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Chapter 13: Rolling Element Bearings

An assortment of rolling-element bearings.
Source: Courtesy of Timken, Inc.

Since there is no model in nature for guiding wheels on axles or axle journals, man faced a great task in designing bearings — a task which has not lost its importance and attraction to this day.

Rolling Bearings and Their Contribution to the Progress of Technology [1986].

Rolling Element Bearings

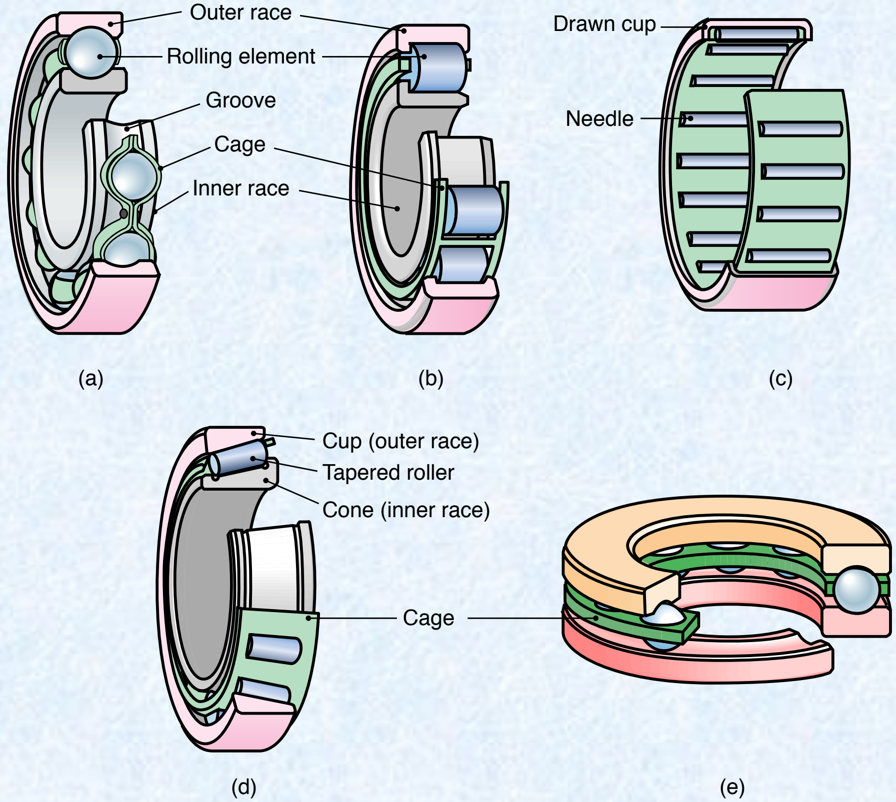
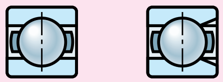
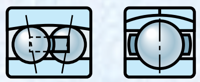
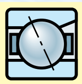
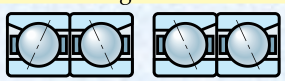
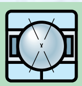
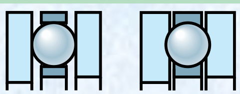
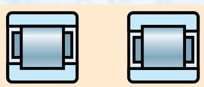


Figure 13.1: Illustration of selected single row rolling-element bearings. (a) Deep groove ball bearing; (b) cylindrical roller bearing; (c) needle bearing with drawn cup and no inner race. In such a circumstance, the needles roll on a ground and hardened shaft. (d) Tapered roller bearing; (e) thrust ball bearing.

Selection Guide for Bearings

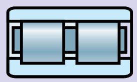
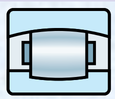
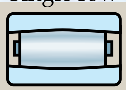
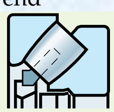
Bearing Type	Examples	Approximate maximum diameter, mm	Radial capacity	Axial capacity	Combined load	Moment load	Speed	Stiffness	Quiet running	Misalignment compensation	Allowable axial displacement	Typical Applications
Radial Ball												
Deep groove	 Conrad, Filling notch	1000	2	2	2	1	2	2	4	1	0	Textiles, power tools, pumps, gearboxes
Self-aligning	 Internal, External	120	2	1	1	0	4	1	3	4	0	Fans, paper making machinery
Angular contact	 Single row	320	2	2	3	1	3	2	3	1	0	Pumps, compressors, centrifuges
Duplex	 Back-to-back, Tandem	320	3	2	3	2	2	3	2	0	0	Pumps, compressors, centrifuges
Two-directional	 Split-ring	110	1	3	2	2	3	2	2	0	0	Compressors
Thrust Ball	 Flat race, Grooved race	1000	0	2	0	0	1	2	1	1	0	Plastic extruder tools, crane hooks
Cylindrical Roller	 Separable inner ring, Separable outer ring	500	3	0	0	0	3	3	3	1	4	Traction motors, electric motors, gearboxes

0: Unsuitable, 1: Poor, 2: Fair, 3: Good, 4: Excellent.
[a] Dual-row only, otherwise 0.

Table 13.1: Selection guide for rolling-element bearings.

CRC
Fundamentals of Machine Elements, 3rd ed.
Schmid, Hamrock and Jacobson

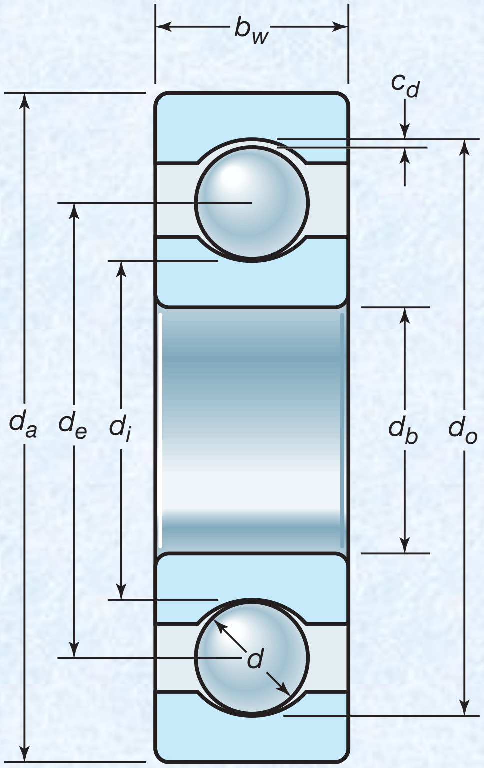
Selection Guide for Bearings

Bearing Type	Examples	Approximate maximum diameter, mm	Radial capacity	Axial capacity	Combined load	Moment load	Speed	Stiffness	Quiet running	Misalignment compensation	Allowable axial displacement	Typical Applications
Full compliment	 Separable inner ring; Separable outer ring	120	4	1	2	0	1	4	1	1	2	Elevators, gearboxes
Double row		1250	4	1	2	2	1	4	1	0	2	Cranes, rolling mills, wire rope sheaves
Spherical Roller	 Single row	320	4	2	4	0	2	3	2	4	0	Fans, gearboxes, crushers, vibrating screens
Toroidal (CARB)		1120	4	0	0	0	2	3	2	4	4	Papermaking machines, gearboxes, fans, electric motors
Needle	 Drawn cup, open end; Grease retained	185	3	0	0	0	2	3	2	0	4	Planetary gearboxes, alternators.
Taper roller - Single row		360	3	3	4	1	2	3	2	1	0	Gearboxes, cone crushers
Taper roller - Double row	 Back-to-back; Tandem	130	4	3	4	2	2	4	2	1	0	Gearboxes, rail car axles

0: Unsuitable, 1: Poor, 2: Fair, 3: Good, 4: Excellent.
[a] Dual-row only, otherwise 0.

