21	1.00	0	0.56	2.15
0.028	0.22	1.00	0	0.56	1.99
0.042	0.24	1.00	0	0.56	1.85
0.056	0.26	1.00	0	0.56	1.71
0.070	0.27	1.00	0	0.56	1.63
0.084	0.28	1.00	0	0.56	1.55
0.110	0.30	1.00	0	0.56	1.45
0.17	0.34	1.00	0	0.56	1.31
0.28	0.38	1.00	0	0.56	1.15
0.42	0.42	1.00	0	0.56	1.04
0.56	0.44	1.00	0	0.56	1.00

*Use 0.014 if $F_a/C_0 < 0.014$.

Combined Radial and Thrust Loading

The *basic static load rating* is the load that will produce a total permanent deformation in the raceway and rolling element at any contact point of 0.0001 times the diameter of the rolling element.

The basic static load rating is typically tabulated, along with the basic dynamic load rating C_{10}, in bearing manufacturers' publications.

The ABMA has established standard boundary dimensions for bearings, which define the bearing bore, the outside diameter (OD), the width, and the fillet sizes on the shaft and housing shoulders.

The basic plan covers all ball and straight roller bearings in the metric sizes. The plan is quite flexible in that, for a given bore, there is an assortment of widths and outside diameters. Furthermore, the outside diameters selected are such that, for a particular outside diameter, one can usually find a variety of bearings having different bores and widths.

Combined Radial and Thrust Loading

Table 11–2

Dimensions and Load Ratings for Single-Row 02-Series Deep-Groove and Angular-Contact Ball Bearings

Bore, mm	OD, mm	Width, mm	Fillet Radius, mm	Shoulder Diameter, mm		Load Ratings, kN			
						Deep Groove		Angular Contact	
				d_S	d_H	C_{10}	C_0	C_{10}	C_0
10	30	9	0.6	12.5	27	5.07	2.24	4.94	2.12
12	32	10	0.6	14.5	28	6.89	3.10	7.02	3.05
15	35	11	0.6	17.5	31	7.80	3.55	8.06	3.65
17	40	12	0.6	19.5	34	9.56	4.50	9.95	4.75
20	47	14	1.0	25	41	12.7	6.20	13.3	6.55
25	52	15	1.0	30	47	14.0	6.95	14.8	7.65
30	62	16	1.0	35	55	19.5	10.0	20.3	11.0
35	72	17	1.0	41	65	25.5	13.7	27.0	15.0
40	80	18	1.0	46	72	30.7	16.6	31.9	18.6
45	85	19	1.0	52	77	33.2	18.6	35.8	21.2
50	90	20	1.0	56	82	35.1	19.6	37.7	22.8
55	100	21	1.5	63	90	43.6	25.0	46.2	28.5
60	110	22	1.5	70	99	47.5	28.0	55.9	35.5
65	120	23	1.5	74	109	55.9	34.0	63.7	41.5
70	125	24	1.5	79	114	61.8	37.5	68.9	45.5
75	130	25	1.5	86	119	66.3	40.5	71.5	49.0

Combined Radial and Thrust Loading

The bearings are identified by a two-digit number called the *dimension-series code*.

The first number in the code is from the *width series,* 0, 1, 2, 3, 4, 5, and 6. The second number is from the *diameter series* (outside), 8, 9, 0, 1, 2, 3, and 4. Figure 11–7 shows the variety of bearings that may be obtained with a particular bore.

Since the dimension series code does not reveal the dimensions directly, it is necessary to resort to tabulations.

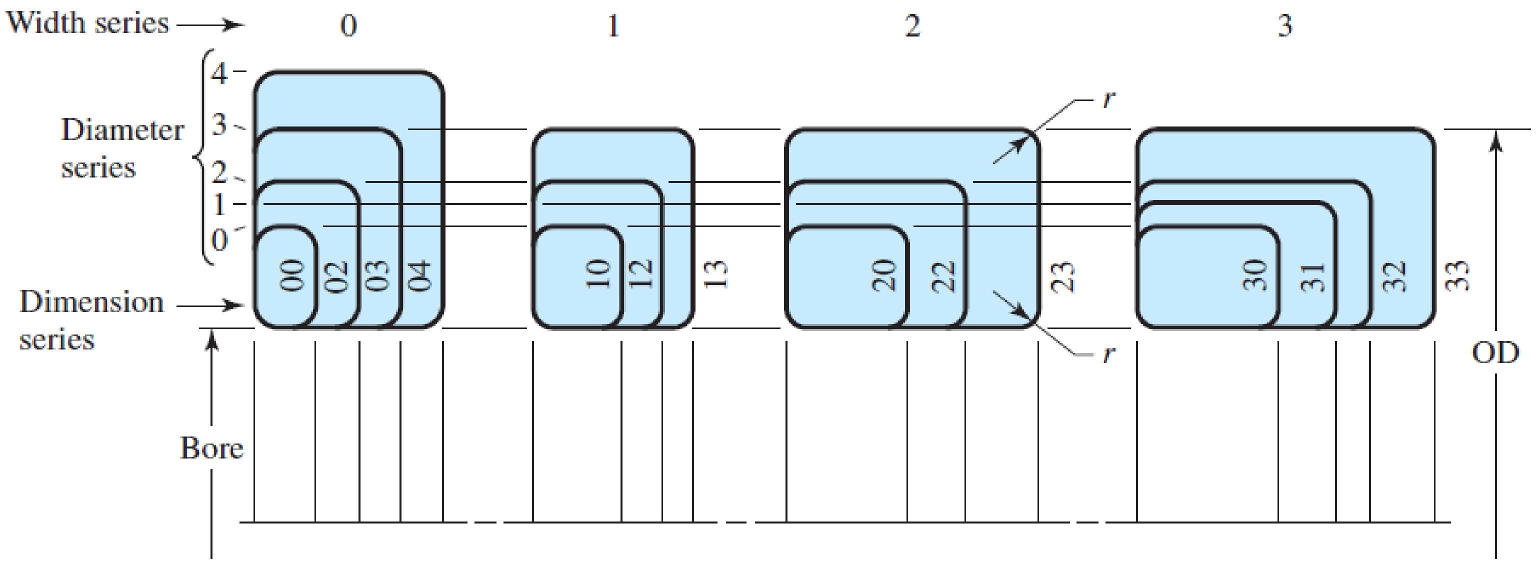


Figure 11–7

The basic ABMA plan for boundary dimensions. These apply to ball bearings, straight roller bearings, and spherical roller bearings, but not to inch-series ball bearings or tapered roller bearings. The contour of the corner is not specified. It may be rounded or chamfered, but it must be small enough to clear the fillet radius specified in the standards.

Combined Radial and Thrust Loading

The 02 series is used here as an example of what is available. See Table 11–2.

The housing and shaft shoulder diameters listed in the tables should be used whenever possible to secure adequate support for the bearing and to resist the maximum thrust loads (Fig. 11–8).

Table 11–3 lists the dimensions and load ratings of some straight roller bearings.

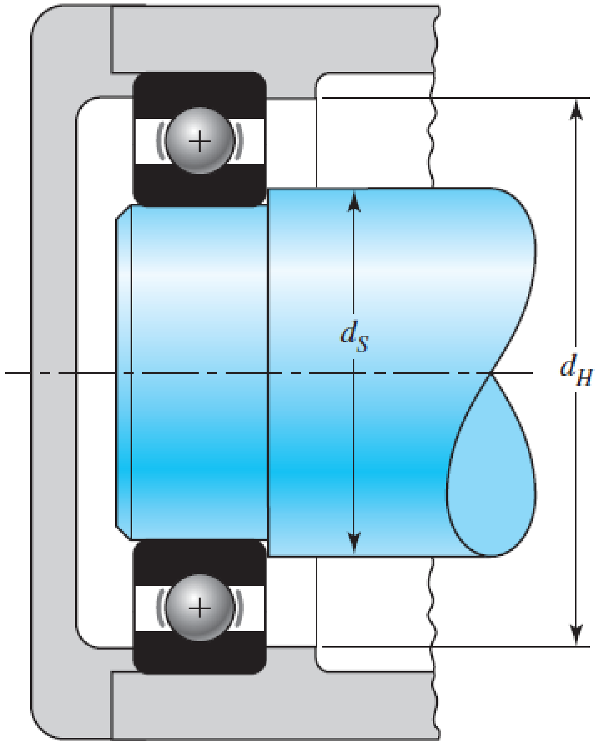


Figure 11–8

Shaft and housing shoulder diameters d_S and d_H should be adequate to ensure good bearing support.

