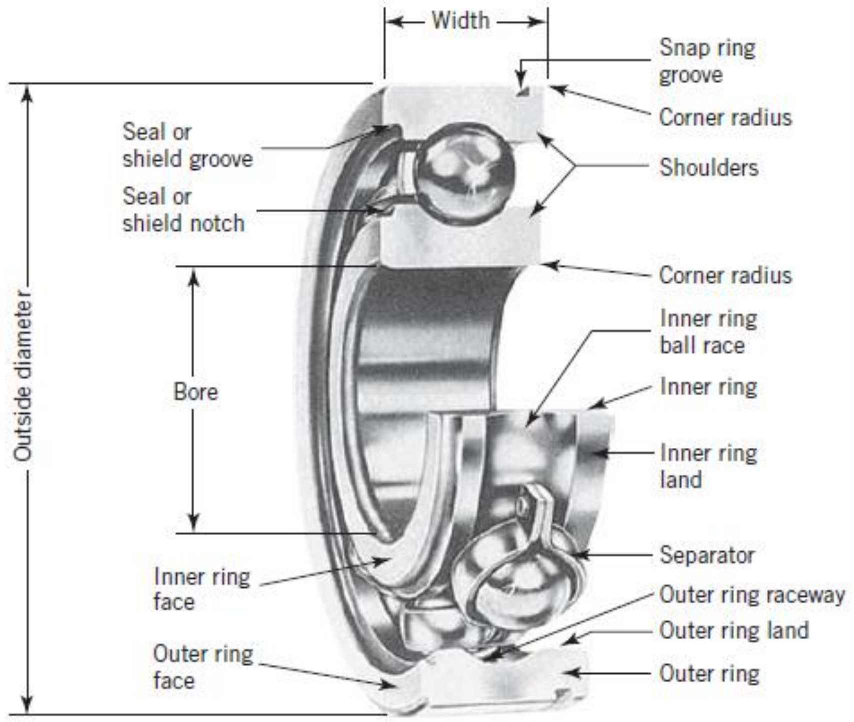
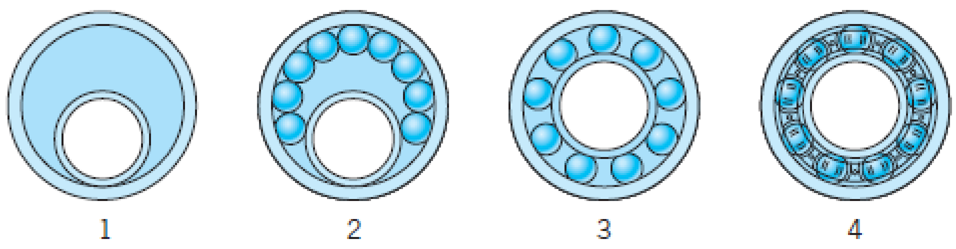
Rolling-Element Bearings

In rolling-element bearings the shaft and outer members are separated by balls or rollers, and thus rolling friction is substituted for sliding friction**.** Examples are shown in Figures (1) through (8). Since the contact areas are small and the stresses high, the loaded parts of rolling-element bearings are normally made of hard, high-strength materials, superior to those of the shaft and outer member. These parts include inner and outer rings and the balls or rollers. An additional component of the bearing is usually a retainer or separator, which keeps the balls or rollers evenly, spaced and separated. Both sliding and rolling-element bearings have their places in modern machinery**. A major advantage of rolling-element bearings** is low starting friction. Sliding bearings can achieve comparably low friction only with full-film lubrication (complete surface separation).

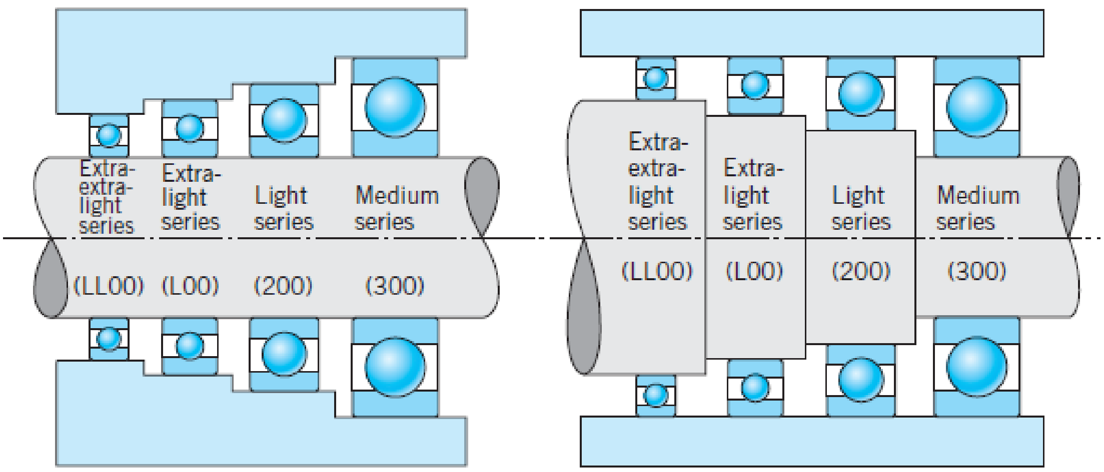


(*a*)
Construction and nomenclature



(b)
Steps in assembly

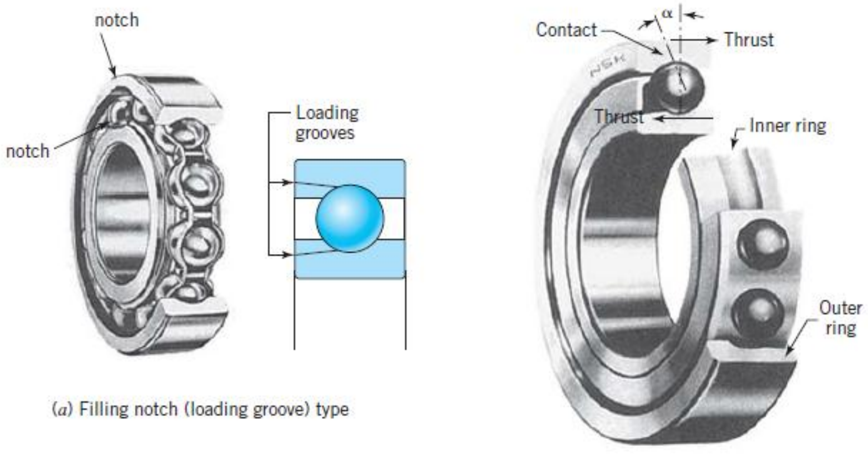
Fig.(1) Radial ball bearing



(a)
Relative proportions of bearings
with same bore dimension

(b)
Relative proportions of bearings
with same outside diameter

Fig.(2) Relative proportions of bearings of different series.