Table 13.1: Selection guide for rolling-element bearings.

Radial Ball Bearing



(a)

(b)

Figure 13.2: (a) Cross-section through radial single-row ball bearings; (b) examples of radial single-row ball bearings. *Source:* (b) Courtesy of SKF USA, Inc.

Race Conformity and Contact Angle

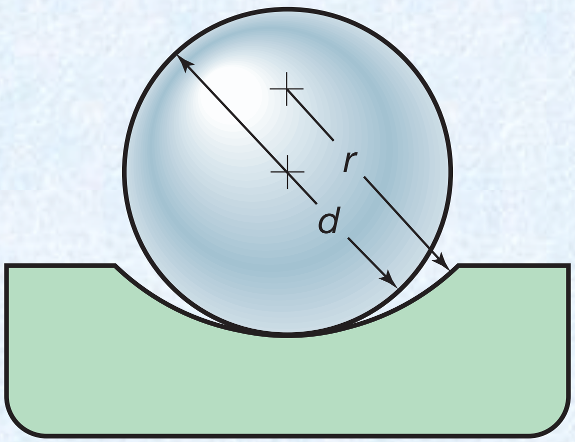


Figure 13.3: Cross-section of ball and outer race, showing race conformity.

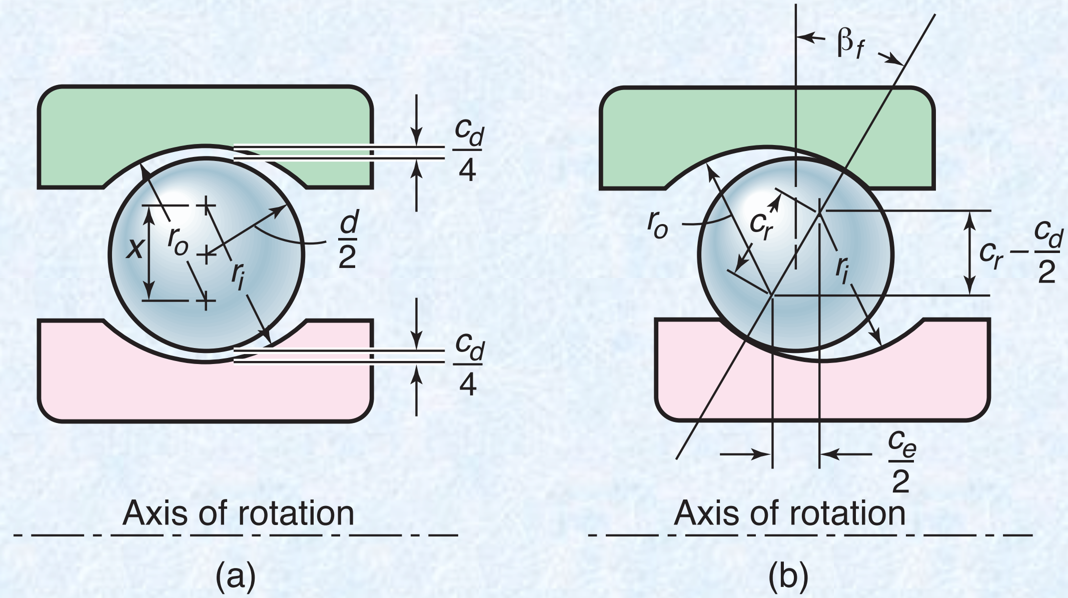


Figure 13.4: Cross-section of radial bearing, showing ball-race contact due to axial shift of inner and outer races. (a) Initial position; (b) shifted position.

Free Contact Angle and Endplay

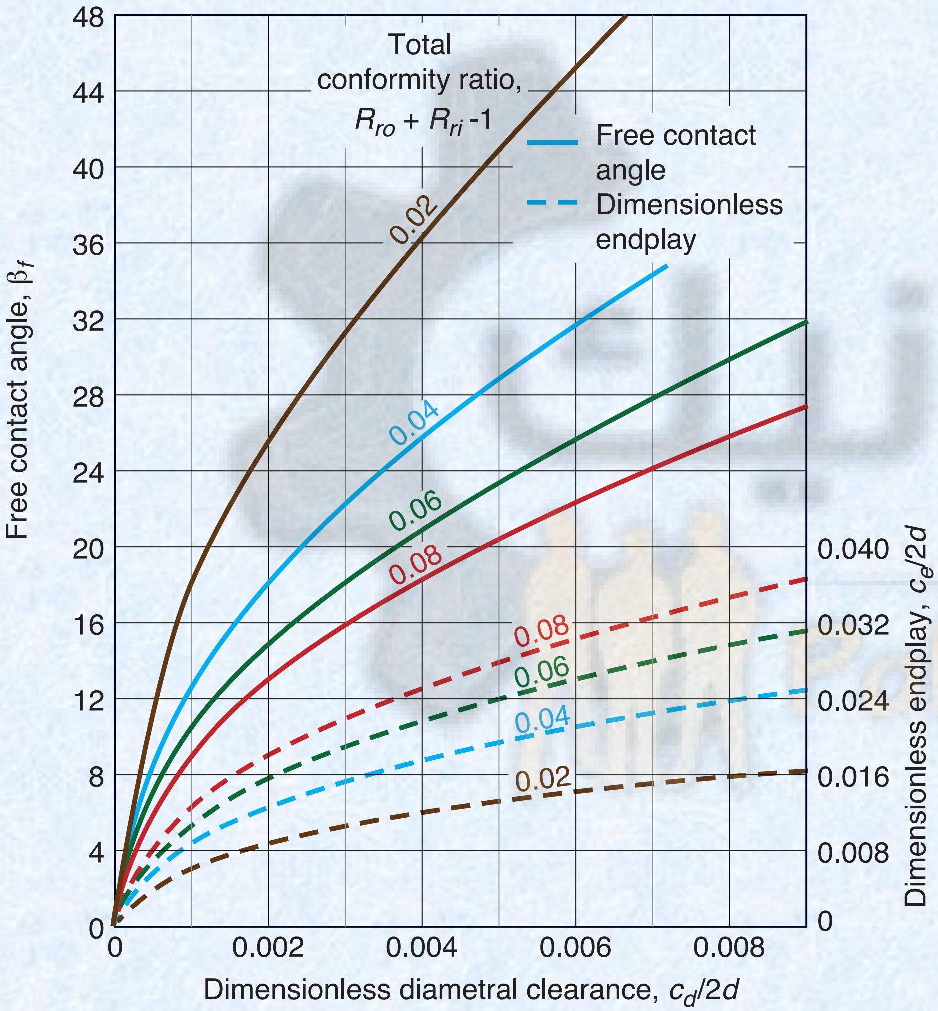


Figure 13.5: Free contact angle and endplay as function of $c_d/2d$.

Shoulder Height

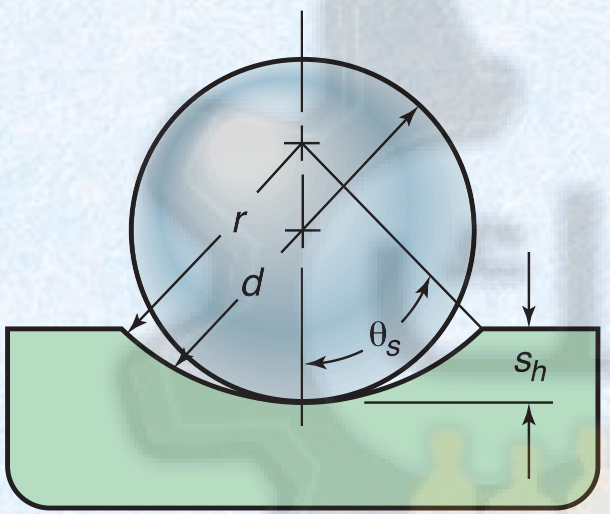


Figure 13.6: Shoulder height in a ball bearing.