Combined Radial and Thrust Loading

Table 11–3

Dimensions and Basic Load Ratings for Cylindrical Roller Bearings

	02-Series				03-Series			
Bore, mm	OD, mm	Width, mm	Load Rating, kN C_{10}	Load Rating, kN C_0	OD, mm	Width, mm	Load Rating, kN C_{10}	Load Rating, kN C_0
25	52	15	16.8	8.8	62	17	28.6	15.0
30	62	16	22.4	12.0	72	19	36.9	20.0
35	72	17	31.9	17.6	80	21	44.6	27.1
40	80	18	41.8	24.0	90	23	56.1	32.5
45	85	19	44.0	25.5	100	25	72.1	45.4
50	90	20	45.7	27.5	110	27	88.0	52.0
55	100	21	56.1	34.0	120	29	102	67.2
60	110	22	64.4	43.1	130	31	123	76.5
65	120	23	76.5	51.2	140	33	138	85.0
70	125	24	79.2	51.2	150	35	151	102
75	130	25	93.1	63.2	160	37	183	125
80	140	26	106	69.4	170	39	190	125
85	150	28	119	78.3	180	41	212	149
90	160	30	142	100	190	43	242	160
95	170	32	165	112	200	45	264	189
100	180	34	183	125	215	47	303	220

Combined Radial and Thrust Loading

To assist the designer in the selection of bearings, most of the manufacturers' handbooks contain data on bearing life for many classes of machinery, as well as information on load-application factors.

Such information has been accumulated the hard way, that is, by experience, and the beginner designer should utilize this information until he or she gains enough experience to know when deviations are possible.

Table 11–4 contains recommendations on bearing life for some classes of machinery. The load-application factors in Table 11–5 serve the same purpose as factors of safety; use them to increase the equivalent load before selecting a bearing.

Combined Radial and Thrust Loading

Table 11–4

Bearing-Life Recommendations for Various Classes of Machinery

Type of Application	Life, kh
Instruments and apparatus for infrequent use	Up to 0.5
Aircraft engines	0.5–2
Machines for short or intermittent operation where service interruption is of minor importance	4–8
Machines for intermittent service where reliable operation is of great importance	8–14
Machines for 8-h service that are not always fully utilized	14–20
Machines for 8-h service that are fully utilized	20–30
Machines for continuous 24-h service	50–60
Machines for continuous 24-h service where reliability is of extreme importance	100–200

Combined Radial and Thrust Loading

Table 11–5

Load-Application Factors

Type of Application	Load Factor
Precision gearing	1.0–1.1
Commercial gearing	1.1–1.3
Applications with poor bearing seals	1.2
Machinery with no impact	1.0–1.2
Machinery with light impact	1.2–1.5
Machinery with moderate impact	1.5–3.0

Example 02

An SKF 6210 angular-contact ball bearing has an axial load F_a of 400 lbf and a radial load F_r of 500 lbf applied with the outer ring stationary.

The basic static load rating C_0 is 4450 lbf and the basic load rating C_{10} is 7900 lbf. Estimate the $\mathcal{L}_{10}$ life at a speed of 720 rev/min.

Solution

1. Find the combined load, Fe
2. Calculate $\mathcal{L}_{10}$ from equation 11-3.

Comparison of Bearing Types

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

Bearing Materials

Comparison of Bearing Materials

Property	Unit	Steels: Beariing Steel 52 100	Steels: Stainless Steel 440C	Titanium/Nickel: Nitinol 60NiTi	Cermics: Silicon Nitride Si_3N_4	Cermics: Zirconia Oxide ZrO_2	Cermics: Alumina Oxide Al_2O_3	Cermics: Silicon Carbide SiC	Monel: K-500 Metal	Plastic: Polyamide (Nylon 66)
Density	kg/m^3	7680	7750	6700	3230	6050	3920	3120	8434	1360
	lbm/ft^3	480	484	418	202	378	245	195	527	85
Modulus of elasticity	GPa	207	200	114	300	210	340	440	179	4.2
	ksi	30 000	29 000	16 500	43 500	30 500	49 300	63 800	25 950	610
Hardness	Vickers	700	700	650	1500	1200	1650	2800	263	—
Flexural strength	MPa	2240	1930	900	450	210	230	380	965	82
	ksi	325	280	131	65	31	33	55	140	11.9
Maximum use temperature	°C	300	350	400	1050	750	1500	1700	315	130
	°F	570	660	750	1920	1380	2730	3100	600	270

Note: Data taken from a variety of sources and are representative only. Actual properties highly dependent on specific composition, processing, thermal treatment, and form.

Example 03

Select a single-row, deep-groove SKF ball bearing to carry 650 lb of pure radial load from a shaft that rotates at 600 rpm. The design life is to be 30 000 h. The bearing is to be mounted on a shaft with a minimum acceptable diameter of 1.48 in. Use the table in next slides. Go to SKF website and find the full properties of the selected bearing: CAD model, Technical specifications datasheet, (www.skf.com).

Example 04

Select a single-row, deep-groove SKF ball bearing from the Table in the next slides 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. Go to SKF website and find the full properties of the selected bearing: CAD model, Technical specifications datasheet, (www.skf.com).

Dimensions for Single Row, Deep-groove Ball Bearings

Dimensions for Single Row, Deep-groove Ball Bearings

Bearing number	Nominal bearing dimensions: Bore, d		Outside dia., D		Width, B		Basic load ratings: Static, C_o		Dynamic, C		Maximum fillet radius r_{max}[1]		Minimum shaft shoulder diameter, S		Maximum housing shoulder diameter, H		Bearing mass	
	mm	in	mm	in	mm	in	kN	lb_f	kN	lb_f	mm	in	mm	in	mm	in	kg	lb_m
6000	**10**	0.3937	26	1.0236	8	0.3150	1.96	441	4.62	1039	0.3	0.012	12	0.472	24	0.945	0.019	0.042
6200	**10**	0.3937	30	1.1811	9	0.3543	2.36	531	5.07	1140	0.6	0.024	14	0.551	26	1.024	0.032	0.071
6300	**10**	0.3937	35	1.3780	11	0.4331	8.06	1812	3.40	764	0.6	0.024	14	0.551	31	1.220	0.053	0.117
6001	**12**	0.4724	28	1.1024	8	0.3150	2.36	531	5.07	1140	0.3	0.012	14	0.551	26	1.024	0.022	0.049
6201	**12**	0.4724	32	1.2598	10	0.3937	3.10	697	6.89	1549	0.6	0.024	16	0.630	28	1.102	0.037	0.082
6301	**12**	0.4724	37	1.4567	12	0.4724	4.15	933	9.75	2192	1.0	0.039	17	0.669	32	1.260	0.060	0.132
6002	**15**	0.5906	32	1.2598	9	0.3543	2.85	641	5.59	1257	0.3	0.012	17	0.669	30	1.181	0.030	0.066
6202	**15**	0.5906	35	1.3780	11	0.4331	3.75	843	7.80	1754	0.6	0.024	19	0.748	31	1.220	0.045	0.099
6302	**15**	0.5906	42	1.6535	13	0.5118	5.40	1214	11.40	2563	1.0	0.039	20	0.787	37	1.457	0.082	0.181
6003	**17**	0.6693	35	1.3780	10	0.3937	3.25	731	6.05	1360	0.3	0.012	19	0.748	33	1.299	0.039	0.086
6203	**17**	0.6693	40	1.5748	12	0.4724	4.75	1068	9.56	2149	0.6	0.024	21	0.827	36	1.417	0.065	0.143
6303	**17**	0.6693	47	1.8504	14	0.5512	6.55	1473	13.50	3035	1.0	0.039	22	0.866	42	1.654	0.120	0.265
6004	**20**	0.7874	42	1.6535	12	0.4724	5.00	1124	9.36	2104	0.6	0.024	24	0.945	38	1.496	0.069	0.152
6204	**20**	0.7874	47	1.8504	14	0.5512	6.55	1473	12.70	2855	1.0	0.039	25	0.984	42	1.654	0.110	0.243
6304	**20**	0.7874	52	2.0472	15	0.5906	7.80	1754	15.90	3575	1.0	0.039	27	1.063	45	1.772	0.140	0.309
6005	**25**	0.9843	47	1.8504	12	0.4724	6.55	1473	11.20	2518	0.6	0.024	29	1.142	43	1.693	0.080	0.176
6205	**25**	0.9843	52	2.0472	15	0.5906	7.80	1754	14.00	3147	1.0	0.039	30	1.181	47	1.850	0.130	0.287
6305	**25**	0.9843	62	2.4409	17	0.6693	11.60	2608	22.50	5058	1.0	0.039	32	1.260	55	2.165	0.230	0.507
6006	**30**	1.1811	55	2.1654	13	0.5118	8.30	1866	13.30	2990	1.0	0.039	35	1.378	50	1.969	0.160	0.353
6206	**30**	1.1811	62	2.4409	16	0.6299	11.2	2518	19.5	4384	1.0	0.039	35	1.378	57	2.244	0.200	0.441
6306	**30**	1.1811	72	2.8346	19	0.7480	16.0	3597	28.1	6317	1.0	0.039	37	1.457	65	2.559	0.350	0.772
6007	**35**	1.3780	62	2.4409	14	0.5512	10.2	2293	15.9	3575	1.0	0.039	40	1.575	57	2.244	0.160	0.353
6207	**35**	1.3780	72	2.8346	17	0.6693	15.3	3440	25.5	5733	1.0	0.039	42	1.654	65	2.559	0.290	0.639
6307	**35**	1.3780	80	3.1496	21	0.8268	19.0	4272	33.2	7464	1.5	0.059	43	1.693	72	2.835	0.460	1.014
6008	**40**	1.5748	68	2.6772	15	0.5906	11.6	2608	16.8	3777	1.0	0.039	45	1.772	63	2.480	0.190	0.419
6208	**40**	1.5748	80	3.1496	18	0.7087	19.0	4272	30.7	6902	1.0	0.039	47	1.850	73	2.874	0.370	0.816
6308	**40**	1.5748	90	3.5433	23	0.9055	24.0	5396	41.0	9218	1.5	0.059	48	1.890	82	3.228	0.630	1.389

