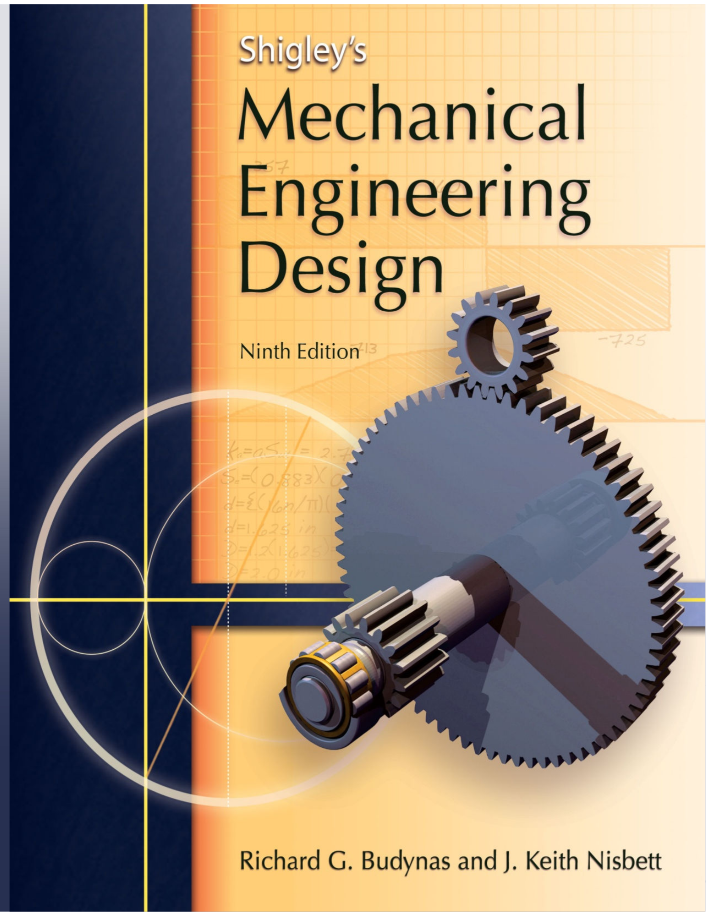
Lecture Slides

Chapter 11

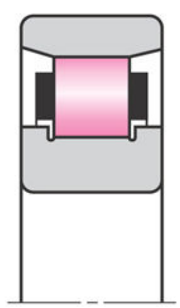
Rolling-Contact Bearings



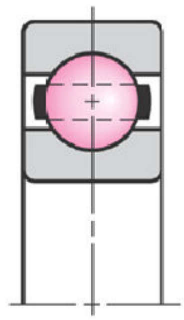
Chapter Outline

Three Types of Bearings

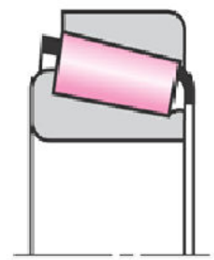
- Straight roller bearings can carry large radial loads, but **no axial load**.
- Ball bearings can carry moderate radial loads, and **small axial loads**.
- Tapered roller bearings rely on roller tipped at an angle to allow them to carry **large radial and large axial loads**.



Straight roller bearing
(Silindirik makaralı rulman)