(a) Filling notch (loading groove) type

(b) Angular-contact type

Fig.(3)

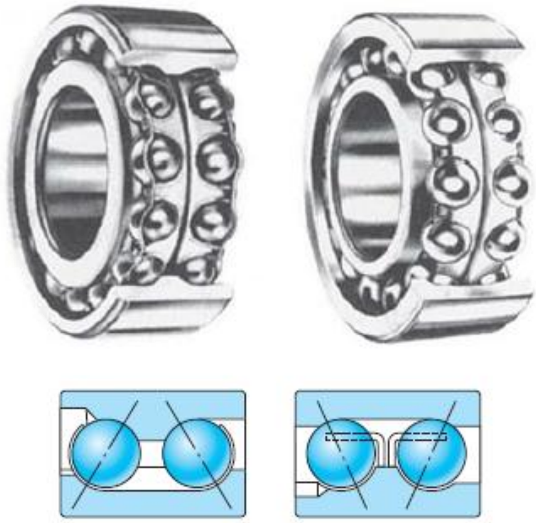
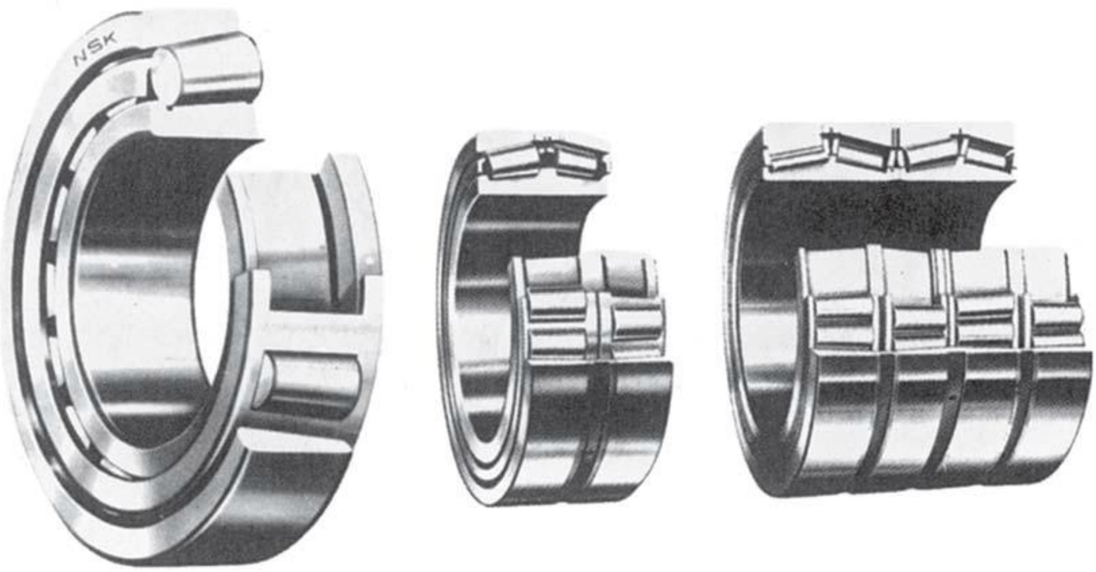


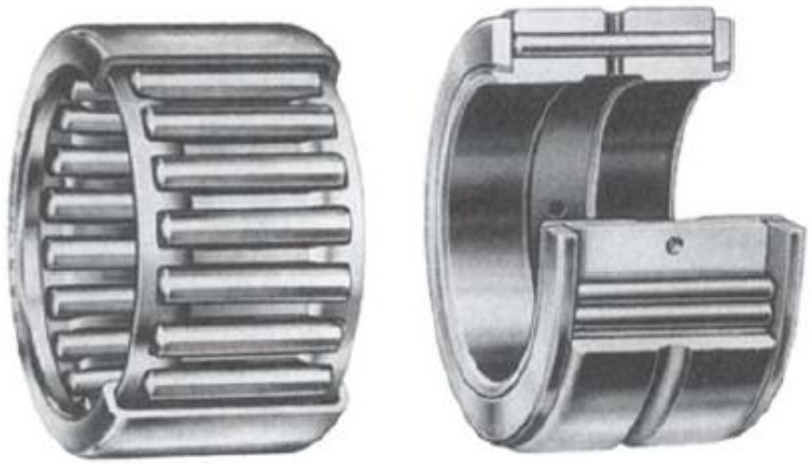
Fig.(4) Double row ball bearing

Fig.(5) Thrust Bearing

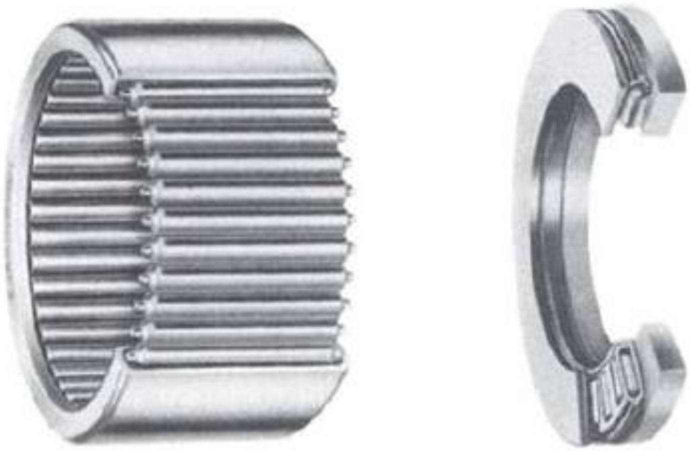


(*a*) Single-row (*b*) Double-row (*c*) Four-row

Fig.(6)

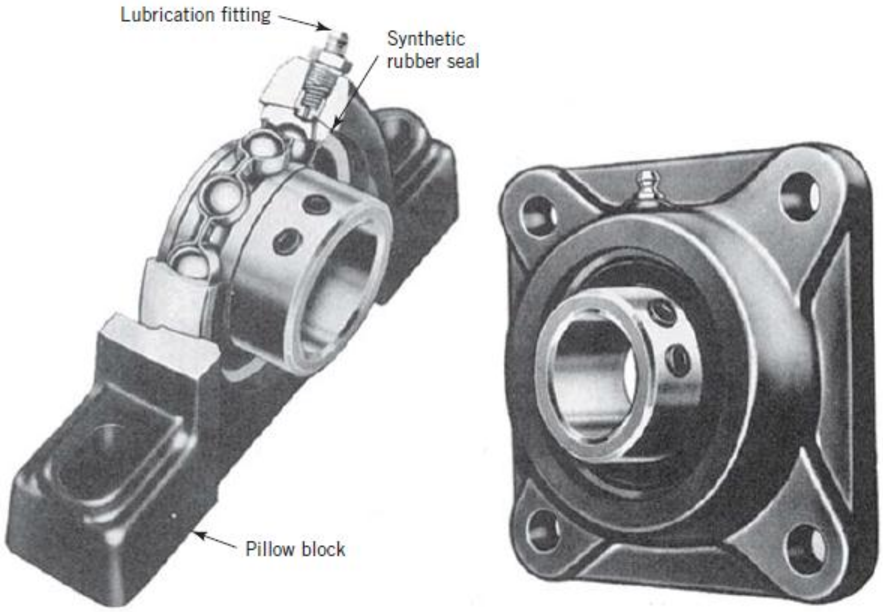


(a) Drawn cup caged (b) Full complement aircraft



(c)Full-complement drawn-cup (d) Thrust

Fig.(7)



(a) Pillow block mounting **(b)** Flange bearing

Fig.(8) Sample special bearings

Manufacturing tolerances are extremely critical. In the case of ball bearings, the Annular Bearing Engineers' Committee (ABEC) of the Anti-Friction Bearing Manufacturers Association (AFBMA) has established four primary grades of precision, designated ABEC 1, 5, 7, and 9. ABEC 1 is the standard grade and is adequate for most normal applications. The other grades have progressively finer tolerances. For example, tolerances on bearing bores between 35 and 50 mm range from +0.0000 in. to -0.0005 in. for ABEC grade 1 to +0.00000 in. to -0.00010 in. for ABEC grade 9. Tolerances on other dimensions are comparable.