Dimensions for Single Row, Deep-groove Ball Bearings

Dimensions for Single Row, Deep-groove Ball Bearings (*continued*)

Bearing number	Nominal bearing dimensions: Bore, d		Outside dia., D		Width, B		Basic load ratings: Static, C_0		Dynamic, C		Maximum fillet radius r_{max}[1]		Minimum shaft shoulder diameter, S		Maximum housing shoulder diameter, H		Bearing mass	
	mm	in	mm	in	mm	in	kN	lb_f	kN	lb_f	mm	in	mm	in	mm	in	kg	lb_m
6009	**45**	1.7717	75	2.9528	16	0.6299	14.6	3282	20.8	4676	1.0	0.039	50	1.969	70	2.756	0.250	0.551
6209	**45**	1.7717	85	3.3465	19	0.7480	21.6	4856	33.2	7464	1.0	0.039	52	2.047	78	3.071	0.410	0.904
6309	**45**	1.7717	100	3.9370	25	0.9843	31.5	7082	52.7	11 848	1.5	0.059	53	2.087	92	3.622	0.830	1.830
6010	**50**	1.9685	80	3.1496	16	0.6299	16.0	3597	21.6	4856	1.0	0.039	55	2.165	75	2.953	0.260	0.573
6210	**50**	1.9685	90	3.5433	20	0.7874	23.2	5216	35.1	7891	1.0	0.039	57	2.244	83	3.268	0.460	1.014
6310	**50**	1.9685	110	4.3307	27	1.0630	38.0	8543	61.8	13 894	2.0	0.079	59	2.323	101	3.976	1.050	2.315
6011	**55**	2.1654	90	3.5433	18	0.7087	21.2	4766	28.1	6317	1.0	0.039	62	2.441	83	3.268	0.390	0.860
6211	**55**	2.1654	100	3.9370	21	0.8268	29.0	6520	43.6	9802	1.5	0.059	63	2.480	92	3.622	0.610	1.345
6311	**55**	2.1654	120	4.7244	29	1.1417	45.0	10 117	71.5	16 075	2.0	0.079	64	2.520	111	4.370	1.350	2.977
6012	**60**	2.3622	95	3.7402	18	0.7087	23.2	5216	29.6	6655	1.0	0.039	67	2.638	88	3.465	0.420	0.926
6212	**60**	2.3622	110	4.3307	22	0.8661	32.5	7307	47.5	10 679	1.5	0.059	68	2.677	102	4.016	0.780	1.720
6312	**60**	2.3622	130	5.1181	31	1.2205	52.0	11 691	81.9	18 413	2.0	0.079	71	2.795	119	4.685	1.700	3.749
6013	**65**	2.5591	100	3.9370	18	0.7087	25.0	5621	30.7	6902	1.0	0.039	72	2.835	93	3.661	0.440	0.970
6213	**65**	2.5591	120	4.7244	23	0.9055	40.5	9105	55.9	12 567	1.5	0.059	73	2.874	112	4.409	0.990	2.183
6313	**65**	2.5591	140	5.5118	33	1.2992	60.0	13 489	92.3	20 751	2.0	0.079	76	2.992	129	5.079	2.100	4.631
6014	**70**	2.7559	110	4.3307	20	0.7874	31.0	6969	37.7	8476	1.0	0.039	77	3.031	103	4.055	0.600	1.323
6214	**70**	2.7559	125	4.9213	24	0.9449	45.0	10 117	60.5	13 602	1.5	0.059	78	3.071	117	4.606	1.050	2.315
6314	**70**	2.7559	150	5.9055	35	1.3780	68.0	15 288	104.0	23 381	2.0	0.079	81	3.189	139	5.472	2.500	5.513
6015	**75**	2.9528	115	4.5276	20	0.7874	33.5	7531	39.7	8925	1.0	0.039	82	3.228	108	4.252	0.640	1.411
6215	**75**	2.9528	130	5.1181	25	0.9843	49.0	11 016	66.3	14 906	1.5	0.059	83	3.268	122	4.803	1.200	2.646
6315	**75**	2.9528	160	6.2992	37	1.4567	76.5	17 199	114.0	25 629	2.0	0.079	86	3.386	149	5.866	3.000	6.615
6016	**80**	3.1496	125	4.9213	22	0.8661	40.0	8993	47.5	10 679	1.0	0.039	87	3.425	118	4.646	0.850	1.874
6216	**80**	3.1496	140	5.5118	26	1.0236	55.0	12 365	70.2	15 782	2.0	0.079	89	3.504	131	5.157	1.400	3.087
6316	**80**	3.1496	170	6.6929	39	1.5354	86.5	19 447	124.0	27 878	2.0	0.079	91	3.583	159	6.260	3.600	7.938

(*continued*)

Dimensions for Single Row, Deep-groove Ball Bearings

Dimensions for Single Row, Deep-groove Ball Bearings (*continued*)