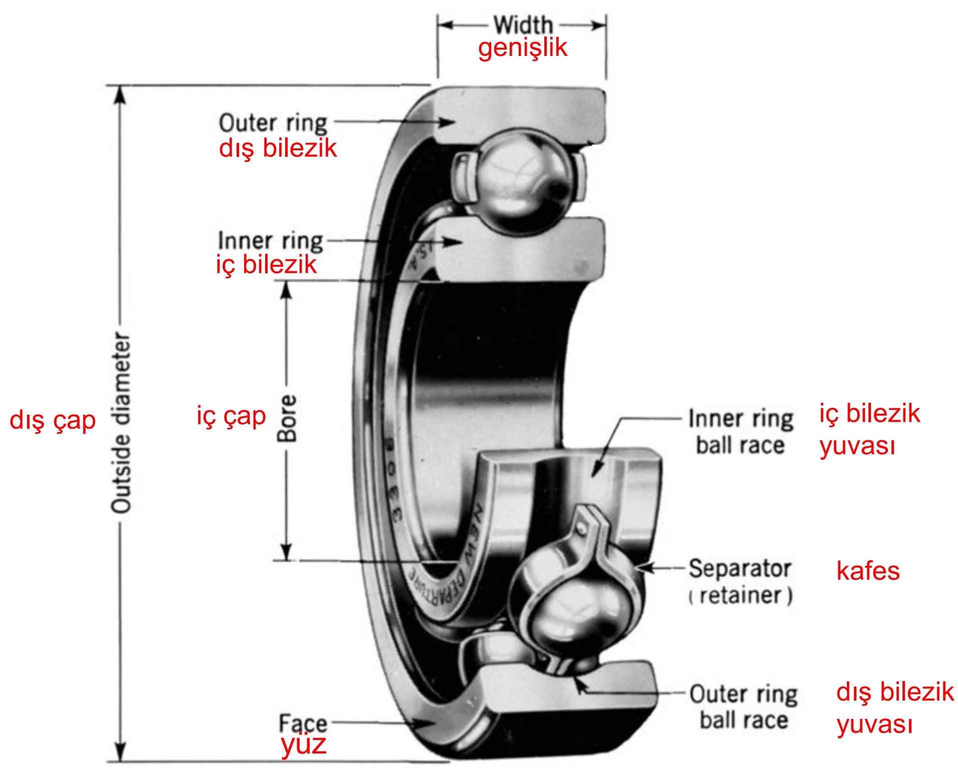


Ball bearing
(Bilyalı rulman)

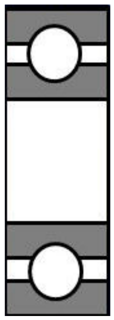


Tapered roller bearing
(Konik makaralı rulman)

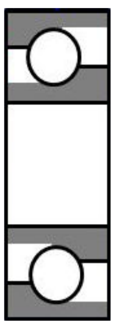
Nomenclature of a Ball Bearing



Most Popular Types of Ball Bearings



- **Deep groove ball bearings** are used to transmit loads from rotating parts to housings with minimal friction losses.
- Deep groove bearings support axial and radial loads in both directions and are suitable for high speeds.
- A distinct advantage over angular contact ball bearings is that they can accept axial load in both directions.



- **Angular contact ball bearings** are typically used in machinery that requires high performance and high accuracy.
- They can carry both radial and axial loads.
- The loads are transferred from one raceway to other through the bearing balls along a specifically designed contact angle.
- Angular contact bearings have a much higher speed rating than radial ball bearings because of the constant contact of the balls to both raceways.

Definitions

- ***Life***: Number of revolutions (or hours @ given speed) to failure.
- ***Rating Life***: *Life* required for 10% of sample to fail.
  - Also called *Minimum Life* or L_{10} *Life*
- ***Catalog Load Rating, C_{10}***: Constant radial load that causes 10% of a group of bearings to fail at the manufacturer's rating life.
- ***Static Load Rating, C_o***:
  Static radial load which corresponds to a permanent deformation of 0.0001d, where d = diameter of roller
- ***Equivalent Radial Load, F_e***:
  Constant stationary load applied to bearing with rotating inner ring which gives the same life as actual load and rotation conditions.

Load-Life Relationship

- Nominally identical groups of bearings are tested to the life-failure criterion at different loads.
- A plot of load vs. life on log-log scale is approximately linear.
- Using a regression equation to represent the line,

$$F L^{1/a} = \text{constant} \qquad (11\text{–}1)$$

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

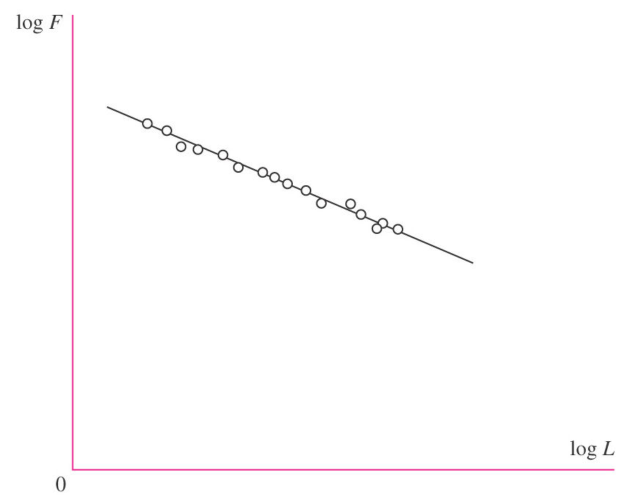


Fig. 11–4

Load-Life Relationship

- Given the desired design load F_D and life L_D, **the catalog load rating C_{10} is calculated to find a suitable bearing in the catalog.**