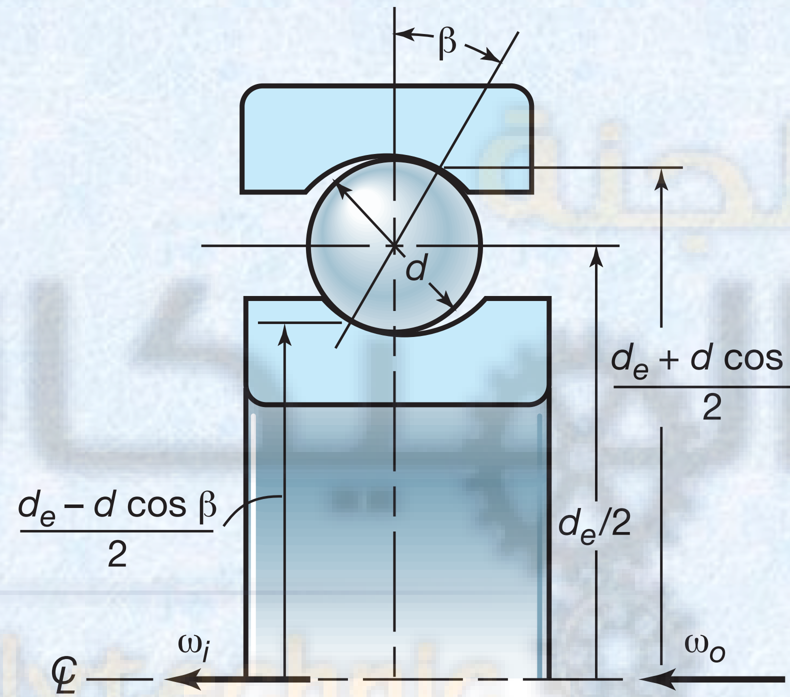


Figure 13.7: Cross-section of ball bearing.

Spheroidal and CARB Bearings

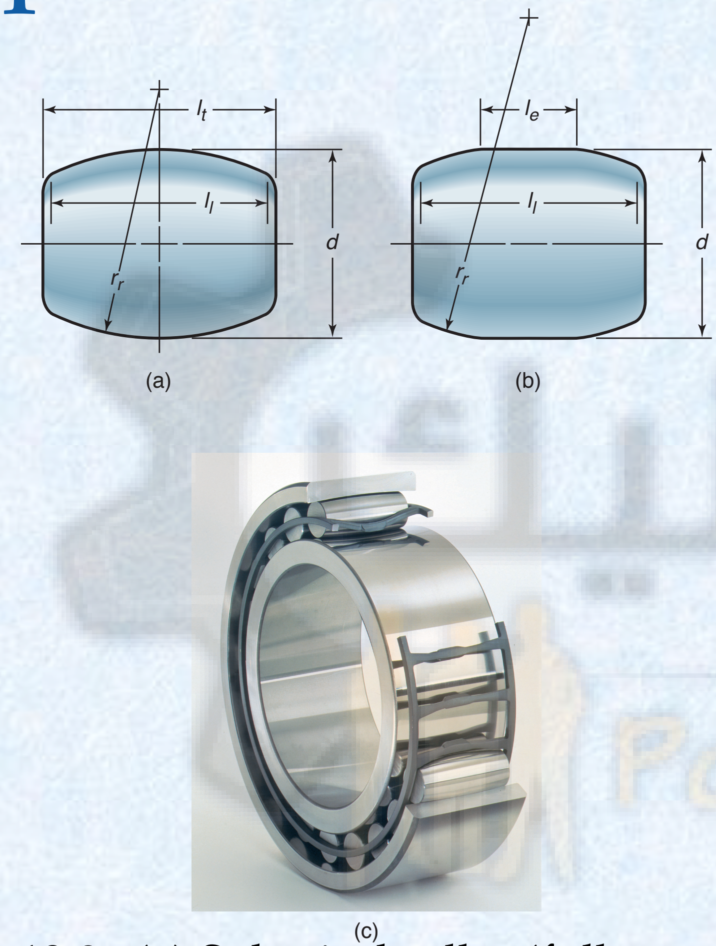


Figure 13.8: (a) Spherical roller (fully crowned); (b) cylindrical roller; (c) section of a toroidal roller bearing (CARB). *Source:* Courtesy of SKF USA, Inc.

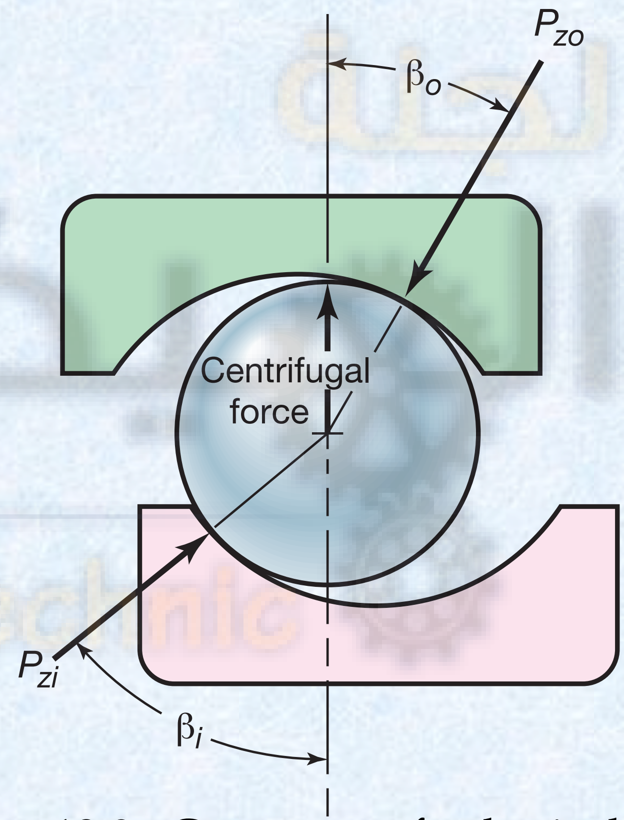


Figure 13.9: Geometry of spherical roller bearing.