Bearing number	Nominal bearing dimensions						Basic load ratings				Maximum fillet radius r_{max}[1]		Minimum shaft shoulder diameter, *S*		Maximum housing shoulder diameter, *H*		Bearing mass	
	Bore, *d*		Outside dia., *D*		Width, *B*		Static, C_0		Dynamic, *C*									
	mm	in	mm	in	mm	in	kN	lb_f	kN	lb_f	mm	in	mm	in	mm	in	kg	lb_m
6017	**85**	3.3465	130	5.1181	22	0.8661	43.0	9667	49.4	11 106	1.0	0.039	92	3.622	123	4.843	0.890	1.962
6217	**85**	3.3465	150	5.9055	28	1.1024	64.0	14 388	83.2	18 705	2.0	0.079	94	3.701	141	5.551	1.800	3.969
6317	**85**	3.3465	180	7.0866	41	1.6142	96.5	21 695	133.0	29 901	2.5	0.098	98	3.858	167	6.575	4.250	9.371
6018	**90**	3.5433	140	5.5118	24	0.9449	50.0	11 241	58.5	13 152	1.5	0.059	98	3.858	132	5.197	1.150	2.536
6218	**90**	3.5433	160	6.2992	30	1.1811	73.5	16 524	95.6	21 493	2.0	0.079	99	3.898	151	5.945	2.150	4.741
6318	**90**	3.5433	190	7.4803	43	1.6929	108.0	24 281	143.0	32 149	2.5	0.098	103	4.055	177	6.969	4.900	10.805
6019	**95**	3.7402	145	5.7087	24	0.9449	54.0	12 140	60.5	13 602	1.5	0.059	103	4.055	137	5.394	1.200	2.646
6219	**95**	3.7402	170	6.6929	32	1.2598	81.5	18 323	108.0	24 281	2.0	0.079	106	4.173	159	6.260	2.600	5.733
6319	**95**	3.7402	200	7.8740	45	1.7717	118.0	26 529	153.0	34 397	2.5	0.098	108	4.252	187	7.362	5.650	12.458
6020	**100**	3.9370	150	5.9055	24	0.9449	54.0	12 140	60.5	13 602	1.5	0.059	108	4.252	142	5.591	1.250	2.756
6220	**100**	3.9370	180	7.0866	34	1.3386	93.0	20 908	124.0	27 878	2.0	0.079	111	4.370	169	6.654	3.150	6.946
6320	**100**	3.9370	215	8.4646	47	1.8504	140.0	31 475	174.0	39 119	2.5	0.098	113	4.449	202	7.953	7.000	15.435
6021	**105**	4.1339	160	6.2992	26	1.0236	65.5	14 726	72.8	16 367	2.0	0.079	114	4.488	151	5.945	1.600	3.528
6221	**105**	4.1339	190	7.4803	36	1.4173	104.0	23 381	133.0	29 901	2.0	0.079	116	4.567	179	7.047	3.700	8.159
6321	**105**	4.1339	225	8.8583	49	1.9291	153.0	34 397	182.0	40 917	2.5	0.098	118	4.646	212	8.346	8.250	18.191
6022	**110**	4.3307	170	6.6929	28	1.1024	73.5	16 524	81.9	18 413	2.0	0.079	119	4.685	161	6.339	1.950	4.300
6222	**110**	4.3307	200	7.8740	38	1.4961	118.0	26 529	143.0	32 149	2.0	0.079	121	4.764	189	7.441	4.350	9.592
6322	**110**	4.3307	240	9.4488	50	1.9685	180.0	40 468	203.0	45 638	2.5	0.098	123	4.843	227	8.937	9.550	21.058
6024	**120**	4.7244	180	7.0866	28	1.1024	80.0	17 986	85.2	19 155	2.0	0.079	129	5.079	171	6.732	2.050	4.520
6224	**120**	4.7244	215	8.4646	40	1.5748	118.0	26 529	146.0	32 824	2.0	0.079	131	5.157	204	8.031	5.150	11.356
6324	**120**	4.7244	260	10.2362	55	2.1654	186.0	41 817	208.0	46 763	2.5	0.098	133	5.236	247	9.724	14.500	31.973
6026	**130**	5.1181	200	7.8740	33	1.2992	100.0	22 482	106.0	23 831	2.0	0.079	139	5.472	191	7.520	3.150	6.946
6226	**130**	5.1181	230	9.0551	40	1.5748	132.0	29 676	156.0	35 072	2.5	0.098	143	5.630	217	8.543	5.800	12.789
6326	**130**	5.1181	280	11.0236	58	2.2835	216.0	48 561	229.0	51 484	3.0	0.118	146	5.748	264	10.394	18.000	39.690

[1]Maximum fillet on shaft shoulder that will clear radius on bearing race

Adjustment of Life Rating for Reliability

Thus far we have used the basic *L*10 life for selecting rolling contact bearings. This is the general industrial practice and the basis for data published by most bearing manufacturers.

Recall that *L*10 life indicates a 90% probability that the selected bearing would carry its rated dynamic load for the specified number of design hours. That leaves a 10% probability that any given bearing would have a lower life.

Certain applications call for greater reliability. Examples can be found in the aerospace, military, instrumentation, and medical fields.

It is then desirable to be able to adjust the expected life of a bearing for higher reliability.

Adjustment of Life Rating for Reliability

$$L_{aR} = C_R L_{10}$$

where
L_{10} = Life in millions of revolutions for 90% reliability
L_{aR} = Life adjusted for reliability
C_R = Adjustment factor for reliability (Values can taken from the Table below)

It should be noted that one result of designing for higher reliability is that the bearings would be larger and more expensive.

ASME Tribology Division. *Standard ISO 281/2—Life Ratings for Modern Rolling Bearings.* New York: ASME Press, 2003.

Life Adjustment Factors for Reliability, C_R

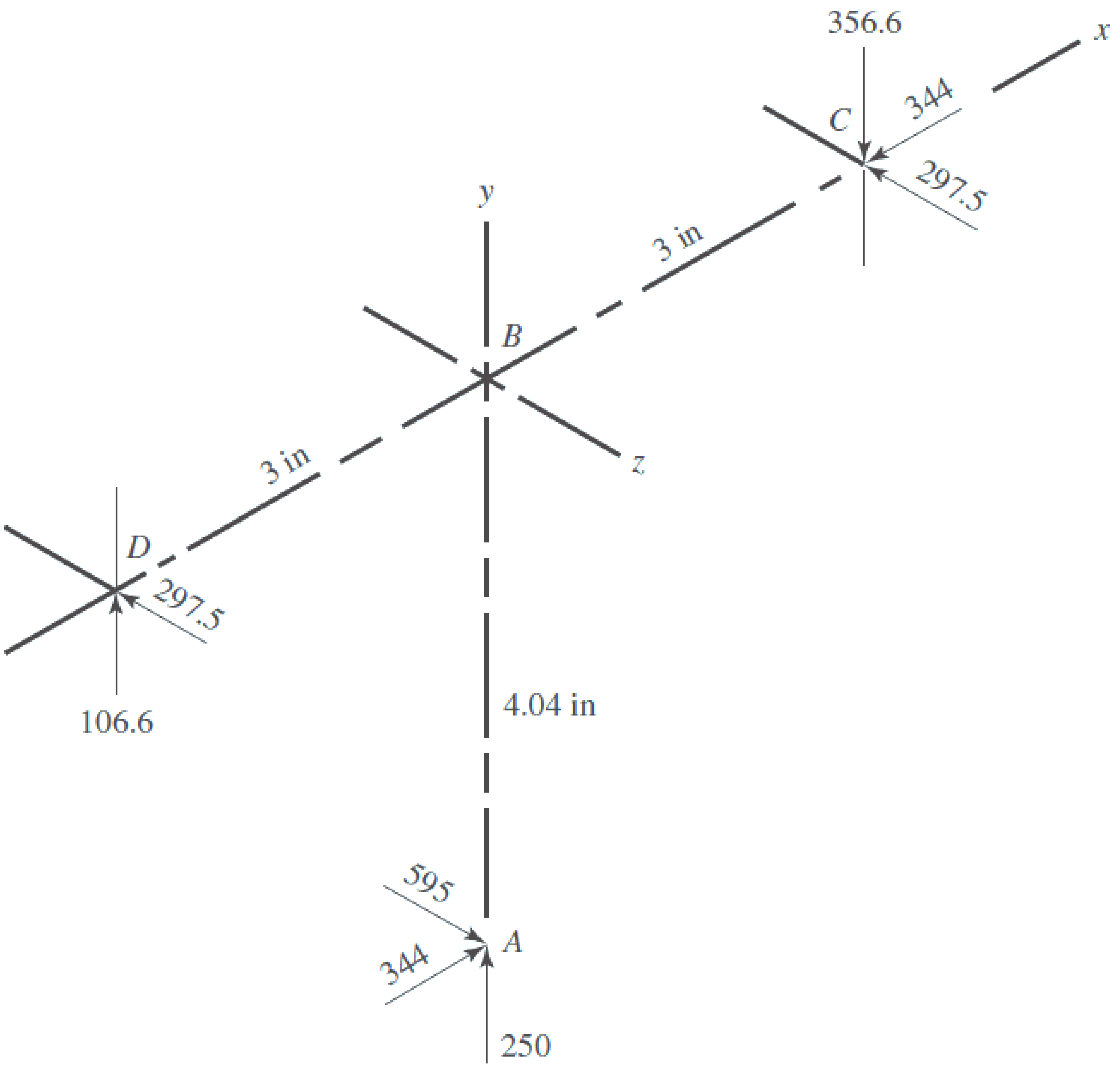
Reliability (%)	C_R	Life designation
90	1.0	L_{10}
95	0.62	L_5
96	0.53	L_4
97	0.44	L_3
98	0.33	L_2
99	0.21	L_1

Example 05

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.