Fitting of Rolling-Element Bearings

Normal practice is to fit the stationary ring with a "slip" or "tap" fit and the rotating ring 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.

"Catalogue Information" for Rolling-Element Bearings

Bearing manufacturers' catalogues identify bearings by number, give complete dimensional information, list rated load capacities, and furnish details concerning mounting, lubrication, and operation. Dimensions of the more common series of radial ball bearings, angular ball bearings, and cylindrical roller bearings are given in Table (1) and illustrated in Figure(9). **For bearings of these types having bores of 20 mm and larger, the bore diameter is five times the last two digits in the bearing number. For example, No. L08 is an extra-light series bearing with a 40-mm bore, No. 316 is a medium series with an 80-mm bore, and so on.** Actual bearing numbers include additional letters and numbers to provide more information. Many bearing varieties are also available in inch series.

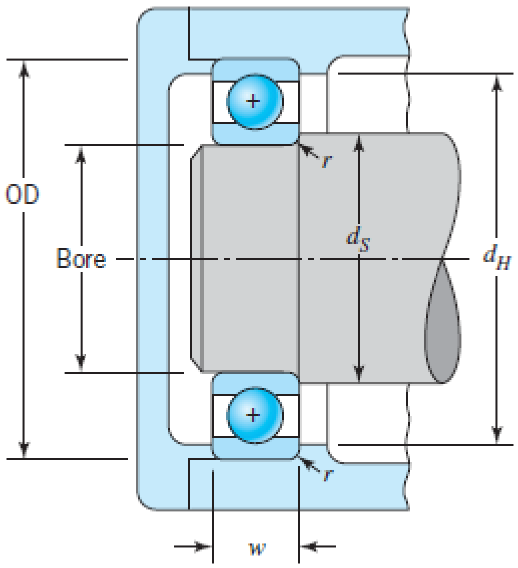


Fig.(9) Shaft and housing shoulder dimensions.

Table (1) Bearing Dimensions

Bearing Basic Number	Bore (mm)	Ball Bearings OD (mm)	w (mm)	r^a (mm)	d_S (mm)	d_H (mm)	Roller Bearings 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
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
L11	55	90	18	1.02	61.7	83.1	90	18	1.52	62.0	83.6
211	55	100	21	1.52	65.0	90.2	100	21	2.03	64.0	91.4
311	55	120	29	2.03	69.8	106.2	120	29	2.03	66.5	108.7
L12	60	95	18	1.02	66.8	87.9	95	18	1.52	67.1	88.6
212	60	110	22	1.52	70.6	99.3	110	22	2.03	69.3	101.3
312	60	130	31	2.03	75.4	115.6	130	31	2.54	72.9	117.9
L13	65	100	18	1.02	71.9	92.7	100	18	1.52	72.1	93.7
213	65	120	23	1.52	76.5	108.7	120	23	2.54	77.0	110.0
313	65	140	33	2.03	81.3	125.0	140	33	2.54	78.7	127.0
L14	70	110	20	1.02	77.7	102.1	110	20	Not Available		
214	70	125	24	1.52	81.0	114.0	125	24	2.54	81.8	115.6
314	70	150	35	2.03	86.9	134.4	150	35	3.18	84.3	135.6
L15	75	115	20	1.02	82.3	107.2	115	20	Not Available		
215	75	130	25	1.52	86.1	118.9	130	25	2.54	85.6	120.1
315	75	160	37	2.03	92.7	143.8	160	37	3.18	90.4	145.8

Bearing Basic Number	Bore (mm)	Ball Bearings OD (mm)	w (mm)	r^a (mm)	d_S (mm)	d_H (mm)	Roller Bearings OD (mm)	w (mm)	r^a (mm)	d_S (mm)	d_H (mm)
L16	80	125	22	1.02	88.1	116.3	125	22	2.03	88.4	117.6
216	80	140	26	2.03	93.2	126.7	140	26	2.54	91.2	129.3
316	80	170	39	2.03	98.6	152.9	170	39	3.18	96.0	154.4
L17	85	130	22	1.02	93.2	121.4	130	22	2.03	93.5	122.7
217	85	150	28	2.03	99.1	135.6	150	28	3.18	98.0	139.2
317	85	180	41	2.54	105.7	160.8	180	41	3.96	102.9	164.3
L18	90	140	24	1.52	99.6	129.0	140	24		Not Available	
218	90	160	30	2.03	104.4	145.5	160	30	3.18	103.1	147.6
318	90	190	43	2.54	111.3	170.2	190	43	3.96	108.2	172.7
L19	95	145	24	1.52	104.4	134.1	145	24		Not Available	
219	95	170	32	2.03	110.2	154.9	170	32	3.18	109.0	157.0
319	95	200	45	2.54	117.3	179.3	200	45	3.96	115.1	181.9
L20	100	150	24	1.52	109.5	139.2	150	24	2.54	109.5	141.7
220	100	180	34	2.03	116.1	164.1	180	34	3.96	116.1	167.1
320	100	215	47	2.54	122.9	194.1	215	47	4.75	122.4	194.6
L21	105	160	26	2.03	116.1	146.8	160	26		Not Available	
221	105	190	36	2.03	121.9	173.5	190	36	3.96	121.4	175.3
321	105	225	49	2.54	128.8	203.5	225	49	4.75	128.0	203.5
L22	110	170	28	2.03	122.7	156.5	170	28	2.54	121.9	159.3
222	110	200	38	2.03	127.8	182.6	200	38	3.96	127.3	183.9
322	110	240	50	2.54	134.4	218.2	240	50	4.75	135.9	217.2
L24	120	180	28	2.03	132.6	166.6	180	28		Not Available	
224	120	215	40	2.03	138.2	197.1	215	40	4.75	139.2	198.9
324	120		Not Available				260	55	6.35	147.8	235.2
L26	130	200	33	2.03	143.8	185.4	200	33	3.18	143.0	188.2
226	130	230	40	2.54	149.9	210.1	230	40	4.75	149.1	213.9
326	130	280	58	3.05	160.0	253.0	280	58	6.35	160.3	254.5
L28	140	210	33	2.03	153.7	195.3	210	33		Not Available	
228	140	250	42	2.54	161.5	228.6	250	42	4.75	161.5	232.4
328	140		Not Available				300	62	7.92	172.0	271.3
L30	150	225	35	2.03	164.3	209.8	225	35	3.96	164.3	212.3
230	150	270	45	2.54	173.0	247.6	270	45	6.35	174.2	251.0
L32	160	240	38	2.03	175.8	223.0	240	38		Not Available	
232	160		Not Available				290	48	6.35	185.7	269.5
L36	180	280	46	2.03	196.8	261.6	280	46	4.75	199.6	262.9
236	180		Not Available				320	52	6.35	207.5	298.2
L40	200						310	51		Not Available	
240	200		Not Available				360	58	7.92	232.4	334.5
L44	220						340	56		Not Available	
244	220		Not Available				400	65	9.52	256.0	372.1
L48	240						360	56		Not Available	
248	240		Not Available				440	72	9.52	279.4	408.4

Table (2) lists **rated load capacities**, *C*. These values correspond to a constant radial load that 90 percent of a group of presumably identical bearings can endure for $9 * 10^7$ revolutions (as 3000 hours of 500-rpm operation) without the onset of surface fatigue failures.

Caution: Rated capacities given by different bearing manufacturers are not always directly comparable. The basis for ratings must always be checked.