Contact Angle

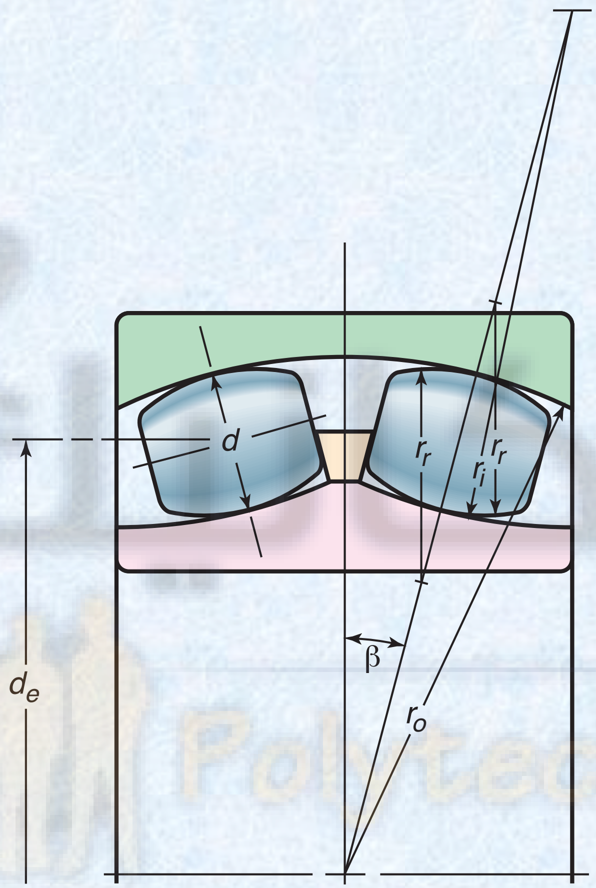


Figure 13.10: Contact angles in ball bearing at appreciable speeds.

Ball Velocity and Spin

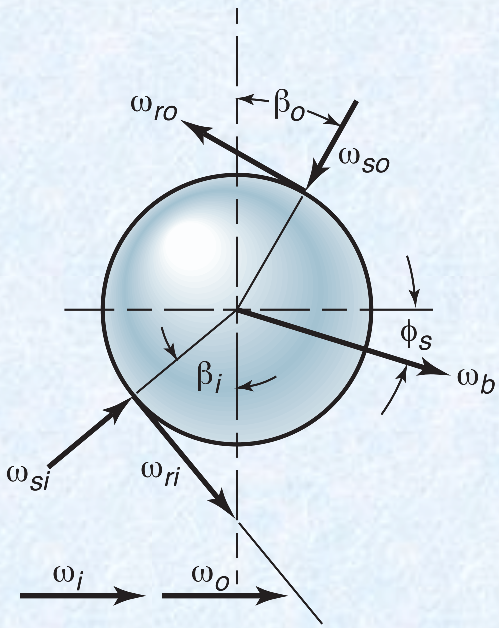


Figure 13.11: Angular velocities of ball.

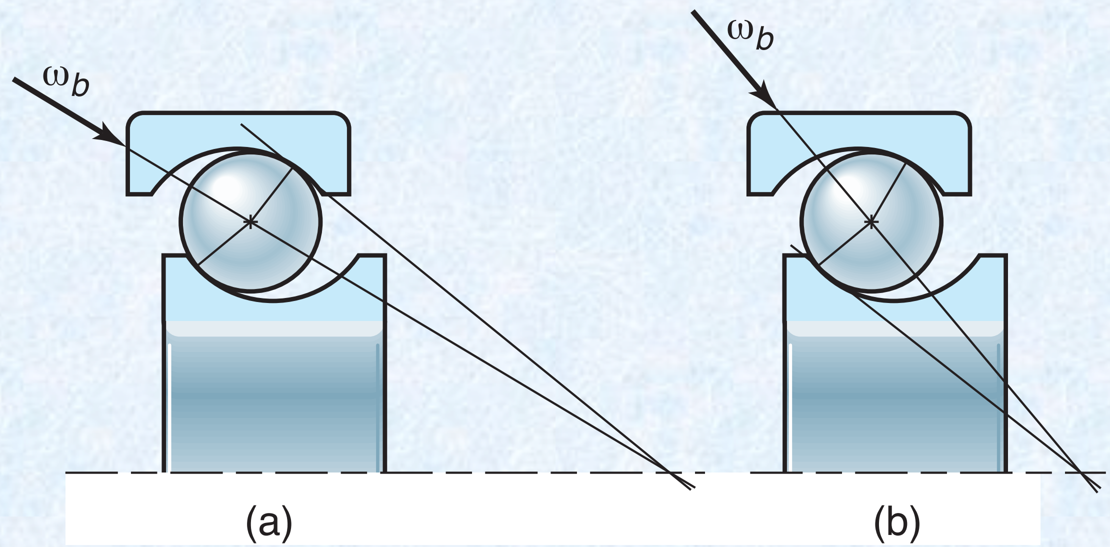
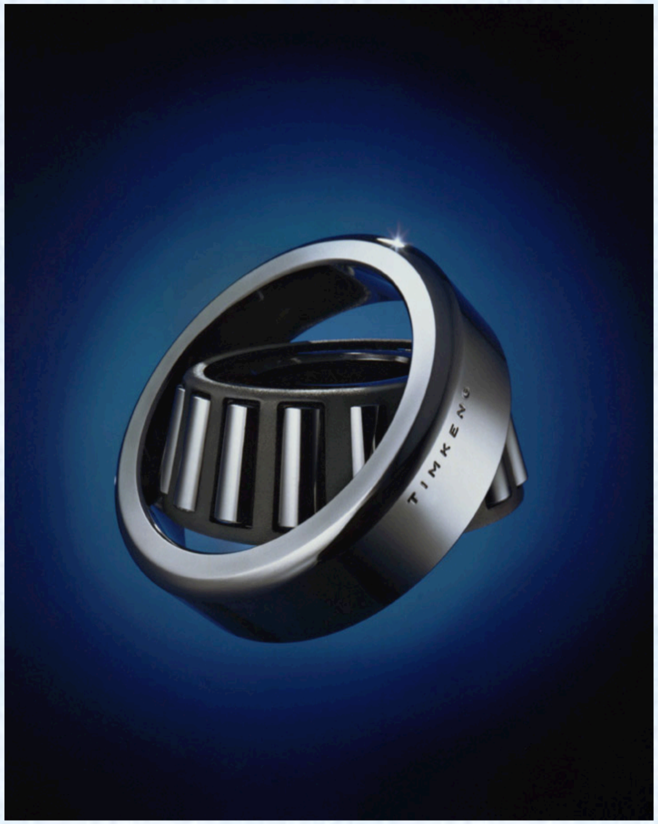


Figure 13.12: Ball-spin axis orientations for (a) outer-race control and (b) inner-race control.

Tapered-Roller Bearing



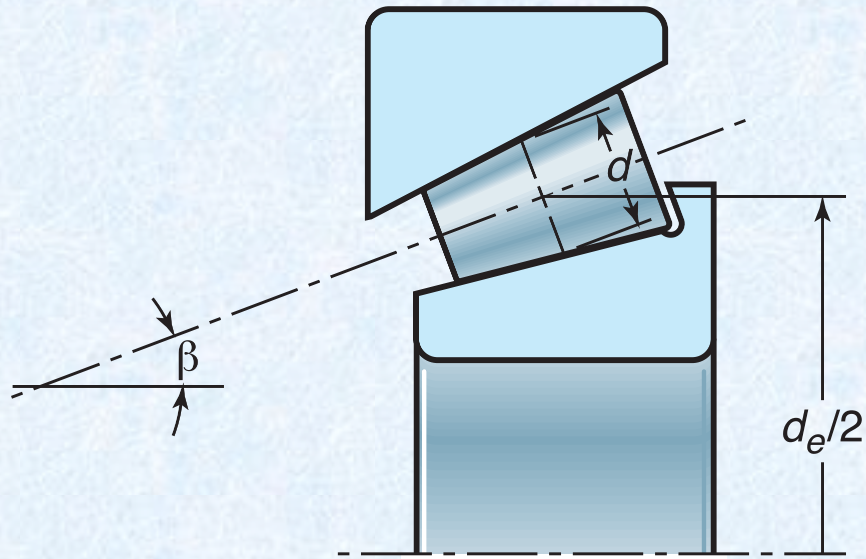


Figure 13.13: Tapered-roller bearing, (a) Tapered roller bearing with outer race removed to show rolling elements. *Source:* From Timken, Inc.; (b) simplified geometry for tapered-roller bearing.