The components of the gear force transmitted to the second shaft are shown at point *A*. The bearing reactions at *C* and *D*, assuming simple-supports, are also shown.

An SKF ball bearing is to be selected for location *C* to accept the thrust (why?), and an SKF cylindrical roller bearing is to be utilized at location *D*.

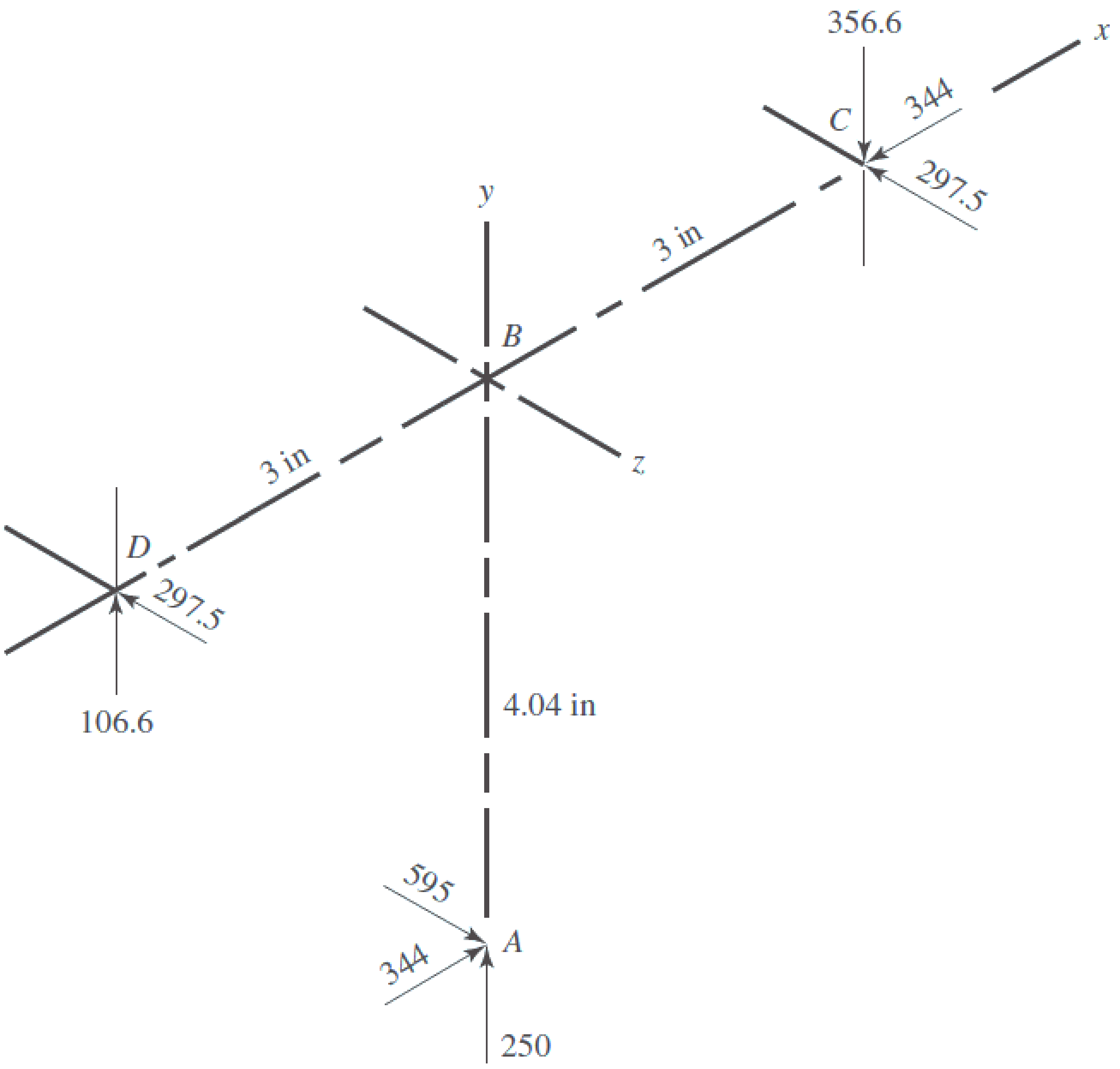


Example 05

The life goal of the speed reducer is 10 kh, with a reliability factor for the ensemble of all four bearings (both shafts) to equal or exceed 0.96. The application factor is to be 1.2.

1. Select the roller bearing for location *D*.
2. Select the ball bearing (angular contact) for location *C*, assuming the inner ring rotates.

Provide full specifications of the selected bearings.



Variable Loading

Bearing loads are frequently variable and occur in some identifiable patterns:

- Piecewise constant loading in a cyclic pattern
- Continuously variable loading in a repeatable cyclic pattern
- Random variation

Equation (11–1) can be written as

$$F^a L = \text{constant} = K \qquad (a)$$

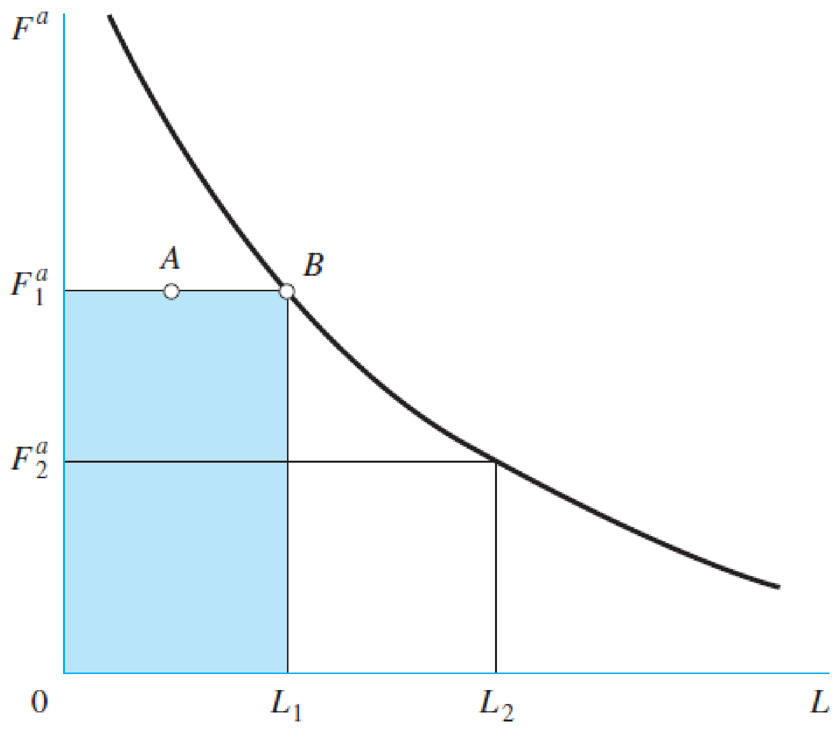
Note that *F* may already be an equivalent steady radial load for a radial–thrust load combination.

Variable Loading

Figure 11–9 is a plot of F^a as ordinate and L as abscissa for Eq. (a). If a load level of F_1 is selected and run to the failure criterion, then the area under the F_1-L_1 trace is numerically equal to K. The same is true for a load level F_2; that is, the area under the F_2-L_2 trace is numerically equal to K. The linear damage theory says that in the case of load level F_1, the area from L = 0 to $L = L_A$ does damage measured by $F^a{}_1 L_A = D$.

Figure 11–9

Plot of F^a as ordinate and L as abscissa for F^aL = constant. The linear damage hypothesis says that in the case of load F_1, the area under the curve from $L = 0$ to $L = L_A$ is a measure of the damage $D = F_1^a L_A$. The complete damage to failure is measured by $C_{10}^a L_B$.