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

- The rated life L_R will be stated by the specific bearing manufacturer. Many catalogs rate at $L_R = 10^6$ revolutions.
- The units of L are revolutions. If life $\mathcal{L}$ is given in hours at a given speed n in rev/min, we apply a conversion of 60 min/h,

$$L = 60\, \mathcal{L} n$$

- It is often convenient to define a dimensionless *multiple of rating life* $x_D = L_D / L_R$

Example 11–1

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 1.8 kN with a reliability of 90 percent, for which catalog rating would you search in an SKF catalog?

Solution

Representative Catalog Data for Ball Bearings (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 d_S	Shoulder Diameter, mm d_H	Load Ratings, kN Deep Groove C_{10}	Load Ratings, kN Deep Groove C_0	Load Ratings, kN Angular Contact C_{10}	Load Ratings, kN Angular Contact 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
80	140	26	2.0	93	127	70.2	45.0	80.6	55.0
85	150	28	2.0	99	136	83.2	53.0	90.4	63.0
90	160	30	2.0	104	146	95.6	62.0	106	73.5
95	170	32	2.0	110	156	108	69.5	121	85.0

Representative Catalog Data for Cylindrical Roller Bearings (Table 11–3)

	02-Series				03-Series			
Bore, mm	OD, mm	Width, mm	Load Rating, kN C_{10}	C_0	OD, mm	Width, mm	Load Rating, kN C_{10}	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
110	200	38	229	167	240	50	391	304
120	215	40	260	183	260	55	457	340
130	230	40	270	193	280	58	539	408
140	250	42	319	240	300	62	682	454
150	270	45	446	260	320	65	781	502

Relating Load, Life, and Reliability

- If the desired reliability is different than 90%, the formula for the catalog load rating C_{10} should be updated.

$$C_{10} \doteq a_f F_D \left[\frac{x_D}{x_0 + (\theta - x_0)(1 - R_D)^{1/b}} \right]^{1/a} \qquad R \geq 0.90 \qquad (11\text{–}7)$$

- The Weibull distribution parameters x_0, θ, and b are usually provided by the catalog.
- Typical values of Weibull parameters are shown below.
- Manufacturer 1 parameters are common for tapered roller bearings
- Manufacturer 2 parameters are common for ball and straight roller bearings

Manufacturer	Rating Life, Revolutions	Weibull Parameters Rating Lives x_0	θ	b
1	$90(10^6)$	0	4.48	1.5
2	$1(10^6)$	0.02	4.459	1.483

Recommended Load Application Factors (Table 11–5)

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

- The load application factors serve as factors of safety
- We use them to increase the equivalent load before selecting a bearing

Example 11–3

The design load on a ball bearing is 1.8 kN and an application factor of 1.2 is appropriate. The speed of the shaft is to be 300 rev/min, the life to be 30 kh with a reliability of 0.99. What is the C_{10} catalog entry to be sought (or exceeded) when searching for a deep-groove bearing in a manufacturer's catalog on the basis of 10^6 revolutions for rating life? The Weibull parameters are $x_0 = 0.02$, $(\theta - x_0) = 4.439$, and $b = 1.483$.

Solution

Combined Reliability of Multiple Bearings

- If the combined reliability of multiple bearings on a shaft, or in a gearbox, is desired, then the total reliability is equal to the product of the individual reliabilities.
- For two bearings on a shaft, $R = R_A R_B$
- If the bearings are to be identical, each bearing should have a reliability equal to the square root of the total desired reliability.
- If the bearings are not identical, their reliabilities need not be identical, so long as the total reliability is realized.