Table(2) Bearing Rated Capacities, ***C***, for $L_R = 90\times10^6$ Revolution Life with 90 Percent Reliability

	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
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
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	

Life Requirement

Bearing applications usually require lives different from that used for the catalogue rating. **Palmgren's determined that ball-bearing life varies inversely with approximately the third power of the load. Later studies have indicated that this exponent ranges between 3 and 4 for various rolling-element bearings. Many manufacturers retain Palmgren's exponent of 3 for ball bearings and use $\frac{10}{3}$ for roller bearings. The exponent $\frac{10}{3}$ for both bearing types is used. Thus**

$$L = L_R\left(\frac{C}{F_r}\right)^{3.33} \tag{1}$$

$$C = C_{req} = F_r\left(\frac{L}{L_R}\right)^{0.3} \tag{2}$$

where

C = rated capacity (as from Table 2) and C_{req} = the required value of C for the application

L_R = life corresponding to rated capacity (i.e., 9 * 10^7 revolutions)

F_r = radial load involved in the application

L = life corresponding to radial load F_r, or life required by the application

Thus doubling the load on a bearing reduces its life by a factor of about 10. Different manufacturers' catalogues use different values of (L_R).

Some use $L_R = 10^6$ revolutions.

Reliability Requirement:

The standard life is commonly designated as the L_{10} life (sometimes as the B_{10} life). Since this life corresponds to 10 percent failures, it also means that this is the life for which 90 percent have not failed, and corresponds to 90 percent reliability. Thus, the life for 50 percent reliability is about five times the life for 90 percent reliability.

The rated bearing life for any given reliability (greater than 90 percent) is thus the product, $K_r L_R$. Incorporating this factor into Eq. (1) gives:

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

(3)

$$\boldsymbol{C = C_{req} = F_r (\frac{L}{K_r L_R})^{0.3}}$$

(4)

Influence of Axial Loading

Cylindrical roller bearings are very limited in their thrust capacity because axial loads produce sliding friction at the roller ends. Even so, when these bearings are properly aligned, radially loaded, and oil-lubricated, they can carry thrust loads up to 20 percent of their rated radial capacities. This enables pairs of cylindrical roller bearings to support shafts subjected to light thrust, as by spur gears or chain sprockets. **Tapered roller bearings** can, of course, carry substantial thrust as well as radial loads.

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, calculated from the equations that follow. Load angle α is defined in Figure (3b). Radial bearings have a zero load angle ($\alpha=0^o$). Standard values for angular ball bearings are 15°, 25°, and 35°.

For radial bearings($\alpha=0^o$) the equivalent radial load can be calculated as:

$$For\ 0 < {}^{F_t}/_{F_r} < 0.35, \quad F_e = F_r$$

$$For\ 0.35 < {}^{F_t}/_{F_r} < 10, \quad F_e = F_r[1 + 1.115\left(\frac{F_t}{F_r} - 0.35\right)] \qquad (5)$$

$$For\ {}^{F_t}/_{F_r} > 10, \quad F_e = 1.176F_t$$

α=25° (angular ball bearing)

$$For\ 0 < {}^{F_t}/_{F_r} < 0.68, \quad F_e = F_r$$

$$For\ 0.68 < {}^{F_t}/_{F_r} < 10, \quad F_e = F_r[1 + 0.87\left(\frac{F_t}{F_r} - 0.68\right)] \qquad (6)$$

$$For\ {}^{F_t}/_{F_r} > 10, \quad F_e = 0.911F_t$$

Shock Loading:

The standard bearing rated capacity is for the condition of uniform load without shock. This desirable condition may prevail for some applications (such as bearings on the motor and rotor shafts of a belt-driven electric blower), but other applications have various degrees of shock loading. This has the effect of increasing the nominal load by an application factor K_a. Table (3) gives representative sample values.

Table(3) Application Factors K_a

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

Substituting F_e for F_r and adding K_a modifies Eq.(3) and Eq.(4) to give

$$\boldsymbol{L = K_r L_R \left(\frac{C}{F_e K_a}\right)^{3.33}} \qquad \textbf{(7)}$$

$$\boldsymbol{C = C_{req} = F_e K_a \left(\frac{L}{K_r L_R}\right)^{0.3}} \qquad \textbf{(8)}$$

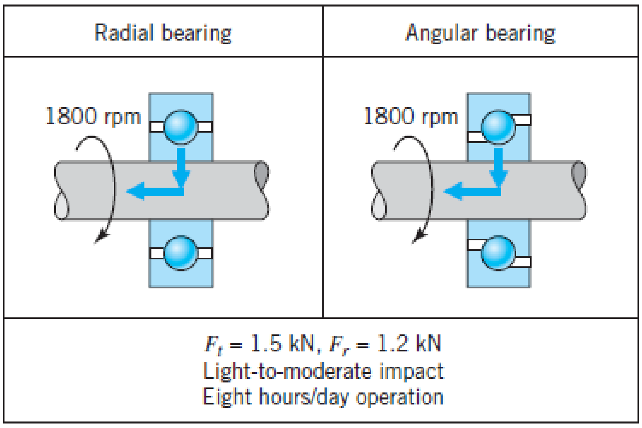
When the preceding equations are used, the question is what life, *L* should be required. Table (4) may be used as a guide when more specific information is not available.

Table (4) Representative Bearing Design Life

Type of Application	Design Life (thousands of hours)
Instruments and apparatus for infrequent use	0.1–0.5
Machines used intermittently, where service interruption is of minor importance	4–8
Machines intermittently used, where reliability is of great importance	8–14
Machines for 8-hour service, but not every day	14–20
Machines for 8-hour service, every working day	20–30
Machines for continuous 24-hour service	50–60
Machines for continuous 24-hour service where reliability is of extreme importance	100–200

Ex (1):

Select a ball bearing for an industrial machine press fit onto a shaft and intended for continuous one-shift (8-hour day) operation at 1800 rpm. Radial and thrust loads are 1.2 and 1.5 kN, respectively, with light-to-moderate impact.



Fig(10) Radial- and angular-contact ball bearings

Solution

From Eqs. (5) and (6), the equivalent radial load for radial and angular ball bearings, respectively,

$$\frac{F_t}{F_r} = \frac{1.5}{1.2} = 1.25$$

Since

$$0 < \frac{F_t}{F_r} < 10$$

So that, use equation (5) to calculate the equivalent load

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

$$F_e = 1.2[1 + 1.115(1.25 - 0.35)] = 2.4kN \ \ (radial\ Bearing)$$

For angular ball bearing (α=25^o) use equation (6)

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

$F_e = 1.2[1 + 0.87(1.25 - 0.68)] = 1.8kN$ (angular bearing)

From table (3) K_a=1.5

From table (4) for a machine with 8-hour service, every working day K_a=(20 to30)×10^3 hours choose K_a=30000hr

The life L can be calculated as

L=1800×30000×60=3240×10^6 rev

For standard 90 percent reliability (K_r = 1), and for L_R = 90 * 10^6 rev (for use with Table (2)).

Calculate the equivalent radial capacity of the bearing as:

$$\boldsymbol{C_{req} = F_e K_a (\frac{L}{K_r L_R})^{0.3}}$$

$$\boldsymbol{C_{req} = 2.4 \times 1.5 \times (\frac{3240}{1 \times 90})^{0.3} = 10.55kN\ (for\ radial\ bearing)}$$

$$\boldsymbol{C_{req} = 1.8 \times 1.5 \times (\frac{3240}{1 \times 90})^{0.3} = 7.91kN\ (for\ angular\ bearing)}$$

With the above values of load rating inter table (2) to define the suitable bore diameter for each group.