Variable Loading

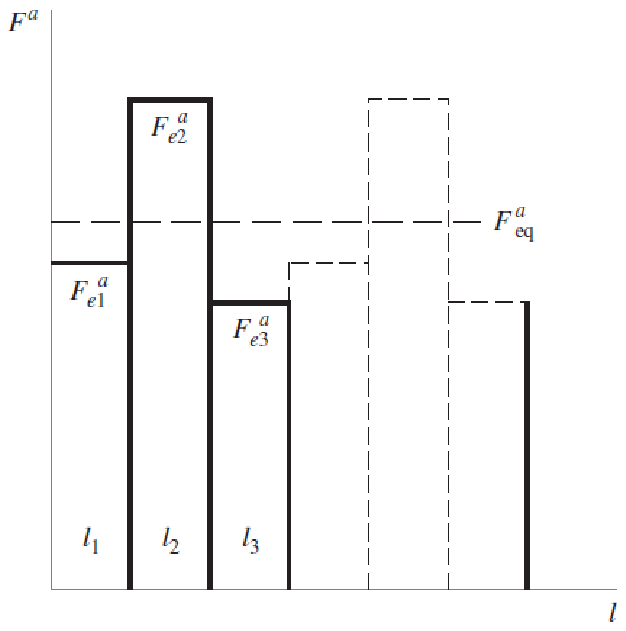
Consider the piecewise continuous cycle depicted in Fig. 11–10. The loads F_{ei} are equivalent steady radial loads for combined radial–thrust loads. The damage done by loads F_{e1}, F_{e2}, and F_{e3} is:

$$D = F_{e1}^a l_1 + F_{e2}^a l_2 + F_{e3}^a l_3 \qquad (b)$$

where l_i is the number of revolutions at life L_i. The equivalent steady load Fe_q when run for $l_1 + l_2 + l_3$ revolutions does the same damage D.

Figure 11–10

A three-part piecewise-continuous periodic loading cycle involving loads F_{e1}, F_{e2}, and F_{e3}. F_{eq} is the equivalent steady load inflicting the same damage when run for $l_1 + l_2 + l_3$ revolutions, doing the same damage D per period.



Variable Loading

Thus $$D = F_{eq}^a(l_1 + l_2 + l_3) \tag{c}$$

Equating Eqs. (*b*) and (*c*), and solving for F_{eq}, we get

$$F_{eq} = \left[\frac{F_{e1}^a l_1 + F_{e2}^a l_2 + F_{e3}^a l_3}{l_1 + l_2 + l_3}\right]^{1/a} = \left[\sum f_i F_{ei}^a\right]^{1/a} \tag{11–13}$$

where f_i is the fraction of revolution run up under load F_{ei}. Since l_i can be expressed as $n_i t_i$, where n_i is the rotational speed at load F_{ei} and t_i is the duration of that speed, then it follows that

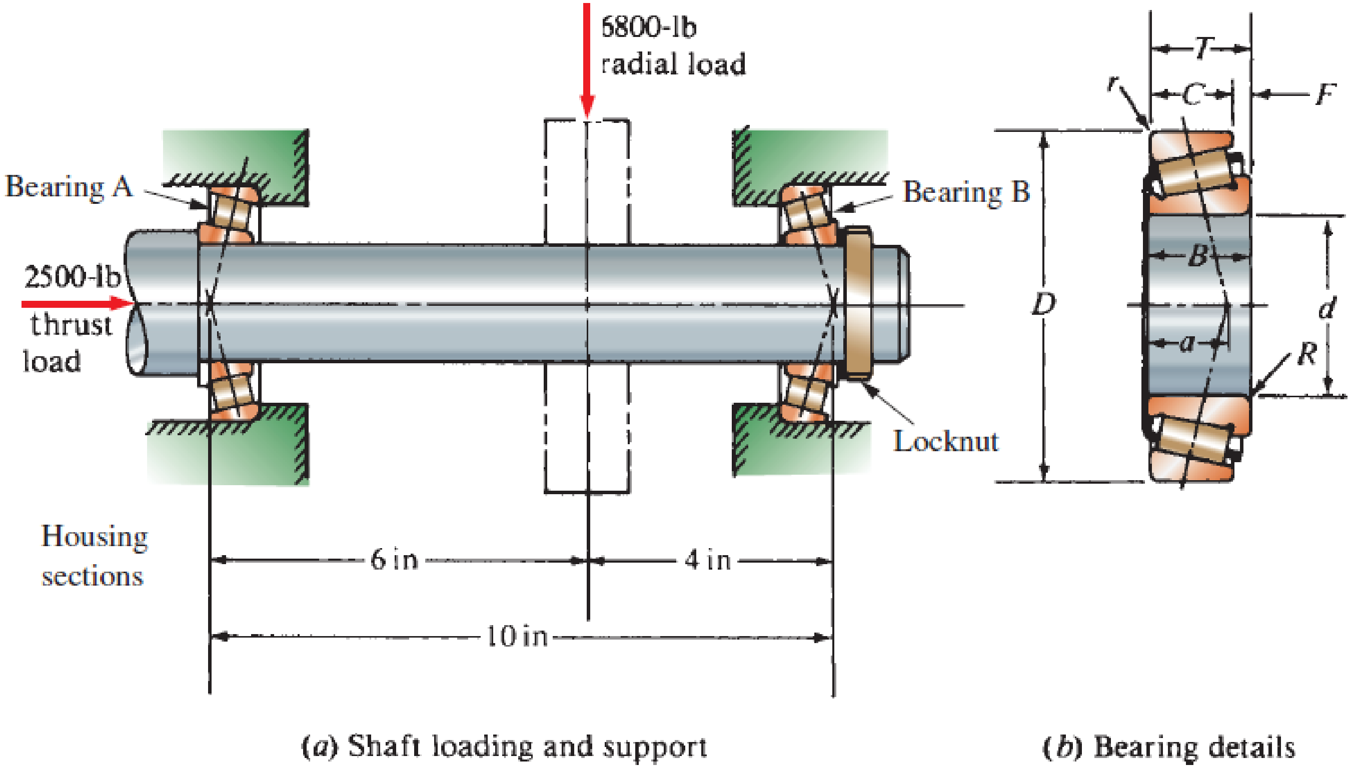
$$F_{eq} = \left[\frac{\sum n_i t_i F_{ei}^a}{\sum n_i t_i}\right]^{1/a} \tag{11–14}$$

The character of the individual loads can change, so an application factor (a_f) can be prefixed to each F_{ei} as $(a_{fi} F_{ei})^a$; then Eq. (11–13) can be written

$$F_{eq} = \left[\sum f_i (a_{fi} F_{ei})^a\right]^{1/a} \qquad L_{eq} = \frac{K}{F_{eq}^a} \tag{11–15}$$

Selection of Tapered Roller Bearings

The taper on the rollers of tapered roller bearings results in a load path different from that for the bearings discussed thus far. The figure below shows two tapered roller bearings supporting a shaft with a combination of a radial load and a thrust load.



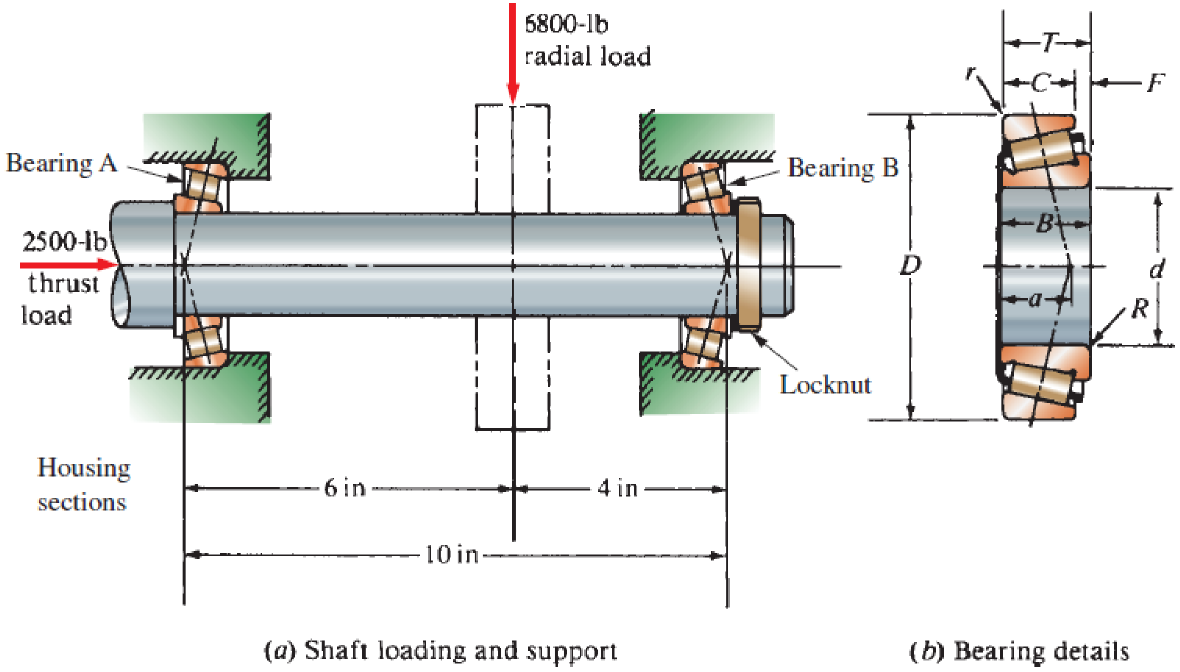
Example of tapered roller bearing installation