Radially-Loaded Ball Bearing

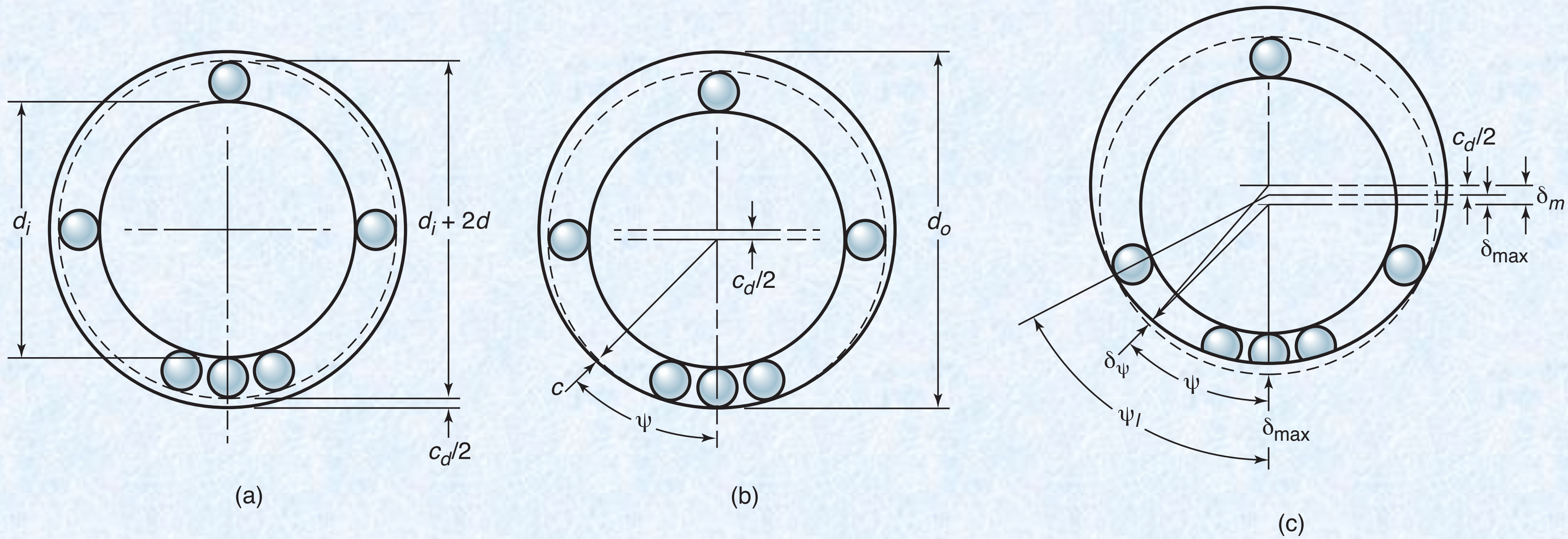


Figure 13.14: Radially loaded rolling-element bearing. (a) Concentric arrangement; (b) initial contact; (c) interference.

Contact Ellipse

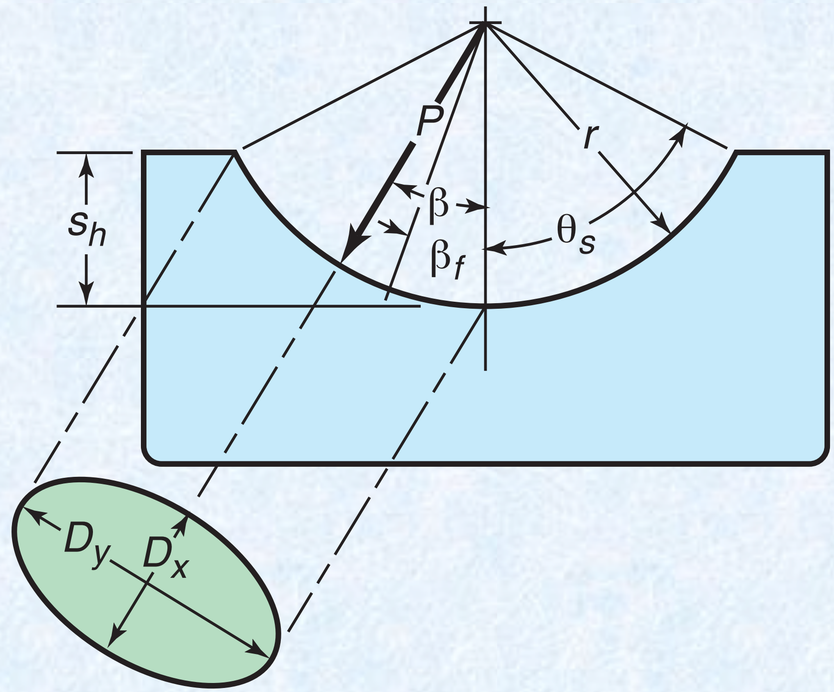


Figure 13.15: Contact ellipse in bearing race under load.

Thrust Loaded Angular Contact Bearing

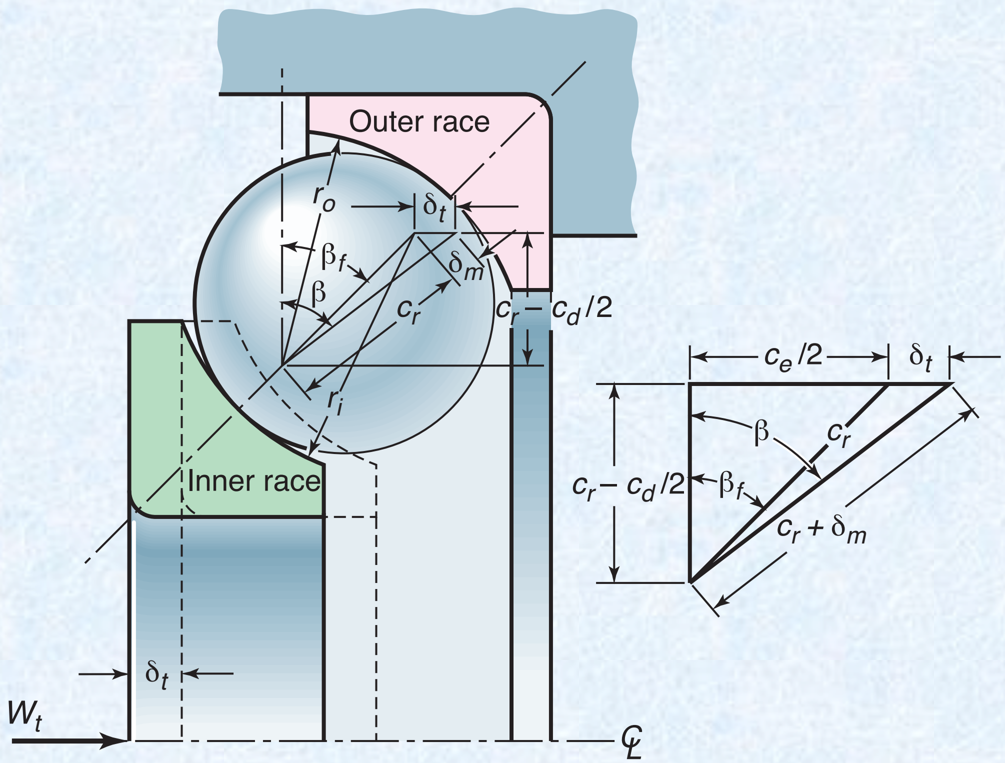


Figure 13.16: Angular-contact ball bearing under thrust load.