For radial bearing (C_{req}=10.55kN)

For series L the bore diameter is 70mm

For series 200 the bore diameter is 55

For series 300 the bore diameter is 35

Now inter table (1) with the above values of diameters (for each group)

For series L : Bearing L14 is suitable

For series 200: Bearing 211 is suitable

For series 300: Bearing 307 is suitable

Repeat the above procedure **for angular contact bearing with $\alpha=25^{o}$** (C=7.91kN) to get:

For series L the bore diameter is 55mm

For series 200 the bore diameter is 35

For series 300 the bore diameter is 30

Now inter table one with the above values of diameters (for each group)

For series L : Bearing L11 is suitable

For series 200: Bearing 207 is suitable

For series 300: Bearing 306 is suitable

Comment: Other factors being equal, the final selection would be made on the basis of cost of the total installation, including shaft and housing. Shaft size should be sufficient to limit bearing misalignment to no more than 15.

Ex (2):

Suppose that radial-contact bearing 211 (C = 12.0 kN) is selected for the application in example (1). (a) Estimate the life of this bearing, with 90 percent reliability. (b) Estimate its reliability for 30,000-hour life.

Solution

(a)$L = K_r L_R (C/F_e K_a)^{3.33}$

$$L = (1)(90\times10^{6})(12/2.4\times1.5)^{3.33}\text{=495,939,5358rev}$$

Convert the revolutions to hours as follows

$$Life\ in\ hours = \frac{Life\ in\ revolutions}{Rotational\ speed \times 60min/hr}$$

$$Life\ in\ hours = \frac{495{,}939{,}535}{1800 \times 60min/hr} = 45920hr$$

(b)

$$\text{Life in revs} = \text{Life in hr} \times \text{rpm} \times 60\text{min/hr}$$

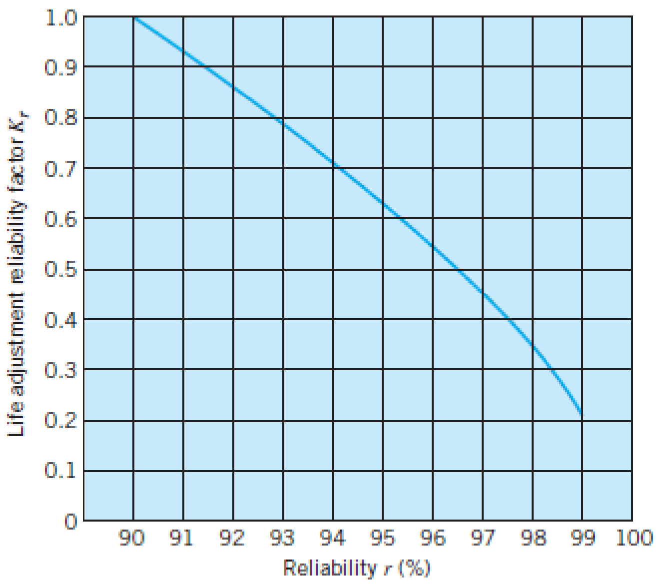
Life in revs=30000×1800×60=3240×10^6 rev

To evaluate K_r

$3240 * 10^6 = K_r(90 * 10^6)(12.0/3.6)^{3.33}$

$K_r = 0.65$

Use the following chart to determine the required reliability



Fig(11) Reliability chart

For K_r=0.65 the reliability of the bearing is 95%

Mounting and Closure of Rolling Bearings

Rolling-element bearings are generally mounted with the rotating inner or outer ring with a press fit. Bearing manufacturers' literature contains extensive information and illustrations on mountings. The basic principle of mounting ball bearings properly is discussed her in. Figure (12) shows a common method of mounting, where the inner rings are backed up against the shaft shoulders and held in position by round nuts threaded into the shaft. As noted, the outer ring of the left-hand bearing is backed up against a housing shoulder and retained in position, but the outer ring of the right-hand bearing floats in the housing. This allows the outer ring to slide both ways in its mounting to avoid thermal-expansion-induced axial forces on the bearings, which would seriously shorten their life. An alternative bearing mounting is illustrated in Figure (13). Here, the inner ring is backed up against the shaft shoulder, as before, however, no retaining device is needed; threads are eliminated. With this assembly, the outer rings of both bearings are completely retained. As a result, accurate dimensions in axial direction or the use of adjusting devices is required.

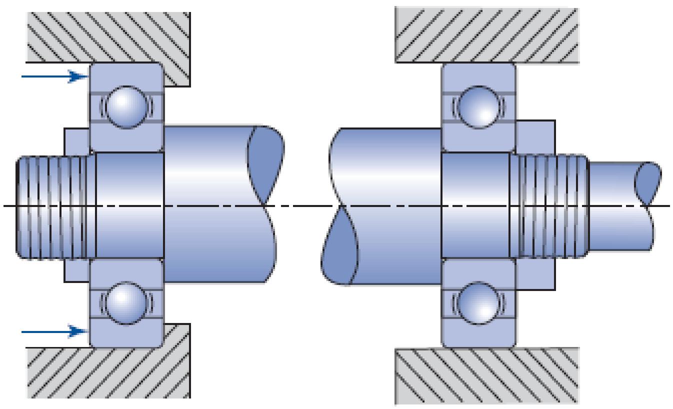


Fig.(12) A common bearing mounting

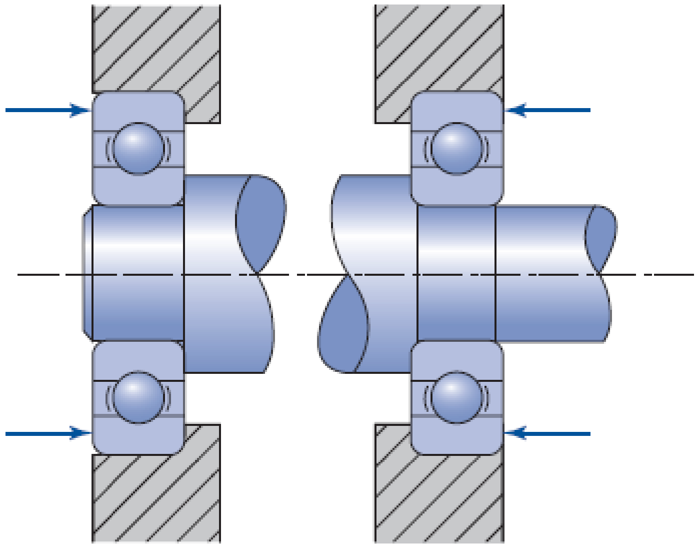


Fig.(13) An alternative bearing mounting. (The outer rings of both bearings are held in position by devices (not shown).

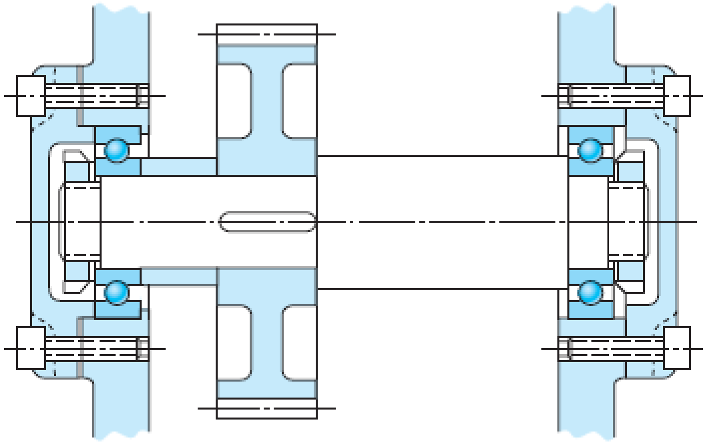


Fig.(14) Bearings mounted so that left bearing takes thrust in both directions.