Combined Radial and Thrust Loading

- When ball bearings carry both an axial thrust load F_a and a radial load F_r, an *equivalent radial load* F_e that does the same damage is used.
- A plot of F_e/VF_r vs. F_a/VF_r is obtained experimentally.
- V is a **rotation factor** to account for the difference in ball rotations for outer ring rotation vs. inner ring rotation.
  - $V = 1$ for inner ring rotation
  - $V = 1.2$ for outer ring rotation

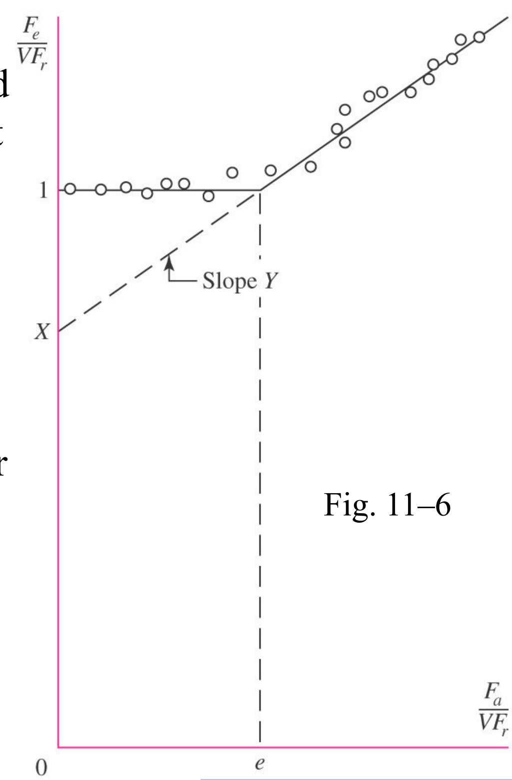


Fig. 11–6

Equivalent Radial Load Factors for Ball Bearings

$$F_e = X_i V F_r + Y_i F_a \qquad (11\text{–}9)$$

Table 11–1

F_a/C_0	e	$F_a/(VF_r) \le e$ X_1	Y_1	$F_a/(VF_r) > e$ 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

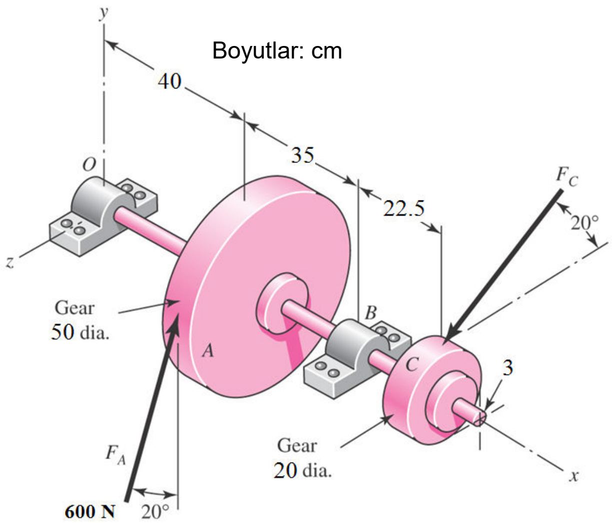
- X and Y are functions of e, which is a function of F_a/C_0.
- C_0 is the *basic static load rating*, which is tabulated in the catalog.

Example 11–4

An SKF 6210 angular-contact ball bearing has an axial load F_a of 1.8 kN and a radial load F_r of 2.2 kN applied with the outer ring stationary. The basic static load rating C_0 is 19.8 kN and the basic load rating C_{10} is 35.1 kN. Estimate the $\mathcal{L}_{10}$ life at a speed of 720 rev/min.

Solution

Örnek



a) Şekildeki şaft 1200 rpm ile dönmektedir. O ve B'deki bilyalı rulmanların (*single row, angular contact*) her birinden en az %95 güvenilirlik ile 15,000 saat ömür beklenmektedir.

O ve B'de aynı rulman kullanılacaktır.

- Rulman seçiminde kullanılacak C_{10} yük sayısını (*load rating*) hesaplayınız.

Dış bileziğin sabit olduğunu varsayınız.

a_f=1.2 kullanınız.

b) F_A ve F_C yüklerine ek olarak, F_a=1 kN eksenel kuvvet uygulanmakta olduğu durum için problemi tekrar çözünüz.