Back-to-Back Arrangement

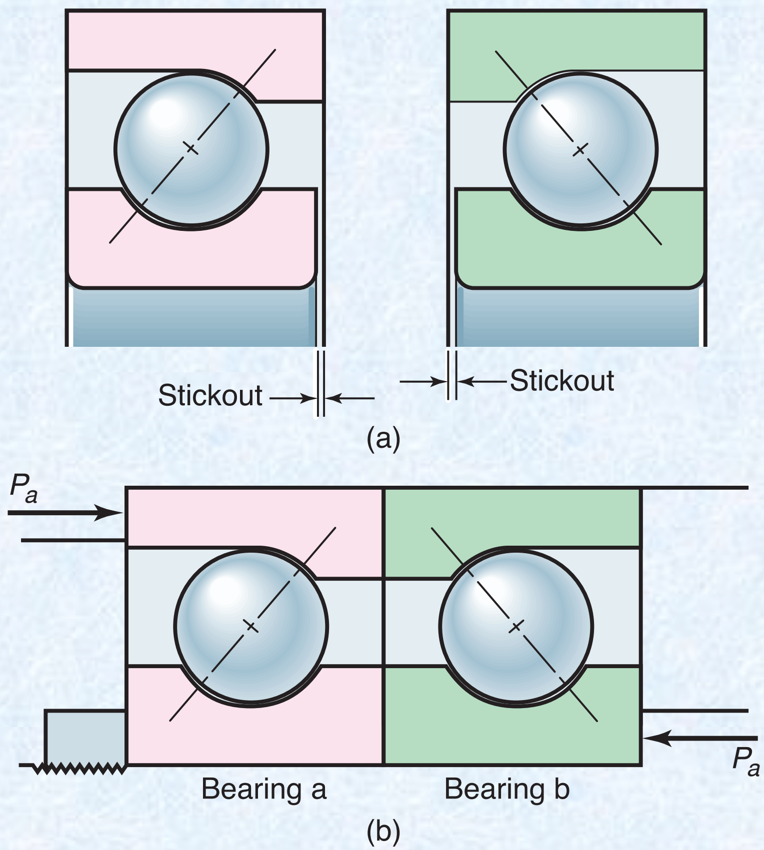


Figure 13.17: Angular contact bearings in back-to-back arrangement, shown (a) individually as manufactured and (b) as mounted with preload.

Loading on Ball Bearing

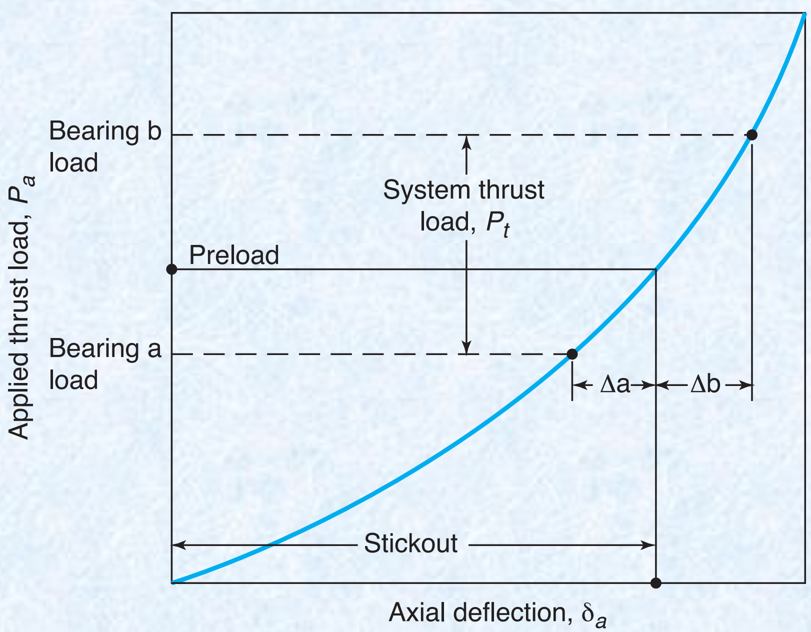


Figure 13.18: Thrust load-axial deflection curve for typical ball bearing.

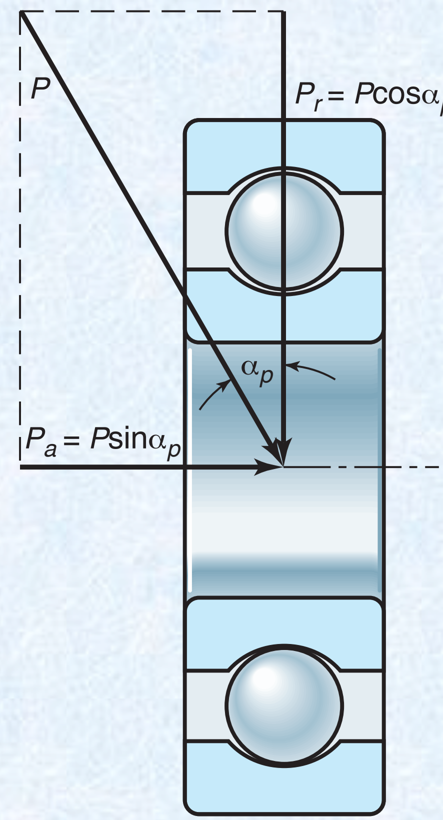


Figure 13.19: Combined load acting on a radial deep-grove ball bearing.