Ex: A transmission shaft, transmitting 8kW of power at 400rpm from a bevel gear G_1 to a helical gear G_2 and mounted on two ball bearings B_1 and B_2 is shown in fig.(15 -a). The gear tooth forces on the helical gear act at a pitch circle radius of 55mm, while those on the bevel gear can be assumed to act at the large end of the tooth at a radius of 50mm. The diameter of the journal at the bearings B_1 and B_2 is 40mm. Bearings B_1 and B_2 are identical and press fitted on the shaft and intended for continuous on shift (8hours day) operation with light to moderate impact. The thrust force due to bevel and helical gears is taken by the bearing B_2. Select suitable ball bearing for this application.

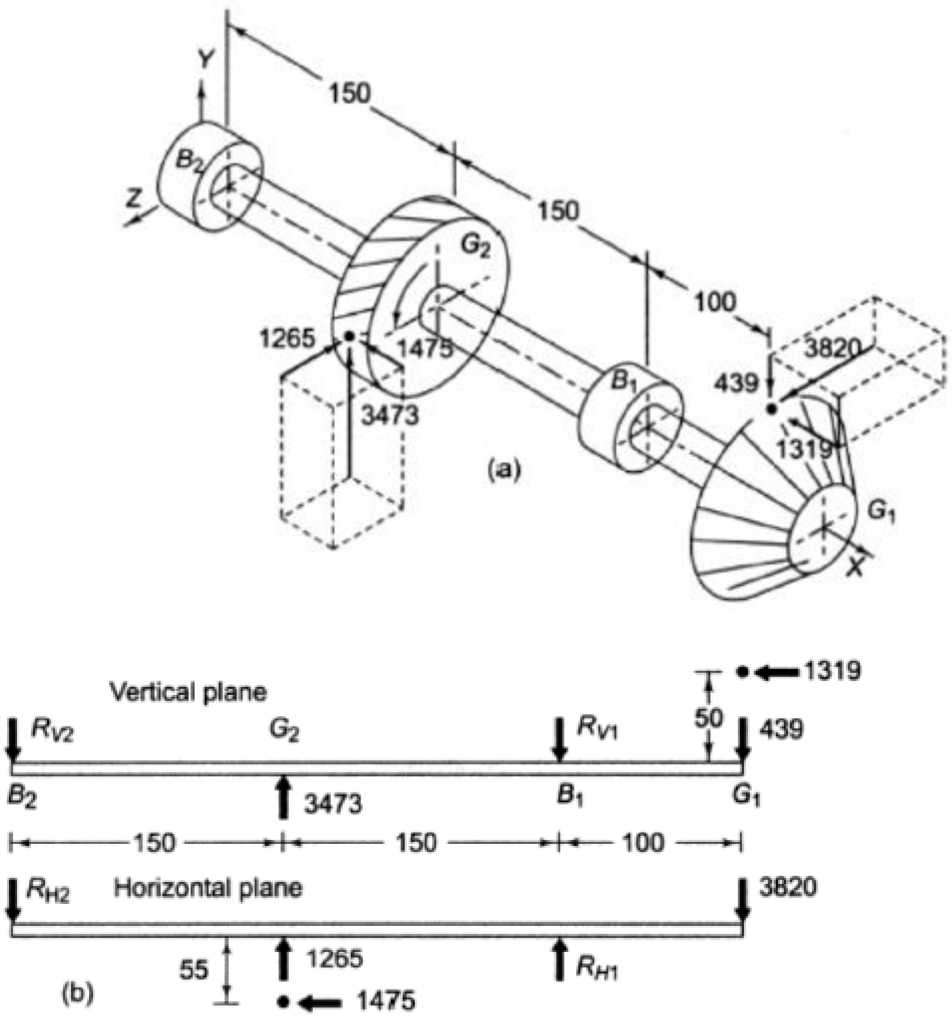


Fig.(15)

Solution:

Considering forces in the vertical plane, taking moments about the bearing B_1,

$3473(150)+439(100)-1319(50) - R_{v2}(300)=0$

Or $R_{v2} = 1663N$

Considering equilibrium of vertical forces

$3473-R_{v1}-1663-439=0$

Or $R_{v1}=1371N$

Considering forces in the horizontal plane and taking moments about the bearing B_1.

$3820(100)+1265(150)+1475(55)-R_{H2}(300)=0$

Or $R_{H2}=2176.25N$

Considering equilibrium of horizontal forces

$2176.25+3820-1265-R_{H1}=0$

Or $R_{H1}=4731.25N$

The radial forces acting on the bearing are as follows

$F_{r1}=[(R_{v1})^2+(R_{H1})^2]^{0.5}=[(1371)^2+(4731.25)^2]^{0.5}=4926N$

$F_{r2}=[(R_{v2})^2+(R_{H2})^2]^{0.5}=[(1663)^2+(2176.25)^2]^{0.5}=2739N$

$F_a=F_t=1319+1475=2794N$

Both types, angular type($\alpha=25^o$) and radial ball bearings may be selected as follow:

At B_2:

Since n=400rpm, for a machine with 8hrs service every day the bearing design life is 30000hr (from table4)

$L=400\times30000\times60=720\times10^6$ rev

$F_t/F_r=2794/2739=1.02$

$$0 < \frac{F_t}{F_r} < 10$$

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

$$F_e = 2739[1 + 1.115(1.02 - 0.35)] = 4785.16 \text{ or } 4.785kN$$

For 90% reliability K_r=1

From table (3) the application factor K_a for light to moderate impact is 1.5

$L_R=90\times10^6$ rev.

$$\boldsymbol{C_{req} = F_e K_a (\frac{L}{K_r L_R})^{0.3}}$$

$$\boldsymbol{C_{req} = 4.78 \times 1.5(\frac{720}{90})^{0.3} = 13.379kN}$$

Enter table with this value of C_{req} to get

	Loo	200	300
Bore	75	60	45
Bearing type(table 1)	L15	212	309

For Bearing at B$_1$

Since there is no axial force at this bearing.

$F_e= F_{r1}$=4926N or 4.926kN

$$\boldsymbol{C_{req} = 4.29 \times 1.5(\frac{720}{90})^{0.3} = 13.788kN}$$

From table (2)

	Loo	**200**	**300**
Bore(mm)	**80**	**65**	**45**
Bearing type	**L16**	**213**	**309**

Ex:

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 in Fig. (16) at point *A*. The bearing reactions at *C* and *D*, assuming simple-supports, are also shown. A ball bearing is to be selected for location *C* to accept the thrust, and a cylindrical roller bearing is to be utilized at location *D*. 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 1 (90% reliability)with light to moderate impact.

(*a*) Select the roller bearing for location *D*.

(*b*) Select the ball bearing (angular contact) for location *C*, assuming the inner ring rotates.