Katalog bilgileri:

C_{10} değerleri L_R=10^6 çevrim için verilmektedir.
Weibull dağılımı parametreleri aşağıdaki tabloda verilmiştir.

x_0	θ	b
0.02	4.459	1.483

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Example 11–7

Shown in Figure 11–12 is a gear-driven squeeze roll that mates with an idler roll. The roll is designed to exert a normal force of 5.25 N/mm of roll length and a pull of 4.2 N/mm on the material being processed. The roll speed is 300 rev/min, and a design life of 30 kh is desired. Use an application factor of 1.2, and select a pair of angular-contact 02-series ball bearings from Table 11–2 to be mounted at 0 and *A*. Use the same size bearings at both locations and a combined reliability of at least 0.92.

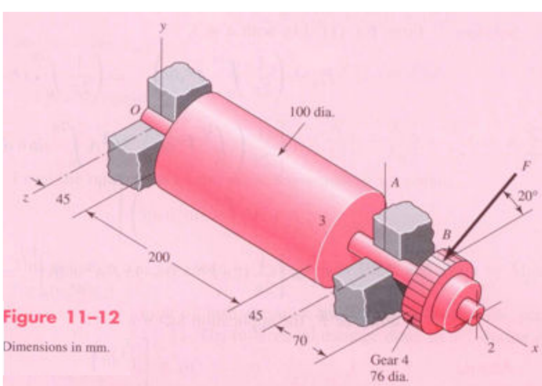
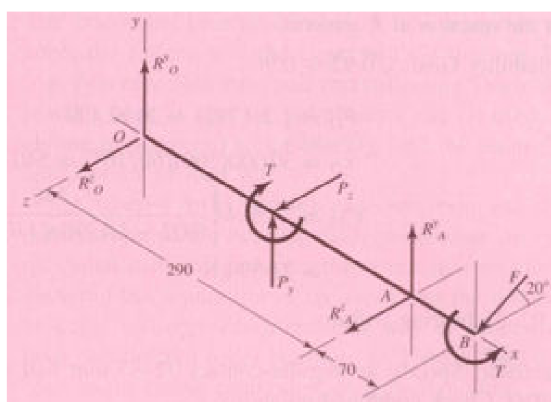


Figure 11–12

Dimensions in mm.



Example 11–7

Representative Catalog Data for Ball Bearings (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 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
75	130	25	1.5	86	119	66.3	40.5	71.5	49.0
80	140	26	2.0	93	127	70.2	45.0	80.6	55.0
85	150	28	2.0	99	136	83.2	53.0	90.4	63.0

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Realized Bearing Reliability

- To determine a suitable catalog rated load for a given design situation and reliability goal, we use

$$C_{10} \doteq a_f F_D \left[\frac{x_D}{x_0 + (\theta - x_0)(1 - R_D)^{1/b}} \right]^{1/a} \qquad R \geq 0.90 \qquad (11\text{–}7)$$

- An actual bearing is selected from a catalog with a rating greater than C_{10}.
- Sometimes it is desirable to determine the realized reliability from the actual bearing (that was slightly higher capacity than needed).
- Solving Eq. (11–6) for the reliability,

$$R \doteq 1 - \left\{ \frac{x_D \left(\dfrac{a_f F_D}{C_{10}} \right)^a - x_0}{\theta - x_0} \right\}^b \qquad R \geq 0.90 \qquad (11\text{–}19)$$

Example 11–9

Compute the realized reliability of the bearings in Example 11-7.

Solution

$$R_O = 1 - \left\{ \frac{540\left(\dfrac{1.2\times 640.6}{27000}\right)^3 - 0.02}{4.439} \right\}^{1.483} \approx 1.0$$

$$R_A = 1 - \left\{ \frac{540\left(\dfrac{1.2\times 1792}{27000}\right)^3 - 0.02}{4.439} \right\}^{1.483} = 0.9857$$

Reliability of the bearing system: $R = R_O \times R_A = (1)(0.9857) = 0.9857$

(Recall that the reliability goal was 0.92)

Tapered Roller Bearings

- Straight roller bearings can carry large radial loads, but **no axial load**.
- Ball bearings can carry moderate radial loads, and **small axial loads**.
- Tapered roller bearings rely on roller tipped at an angle to allow them to carry **large radial and large axial loads**.
- Tapered roller bearings were popularized by the Timken Company.
  - Similar catalogs as in ball bearings are used to select bearings.
  - Read Chapter 11.9 in Shigley's book.