Selection of Tapered Roller Bearings

The design of the shaft is such that the thrust load is resisted by the left bearing. But a peculiar feature of this type of bearing is that a radial load on one of the bearings creates a thrust on the opposing bearing, also; this feature must be considered in analysis of the bearing.

The location of the radial reaction must also be determined with care. Part (b) of the figure shows a dimension *a* that is found by the intersection of a line perpendicular to the axis of the roller and the centerline of the shaft.

The radial reaction at the bearing acts through this point. The distance *a* is reported in the tables of data for the bearings.



Example of tapered roller bearing installation

Selection of Tapered Roller Bearings

The American Bearings Manufacturers' Association (ABMA) recommends the following approach in computing the equivalent loads on a tapered roller bearing:

Equivalent Load for Tapered Roller Bearing:

$$P_A = 0.4F_{rA} + 0.5\frac{Y_A}{Y_B}F_{rB} + Y_A T_A$$

$$P_B = F_{rB}$$

Where:

P_A = equivalent radial load on bearing *A*
P_B = equivalent radial load on bearing *B*
F_{rA} = applied radial load on bearing *A*
F_{rB} = applied radial load on bearing *B*
T_A = thrust load on bearing *A*
Y_A = thrust factor for bearing *A* from tables
Y_B = thrust factor for bearing *B* from tables

Selection of Tapered Roller Bearings

For the several hundred designs of standard tapered roller bearings available commercially, the value of the thrust factor varies from as small as 1.07 to as high as 2.26.

In design problems, a trial-and-error procedure is usually necessary.

Tapered Roller Bearing Data

Bore, d	Outside diameter, D	Width, T	a	Thrust factor, Y	Basic dynamic load rating, C
1.0000	2.5000	0.8125	0.583	1.71	8370
1.5000	3.0000	0.9375	0.690	1.98	12 800
1.7500	4.0000	1.2500	0.970	1.50	21 400
2.0000	4.3750	1.5000	0.975	2.02	26 200
2.5000	5.0000	1.4375	1.100	1.65	29 300
3.0000	6.0000	1.6250	1.320	1.47	39 700
3.5000	6.3750	1.8750	1.430	1.76	47 700

Note: Dimensions are in inches. Load C is in pounds for an L_{10} life of 1 million rev.

Selection of Tapered Roller Bearings

One caution must be observed in using the equations for equivalent loads for tapered roller bearings. If, from the equation, the equivalent load on bearing *A* is less than the applied radial load, the following equation should be used:

If $P_A < F_{rA}$, then let $P_A = F_{rA}$ and compute P_B.

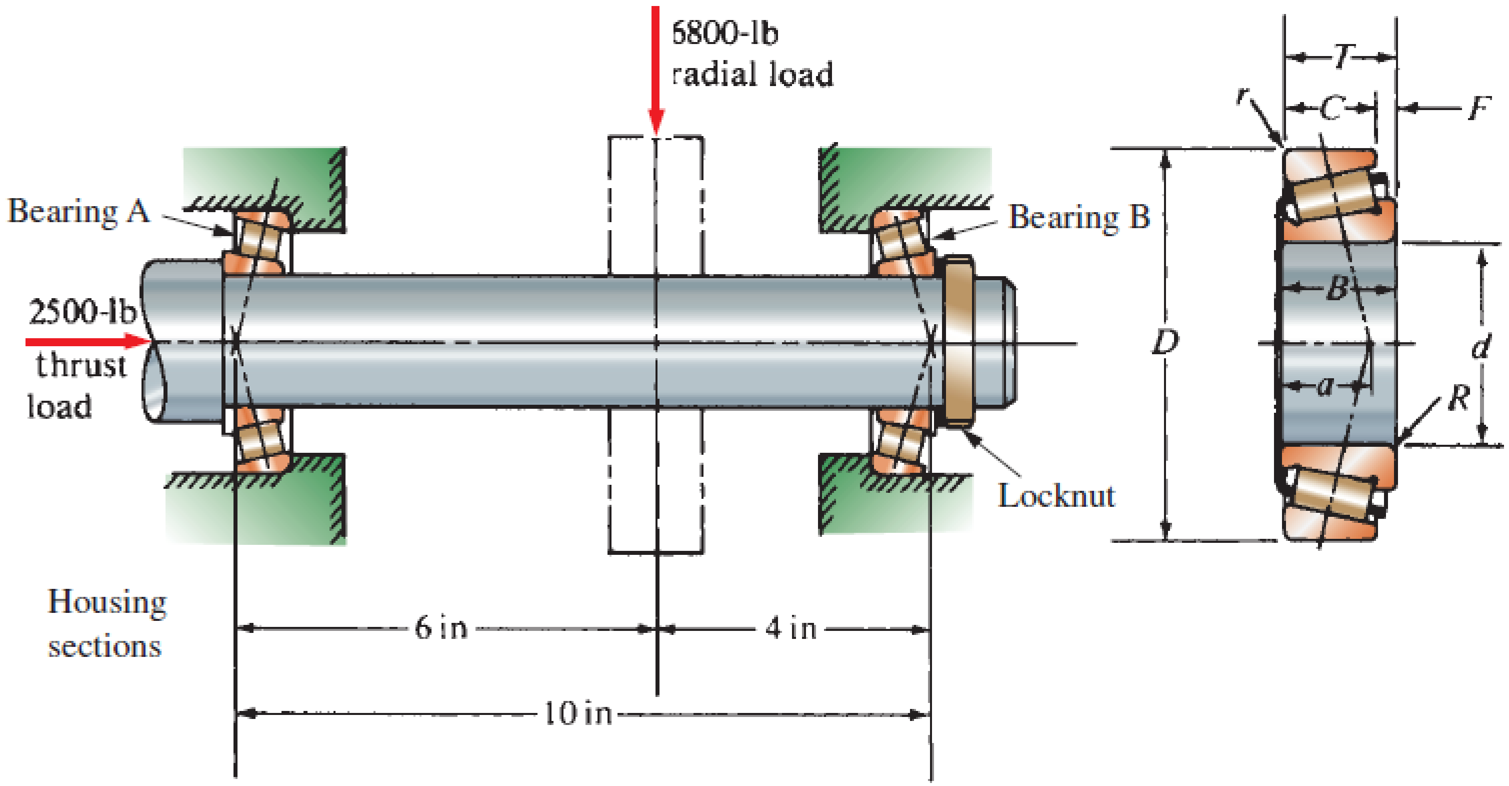
Tapered Roller Bearing Data

Bore, d	Outside diameter, D	Width, T	a	Thrust factor, Y	Basic dynamic load rating, C
1.0000	2.5000	0.8125	0.583	1.71	8370
1.5000	3.0000	0.9375	0.690	1.98	12 800
1.7500	4.0000	1.2500	0.970	1.50	21 400
2.0000	4.3750	1.5000	0.975	2.02	26 200
2.5000	5.0000	1.4375	1.100	1.65	29 300
3.0000	6.0000	1.6250	1.320	1.47	39 700
3.5000	6.3750	1.8750	1.430	1.76	47 700

Note: Dimensions are in inches. Load C is in pounds for an L_{10} life of 1 million rev.