Deep Groove Ball Bearings

Principal dimensions d_b	d_a	b_w	Basic load ratings Dynamic C	Static C_o	Speed ratings Reference	Limiting	Mass	Designation
mm in.	mm in.	mm in.	N lb	N lb	rpm	rpm	kg lbm	–
15 0.5906	32 1.2598	8 0.3510	5850 1315	2850 641	50,000	32,000	0.025 0.055	16002
	32 1.2598	8 0.3543	5850 1315	2850 641	50,000	32,000	0.030 0.066	6002
	35 1.3780	11 0.4331	8060 1810	3750 843	43,000	28,000	0.045 0.099	6202
	35 1.3780	13 0.5118	11,900 2675	5400 1210	38,000	24,000	0.082 0.18	6302
20 0.7874	42 16535	8 0.3150	7280 1640	4050 910	38,000	24,000	0.050 0.11	16004
	42 1.6535	12 0.4724	9950 2240	5000 1120	38,000	24,000	0.090 0.15	6004
	47 1.8504	14 0.5512	13,500 3030	6550 1470	32,000	20,000	0.11 0.15	6204
	52 2.0472	15 0.5906	16,800 3780	7800 1750	30,000	19,000	0.14 0.31	6304
	72 2.8346	19 0.7480	43,600 9800	23,600 3370	18,000	11,000	0.40 0.88	6406
25 0.9843	47 1.8504	12 0.4724	11,900 2680	6550 1470	32,000	20,000	0.080 0.18	6005
	52 2.0472	15 0.5906	14,800 3330	7800 1750	28,000	18,000	0.13 0.29	6205
	62 2.4409	17 0.6693	23,400 5260	11,600 2610	24,000	16,000	0.23 0.51	6305
	80 3.1496	21 0.8268	35,800 8050	19,300 4340	20,000	13,000	0.53 0.51	6405
30 1.1811	55 2.1654	15 0.5118	13,800 3100	8300 1870	28,000	17,000	0.12 0.26	6006
	62 2.4409	16 0.6299	20,300 4560	11,200 2520	24,000	15,000	0.20 0.44	6206
	72 2.8346	19 0.7480	29,600 6650	16,000 3600	20,000	13,000	0.35 0.77	6306
	90 3.5433	23 0.9055	43,600 9800	23,600 5310	18,000	11,000	0.74 1.65	6406
35 1.3780	62 2.4409	14 0.5512	16,800 3780	10,200 2290	24,000	15,000	0.16 0.35	6007
	72 2.8346	17 0.6693	27,000 6070	15,300 3440	20,000	13,000	0.29 0.64	6207
	80 3.1496	21 0.8268	35,100 7890	19,000 4270	19,000	12,000	0.46 1.00	6307
	100 3.9370	25 0.9843	55,300 1240	31,000 6970	16,000	10,000	0.95 2.10	6407
40 1.5748	68 2.6672	15 0.5906	17,800 4000	11,600 2610	22,000	14,000	0.19 0.42	6008
	80 3.1496	18 0.7087	32,500 7310	19,000 4270	18,000	11,000	0.37 0.82	6208
	90 3.5433	23 0.9055	42,300 9510	24,000 5400	17,000	11,000	0.63 1.40	6308
	110 4.3307	27 1.0630	63,700 14,320	36,500 8210	14,000	9000	1.25 2.75	6408
45 1.7717	75 2,9528	16 0.6299	22,100 4970	14,600 3280	20,000	12,000	0.25 0.55	6009
	85 3.3465	19 0.7480	35,100 7890	21,600 4860	17,000	11,000	0.41 0.90	6209
	100 3.9370	25 0.9843	55,300 12,430	31,500 7080	15,000	9500	0.83 1.85	6309
	120 4.7244	29 1.1417	76,100 17,110	45,000 10,100	13,000	8500	0.55 3.40	6409
50 1.9685	80 3.1496	16 0.6299	22,900 5148	16,000 3600	18,000	11,000	0.26 0.57	6010
	90 3.5433	20 0.7874	37,100 8340	23,200 5220	15,000	10,000	0.46 1.00	6210
	110 4.3307	27 1.0630	65,000 14,610	38,000 8540	13,000	8500	1.05 2.30	6310
	130 5.1181	31 1.2205	87,100 19,580	52,000 11,700	12,000	7500	1.90 4.20	6410

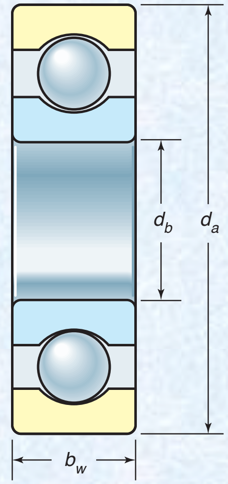
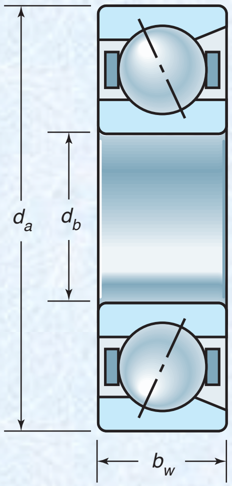


Table 13.2: Selected single-row, deep-groove ball bearings.

Angular Contact Ball Bearings



Principal dimensions			Basic load ratings		Speed ratings		Mass	Designation
			Dynamic	Static	Reference	Limiting		
d_b	d_a	b_w	C	C_o				
mm	mm	mm	N	N			kg	
in.	in.	in.	lb	lb	rpm	rpm	lbm	
10	**30**	**9**	**7020**	**3350**	**30,000**	**30,000**	**0.03**	**7200 BE**
0.3937	1.1811	0.3543	1580	750			0.07	
12	**32**	**10**	**7610**	**3800**	**26,000**	**26,000**	**0.04**	**7201 BE**
0.4724	1.2598	0.3937	1710	850			0.08	
	37	**12**	**10,600**	**5000**	**24,000**	**24,000**	**0.06**	**7301 BE**
	1.4567	0.4724	2400	1120			0.10	
15	**35**	**11**	**8840**	**4800**	**24,000**	**24,000**	**0.05**	**7202 BE**
0.5906	1.3780	0.4331	1990	1080			0.10	
	42	**13**	**13,000**	**6700**	**20,000**	**20,000**	**0.08**	**7302 BE**
	1.6535	0.5118	2900	1510			0.20	
20	**47**	**14**	**13,300**	**8300**	**18,000**	**19,000**	**0.11**	**7204 BE**
0.7874	1.8504	0.5512	2990	1870			0.24	
	52	**15**	**19,000**	**10,400**	**18,000**	**18,000**	**0.15**	**7304 BE**
	2.0472	0.5906	4300	2340			0.30	
25	**52**	**15**	**15,600**	**10,200**	**17,000**	**17,000**	**0.14**	**7205 BE**
0.9843	2.0472	0.5906	3510	2290			0.31	
	62	**17**	**26,500**	**15,600**	**15,000**	**15,000**	**0.24**	**7305 BE**
	2.4409	0.6693	6000	3510			0.50	
	80	**21**	**39,700**	**23,600**	**11,000**	**11,000**	**0.61**	**7405 B**
	3.1496	0.8268	8900	5300			1.30	
30	**62**	**16**	**24,000**	**25,600**	**14,000**	**14,000**	**0.21**	**7206 BE**
1.1811	2.4409	0.6299	5400	3510			0.46	
	72	**19**	**35,500**	**21,200**	**13,000**	**13,000**	**0.37**	**7306 BE**
	2.8346	0.7480	8000	4770			0.80	
	90	**23**	**47,500**	**29,000**	**10,000**	**10,000**	**0.85**	**7406 B**
	3.5433	0.9055	10,700	6500			1.90	
40	**80**	**18**	**36,500**	**26,000**	**11,000**	**11,000**	**0.39**	**7208 BE**
1.5748	3.1496	0.7087	8210	5840			0.86	
	90	**23**	**50,000**	**33,500**	**10,000**	**10,000**	**0.68**	**7308 BE**
	3.5433	0.9055	11,200	7530			1.50	
	110	**27**	**70,200**	**45,500**	**8000**	**8000**	**1.40**	**7408 B**
	4.3307	1.0630	15,800	10,200			3.10	
50	**90**	**20**	**40,000**	**30,500**	**9000**	**9000**	**0.51**	**7210 BE**
1.9685	3.5433	0.7874	8990	6860			1.12	
	110	**27**	**75,000**	**51,000**	**8000**	**8000**	**1.16**	**7310 BE**
	4.3307	1.0630	16,900	11,500			2.60	
	130	**31**	**95,600**	**64,000**	**6300**	**6700**	**2.25**	**7410 B**
	5.1181	1.2205	21,500	14,400			5.00	
75	**130**	**25**	**70,200**	**64,000**	**5600**	**6000**	**1.29**	**7215 BE**
2.9528	5.1181	0.9843	15,800	14,400			2.80	
	160	**37**	**132,000**	**106,000**	**5300**	**5300**	**3.26**	**7315 BE**
	6.2992	1.4567	29,700	23,800			7.20	
	190	**45**	**168,000**	**140,000**	**4300**	**4500**	**6.85**	**7415 B**
	7.4903	1.7717	37,800	31,500			15.10	
100	**180**	**34**	**135,000**	**122,000**	**4000**	**4300**	**3.61**	**7220 BE**
3.9370	7.0866	1.3386	30,300	27,400			8.00	
	215	**47**	**216,000**	**190,000**	**4000**	**4000**	**8.00**	**7320 BE**
	8.4646	1.8504	48,600	42,700			17.60	
	265	**60**	**276,000**	**275,000**	**3200**	**3200**	**15.50**	**7420**
	10.433	2.3622	62,000	61,800			34.20	
150	**270**	**45**	**216,000**	**224,000**	**2600**	**2800**	**10.80**	**7230 B**
5.9055	10.630	1.7717	48,600	50,400			23.80	
	320	**65**	**332,000**	**365,000**	**2400**	**2400**	**25.00**	**7330B**
	12.598	2.5591	74,600	82,100			55.10	
190	**340**	**55**	**307,000**	**355,000**	**2000**	**2200**	**21.90**	**7238 B**
7.4803	13.386	2.1654	69,000	79,800			48.30	
	400	**78**	**442,000**	**560,000**	**1900**	**1900**	**48.30**	**7338 B**
	15.748	3.0709	99,400	125,900			106.50	
240	**440**	**72**	**364,000**	**540,000**	**1600**	**1700**	**49.00**	**7248 B**
9.4488	17.3228	2.8346	81,800	121,400			108.00	