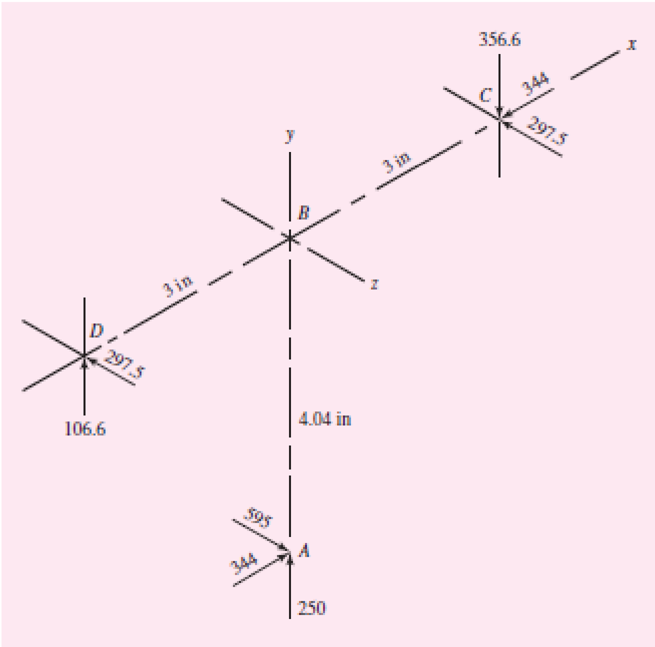


Fig.(16)

Solution

(a) For roller bearing at D

T= 595×4.04=2403 lb.in

Power= (T×n)/63000

n= 63000×power(hp)/T

n=63000×25/2403=655.42rpm

L= 655.42×10000×60=393.252×10^6 rev.

F_r=[297.5^2+106^2]$^{0.5}$=316.16lb or 316.16×4.44=1403.13N= 1.403kN

Since there is no axial force at D

F_e=F_r

$$C_{req} = F_e K_a (\frac{L}{K_r L_R})^{0.3}$$

$$C_{req} = 1.403 \times 1.1(\frac{393.252}{1 \times 90})^{0.3} = 2.40kN$$

Series	**1000**	**1200**	**1300**
Bore(table 2)	**20**	**17**	**17**
Bearing Type	**Lo4**	**203**	**203**

(b) Selection of ball bearing

1. Radial Ball bearing

F_r=[356^2+297.5^2]$^{0.5}$=463.94lb

0.35<F_t/F_r=344/463.62=0.74<10

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

$$F_e = 463.94\ [1 + 1.115(0.741 - 0.35)] = 664.851lb$$

Or 664.851×4.44=2951.93N= 2.951kN

K_r=1, K_a(table 3)=1.5

$$C_{req} = F_e K_a (\frac{L}{K_r L_R})^{0.3}$$

$$C_{req} = 2.951 \times 1.5(\frac{393.252}{1 \times 90})^{0.3} = 6.889kN$$

	XL	**200**	**300**
Bore(table 2)	**55**	**35**	**30**
Bearing type(table1)	**L11**	**207**	**306**

2. **For angular contact withα=25°**

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

$F_e = 463[1 + 0.87(0.741 - 0.68)]$ =**487.168 lb**

Or 487.168×4.44=2163N=2.163kN

$$\boldsymbol{C_{req} = F_e K_a (\frac{L}{K_r L_R})^{0.3}}$$

$$\boldsymbol{C_{req} = 2.163 \times 1.5(\frac{393.25}{90})^{0.3} = 5.04kN}$$

Series	**L00**	**200**	**300**
Bore(table 2)	**45**	**30**	**20**
Bearing type(table1)	**L09**	**206**	**304**

Rolling Bearing Life

Definitions:

We note that **bearing life** is defined as the number of revolutions or hours at some uniform speed at which the bearing operates until fatigue failure.

Rating life L_{10} refers to the number of revolutions (or hours at a uniform speed) that 90% of a group of identical roller bearings will complete or exceed before the first evidence of fatigue develops. The term minimum life is also used to denote the rating life.

Median life refers to the life that 50% of the group of bearings would complete or exceed. Test results show that the median life is about five times the L_{10} life.

Alternative method to calculate equivalent Radial Load

Catalog ratings are based only on the radial load. However, with the exception of thrust bearings, bearings are usually operated with some combined radial and axial loads. It is then necessary to define an equivalent radial load that has the same effect on bearing life as the applied loading. For rolling bearings, the maximum of the values of these two equations is recommended:

$$P = XVF_r + YF_a \quad (1)$$

$$P = VF_r \quad (2)$$

where

P = the equivalent radial load

F_r = the applied radial load

F_a = the applied axial load (thrust)

V = a rotational factor = 1.0 for inner-ring rotation

1.2 for outer-ring rotation

X = a radial factor

Y = a thrust factor

For deep-groove (single-row and double-row) and angular-contact ball bearings, the values of X and Y are given in Tables (5) and (6). Straight cylindrical roller bearings are very limited in their thrust capacity because axial loads produce sliding friction at the roller ends. So, the equivalent load for these bearings can also be estimated using Equation (2).

Table(5) Factors for deep- groove ball bearings

		$F_a/VF_r \le e$		$F_a/VF_r > e$	
F_a/C_s	e	X	Y	X	Y
0.014[a]	0.19				2.30
0.21	0.21				2.15
0.028	0.22				1.99
0.042	0.24				1.85
0.056	0.26				1.71
0.070	0.27	1.0	0	0.56	1.63
0.084	0.28				1.55
0.110	0.30				1.45
0.17	0.34				1.31
0.28	0.38				1.15
0.42	0.42				1.04
0.56	0.44				1.00

Table(6) Factors commonly used for angular contact bearings

			Single-Row Bearing		Double-Row Bearing			
			$F_a/VF_r > e$		$F_a/VF_r \le e$		$F_a/VF_r > e$	
Contact Angle (α)	e	$\frac{iF_a}{C_s}$ [a]	X	Y	X	Y	X	Y
	0.38	0.015		1.47		1.65		2.39
	0.40	0.029		1.40		1.57		2.28
	0.43	0.058		1.30		1.46		2.11
	0.46	0.087		1.23		1.38		2.00
15°	0.47	0.12	0.44	1.19	1.0	1.34	0.72	1.93
	0.50	0.17		1.12		1.26		1.82
	0.55	0.29		1.02		1.14		1.66
	0.56	0.44		1.00		1.12		1.63
	0.56	0.58		1.00		1.12		1.63
25°	0.68		0.41	0.87	1.0	0.92	0.67	1.41
35°	0.95		0.37	0.66	1.0	0.66	0.60	1.07

Equivalent Shock Loading

Some applications have various degrees of shock loading, which has the effect of increasing the equivalent radial load. Therefore, a shock or service factor, K_s, can be substituted into Equations (1) and (2) to account for any shock and impact conditions to which the bearing may be subjected. In so doing, the equivalent radial load becomes the larger of the values given by the two equations:

$$P = K_s (XVF_r + YF_a) \quad (3)$$

$$P = K_s VF_r \quad (4)$$

Selection of Rolling Bearings

Extensive testing of rolling bearings and subsequent statistical analysis has shown that load and life of a bearing are related statistically. This relationship can be expressed as

$$\boldsymbol{L_{10} = \left(\frac{C}{P}\right)^{a}} \quad \textbf{(5)}$$

where

L_{10} = the rating life, in 106 revolution

C = the basic load rating (from Tables (7) and (8))