Example 06

The shaft shown carries a transverse load of 6800 lb and a thrust load of 2500 lb. The thrust is resisted by bearing *A*. The shaft rotates at 350 rpm and is to be used in a piece of agricultural equipment. Specify suitable tapered roller bearings for the shaft.



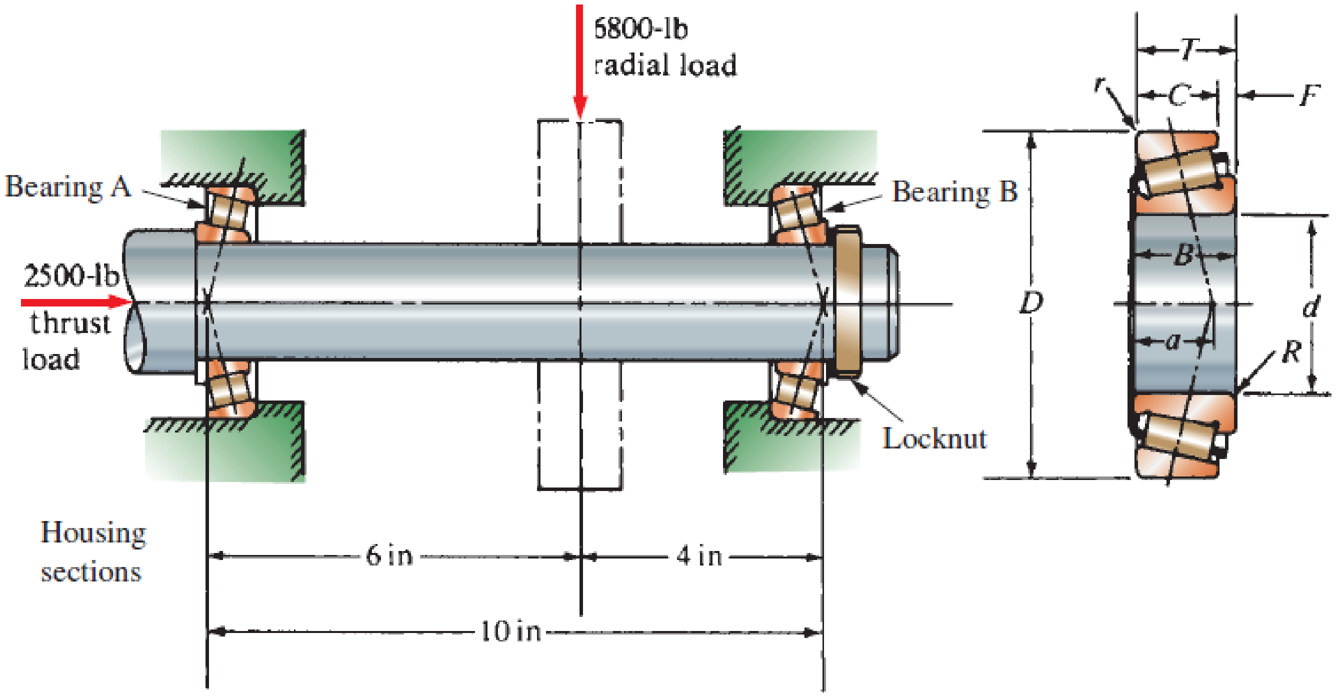
Example 06

1. The loads on the bearings are

F_{rA} = (6800 lb)(4 in/10 in) = 2720 lb

F_{rB} = (6800 lb)(6 in/10 in) = 4080 lb

T_A = 2500 lb



2. To use the design equation, we must have values of Y_A and Y_B.

Let's use $Y_A = Y_B = 1.75$ (as a first assumption). Then:

$$P_A = 0.4F_{rA} + 0.5\frac{Y_A}{Y_B}F_{rB} + Y_A T_A$$

$$P_B = F_{rB}$$

gives:

$$P_A = 0.40(2720\text{ lb}) + 0.5\frac{1.75}{1.75}(4080\text{ lb}) + 1.75(2500\text{ lb}) = 7503\text{ lb}$$

$$P_B = F_{rB} = 4080\text{ lb}$$

Example 06

3. let's select 4000 h as a design life.

Recommended Design Life for Bearings

Application	Design life L_{10}, h
Domestic appliances, instruments, medical apparatus	1000–2000
Aircraft engines	1000–4000
Automotive	1500–5000
Agricultural equipment, hoists, construction machines	3000–6000
Elevators, industrial fans, multipurpose gearing, rotary crushers, cranes	8000–15 000
Electric motors, industrial blowers, general industrial machines, conveyors	20 000–30 000
Pumps and compressors, textile machinery, rolling mill drives	40 000–60 000
Critical equipment in continuous, 24-h operation; power plants, ship drives	100 000–200 000

Source: Eugene A. Avallone and Theodore Baumeister III, eds., *Marks' Standard Handbook for Mechanical Engineers*, 9th ed. New York: McGraw-Hill, 1986.

4. Then the number of revolutions would be

L_d = (4000 h)(350 rpm)(60 min/h) = 8.4 * 10^7 rev

Example 06

5. The required basic dynamic load rating can now be calculated from equation 11-3 with a = 10/3:

C_{10A} = (7503 lb)(8.4 * $10^7/10^6)^{0.30}$ = 28 400 lb
C_{10B} = (4080 lb)(8.4 * $10^7/10^6)^{0.30}$ = 15 400 lb

6. Now from the table choose:

Bearing A
d = 2.5000 in D = 5.0000 in
C = 29 300 lb Y_A = 1.65

Bearing B
d = 1.7500 in D = 4.0000 in
C = 21 400 lb Y_B = 1.50

Tapered Roller Bearing Data

Bore, *d*	Outside diameter, *D*	Width, *T*	*a*	Thrust factor, *Y*	Basic dynamic load rating, *C*
1.0000	2.5000	0.8125	0.583	1.71	8370
1.5000	3.0000	0.9375	0.690	1.98	12 800
1.7500	4.0000	1.2500	0.970	1.50	21 400
2.0000	4.3750	1.5000	0.975	2.02	26 200
2.5000	5.0000	1.4375	1.100	1.65	29 300
3.0000	6.0000	1.6250	1.320	1.47	39 700
3.5000	6.3750	1.8750	1.430	1.76	47 700

Note: Dimensions are in inches. Load *C* is in pounds for an L_{10} life of 1 million rev.

Example 06

7. We can now re-compute the equivalent loads:

$$P_A = 0.40(2720 \text{ lb}) + 0.5\frac{1.65}{1.50}(4080 \text{ lb}) + 1.65(2500 \text{ lb}) = 7457 \text{ lb}$$

$$P_B = F_{rB} = 4080 \text{ lb}$$

8. From these, the new values of C_{10A} = 28 226 lb and C_{10B} = 15 400 lb are still satisfactory for the selected bearings.

Tapered Roller Bearing Data

Bore, *d*	Outside diameter, *D*	Width, *T*	*a*	Thrust factor, *Y*	Basic dynamic load rating, *C*
1.0000	2.5000	0.8125	0.583	1.71	8370
1.5000	3.0000	0.9375	0.690	1.98	12 800
1.7500	4.0000	1.2500	0.970	1.50	21 400
2.0000	4.3750	1.5000	0.975	2.02	26 200
2.5000	5.0000	1.4375	1.100	1.65	29 300
3.0000	6.0000	1.6250	1.320	1.47	39 700
3.5000	6.3750	1.8750	1.430	1.76	47 700

Note: Dimensions are in inches. Load *C* is in pounds for an L_{10} life of 1 million rev.

Angular contact ball bearings

A similar analysis is used for angular contact ball bearings in which the design of the races results in a load path similar to that for tapered roller bearings.

This is equivalent to the line perpendicular to the axis of the tapered roller bearing. The radial reaction on the bearing acts through the intersection of this line and the axis of the shaft.

Also, a radial load on one bearing induces a thrust load on the opposing bearing, requiring the application of the equivalent load formulas of the type used in tapered rolling bearings.

The angle of the load line in commercially available angular contact bearings ranges from 15° to 40°.