P = the equivalent radial load (equations 1 and 2)

a = 3 for ball bearings

10/3 for roller bearings

Table(7) Dimensions and Basic load Rating for 02 series Ball Bearing

Bore, D (mm)	OD, D_o (mm)	Width, w (mm)	Fillet Radius, r (mm)	Load Ratings (kN) Deep Groove C	Deep Groove C_s	Angular Contact C	Angular Contact C_s
10	30	9	0.6	5.07	2.24	4.94	2.12
12	32	10	0.6	6.89	3.10	7.02	3.05
15	35	11	0.6	7.80	3.55	8.06	3.65
17	40	12	0.6	9.56	4.50	9.95	4.75
20	47	14	1.0	12.7	6.20	13.3	6.55
25	52	15	1.0	14.0	6.95	14.8	7.65
30	62	16	1.0	19.5	10.0	20.3	11.0
35	72	17	1.0	25.5	13.7	27.0	15.0
40	80	18	1.0	30.7	16.6	31.9	18.6
45	85	19	1.0	33.2	18.6	35.8	21.2
50	90	20	1.0	35.1	19.6	37.7	22.8
55	100	21	1.5	43.6	25.0	46.2	28.5
60	110	22	1.5	47.5	28.0	55.9	35.5
65	120	23	1.5	55.5	34.0	63.7	41.5
70	125	24	1.5	61.8	37.5	68.9	45.5
75	130	25	1.5	66.3	40.5	71.5	49.0
80	140	26	2.0	70.2	45.0	80.6	55.0
85	150	28	2.0	83.2	53.0	90.4	63.0
90	160	30	2.0	95.6	62.0	106	73.5
95	170	32	2.0	108	69.5	121	85.0

Table(8) Dimensions and Basic load Rating for straight cylindrical Bearing

Bore, D (mm)	02-Series OD, D_o (mm)	02-Series Width, w (mm)	02-Series Load Rating, C (kN)	03-Series OD, D_o (mm)	03-Series Width, w (mm)	03-Series Load Rating, C (kN)
25	52	15	16.8	62	17	28.6
30	62	16	22.4	72	19	36.9
35	72	17	31.9	80	21	44.6
40	80	18	41.8	90	23	56.1
45	85	19	44.0	100	25	72.1
50	90	20	45.7	110	27	88.0
55	100	21	56.1	120	29	102
60	110	22	64.4	130	31	123
65	120	23	76.5	140	33	138
70	125	24	79.2	150	35	151
75	130	25	91.3	160	37	183
80	140	26	106	170	39	190
85	150	28	119	180	41	212
90	160	30	142	190	43	242
95	170	32	165	200	45	264

Alternatively, the foregoing equation may be written in the following form:

$$L_{10} = \frac{10^6}{60n}\left(\frac{C}{P}\right)^a \qquad \textbf{(6)}$$

where

L_{10} represents the rating life, in h

n is the rotational speed, in rpm

When two groups of identical bearings are run with different loads P_1 and P_2, the ratio of their rating lives L'_{10} and L''_{10}, by Equation(5), is

$$\frac{L'_{10}}{L''_{10}} = \left(\frac{P_2}{P_1}\right)^a \qquad \textbf{(7)}$$

Reliability Requirement

The definition of rating life L_{10} is based on a 90% reliability (or 10% failure). In some applications, the foregoing survival rate cannot be tolerated. A *life adjustment factors*, K_r, plotted in Figure (17). This curve can be applied to both ball and roller bearings but is restricted to reliabilities no greater than 99%. The expected bearing life is the product of the rating life and the adjustment factor. Combining this factor with Equation (5) , we have

$$L_5 = K_r\left(\frac{C}{P}\right)^a \qquad \textbf{(8)}$$

The quantity L_5 represents the rating life for any given reliability greater than 90%.

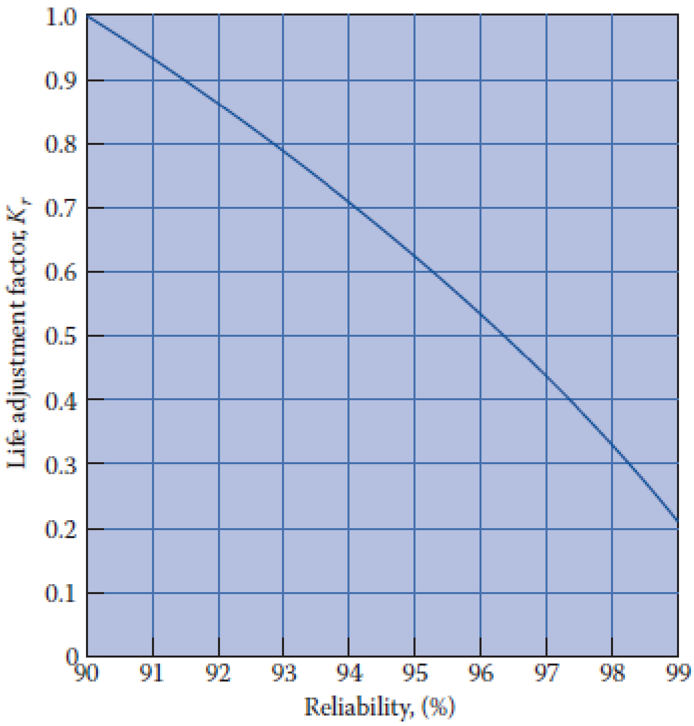


Fig.(17) Reliability factor K_r.

For reference, Table (9) may be used to Represent Rolling Bearing Design Lives.

Table(9) Representative Rolling Bearing Design Lives

Type of Application	Life (kh)
Instruments and apparatus for infrequent use	Up to 0.5
Aircraft engines	0.5–2
Machines used intermittently	
Service interruption is of minor importance	4–8
Reliability is of great importance	8–14
Machines used in an 8 h service working day	
Not always fully utilized	14–20
Fully utilized	20–30
Machines for continuous 24 h service	50–60
Reliability is of extreme importance	100–200

Example: Median Life of a Deep-Groove Ball Bearing

A 50 mm bore (02-series) deep-groove ball bearing, carries a combined load of 9 kN radially and 6 kN axially at 1200 rpm. Calculate

a. The equivalent radial load

b. The median life in hours

The inner ring rotates and the load is steady.

Solution

Referring to Table (7) for a 50 mm bore bearing, $C = 35.1$ kN and C_s = 19.6 kN.

a. To obtain the values of the radial load factors X and Y, it is necessary to obtain

$$\frac{F_a}{C_s} = \frac{6}{19.6} = 0.306, \quad \frac{F_a}{VF_r} = \frac{6}{1(9)} = 0.667$$

We find from Table (5) that $F_a/VF_r > e$: X = 0.56 and Y = 1.13 by interpolation. Applying Equation (1),

$P=XVF_r+YF_a=(0.56)(1)(9)+(1.13)(6)=11.82kN$

Through the use of Equation (2), $P = VF_r = 1(9) = 9$ kN.

b. Since 11.95 > 9 kN, the larger value is used for life calculation. The rating life, from Equation (5), is

$$\boldsymbol{L_{10}} = (\frac{\boldsymbol{C}}{\boldsymbol{P}})^{\boldsymbol{a}} = (\frac{35.1}{11.82})^3 = 26.19(10^6)rev$$

Or life in hours can be calculated:

$$L_{10} = \left(\frac{10^6}{60n}\right)\left(\frac{C}{P}\right)^a = \frac{10^6(26.19)}{60(1200)} = 364h$$

The median life is therefore $5L_{10} = 5\times364=1820$ h.

Ex: Determine the expected life of the bearing in the previous example if only a 6% probability of failure can be permitted.

Solution

From Figure (17), for a reliability of 94%, K_r = 0.7. Using Equation (8), the expected rating life is

$$L_5 = K_r \frac{10^6}{60n}(\frac{C}{P})^a = 0.7(364) = 254h$$

Comment: To improve the reliability of the bearing in the previous example from 90% to 94%, a reduction of median life from 1820 h to $5L_5$ =1274 h is required.