Table 13.3: Selected single-row, angular contact roller bearings. These bearings are often mounted in pairs (see Fig. 13.17).

Cylindrical Roller Bearings

Principal dimensions			Basic load ratings		Speed ratings		Mass	Designation
			Dynamic	Static	Reference	Limiting		
d_b	d_a	b_w	C	C_o				
mm in.	mm in.	mm in.	N lb	N lb	rpm	rpm	kg lbm	
15 0.5906	**35** 1.3780	**11** 0.4331	**12,500** 2810	**10,200** 2290	**22,000**	**26,000**	**0.047** 0.10	NU 202 ECP
	42 1.6535	**13** 0.5118	**17,200** 3870	**14,300** 3210	**19,000**	**22,000**	**0.068** 0.15	NJ 203 ECP
20 0.7874	**47** 1,8504	**14** 0.5512	**25,100** 5640	**22,000** 4950	**16,000**	**19,000**	**0.11** 0.24	NU 204 ECP
	52 2.0472	**15** 0.5906	**35,500** 7980	**26,000** 5850	**15,000**	**18,000**	**0.17** 0.37	NU 304 ECP
25 0.9843	**52** 2.0472	**15** 0.5906	**28,600** 6430	**27,000** 6070	**14,000**	**16,000**	**0.14** 0.31	NU 205 ECP
	62 2.4409	**17** 0.6693	**46,500** 10,400	**36,500** 8210	**12,000**	**15,000**	**0.28** 0.62	NU 305 ECP
30 1.811	**62** 2.4409	**16** 0.6299	**44,000** 9890	**36,500** 8210	**13,000**	**14,000**	**0.22** 0.48	NUP 206 ECP
	72 2.8346	**19** 0.7480	**58,500** 13,150	**48,000** 10,800	**11,000**	**12,000**	**0.40** 0.88	NU 306 ECP
35 1.3780	**72** 2.8346	**17** 0.693	**56,000** 12,600	**48,000** 10,800	**11,000**	**12,000**	**0.30** 0.66	NU 207 ECP
	80 3.1496	**21** 0.8268	**75,000** 16,900	**63,000** 14,200	**9500**	**11,000**	**0.54** 1.19	NU 307 ECP
40 1.5748	**80** 3.1496	**18** 0.7087	**62,000** 13,900	**53,000** 11,900	**9500**	**11,000**	**0.42** 0.92	NU 208 ECP
	90 3.5433	**23** 0.9055	**93,000** 20,900	**78,000** 17,500	**8000**	**9500**	**0.73** 1.61	NU 308 ECP
45 1.7717	**85** 3.3465	**19** 0.7480	**69,500** 15,600	**64,000** 14,400	**9000**	**9500**	**0.48** 1.06	NU 209 ECP
	100 3.9370	**25** 0.9843	**112,000** 25,200	**100,000** 22,500	**7500**	**8500**	**1.0** 2.20	NU 309 ECP
50 1.9685	**90** 3.5433	**20** 0.7874	**73,500** 16,500	**69,500** 15,600	**8500**	**9000**	**0.49** 1.08	NU 210 ECP
	110 4.3307	**27** 1.0630	**127,000** 28,600	**112,000** 25,200	**6700**	**8000**	**1.15** 2.55	NU 310 ECP
60 2.3622	**110** 4.3307	**22** 0.8661	**108,000** 24,300	**102,000** 22,900	**6700**	**7500**	**0.86** 1.89	NU 212 ECP
	130 5.1181	**31** 1.2205	**173,000** 38,900	**160,000** 36,000	**5600**	**6700**	**1.80** 4.00	NU 312 ECP
75 2.9528	**130** 5.1181	**25** 0.9843	**150,000** 33,700	**156,000** 35,100	**5600**	**6000**	**1.25** 2.80	NU 215 ECP
	160 6.2992	**37** 1.4567	**280,000** 62,900	**265,000** 59,600	**4500**	**5300**	**3.30** 7.30	NU 315 ECP
100 3.9370	**180** 7.0866	**34** 1.3386	**285,000** 64,100	**305,000** 68,600	**4000**	**4500**	**3.45** 7.60	NU 220 ECP
	215 8.4646	**47** 1.8504	**450,000** 101,200	**440,000** 98,900	**3200**	**3800**	**7.80** 17.2	NU 320 ECP
120 4.7244	**215** 8.4646	**40** 1.5748	**390,000** 87,700	**430,000** 96,700	**3400**	**3600**	**5.75** 12.6	NU 224 ECP
	260 10.236	**55** 2.1654	**610,000** 137,100	**620,000** 139,400	**2800**	**3200**	**13.3** 29.30	NU 324 ECP
150 5.9055	**270** 10.630	**45** 1.7717	**510,000** 114,600	**600,000** 134,900	**2600**	**2800**	**10.6** 23.3	NU 230 ECM
	320 12.598	**65** 2.5591	**900,000** 202,300	**965,000** 216,900	**2200**	**3400**	**27.5** 60.5	NU 330 ECM
190 7.4803	**340** 13.386	**55** 2.1654	**800,000** 179,800	**965,000** 216,900	**2000**	**2200**	**24.0** 52.8	NU 238 ECM
	400 15.748	**78** 3.0709	**1,140,000** 256,300	**1,500,000** 337,200	**1500**	**200**	**50.00** 110.2	NU 338 ECM

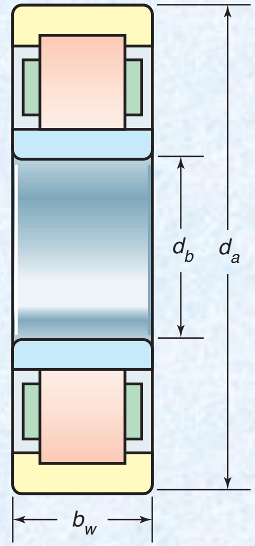
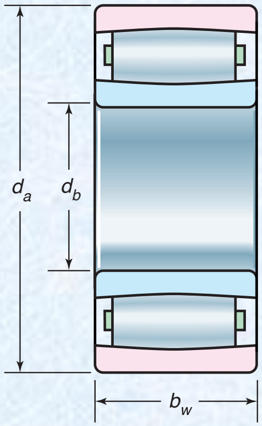


Table 13.4: Selected single-row, cylindrical roller bearings.

Toroidal (CARB) Bearings

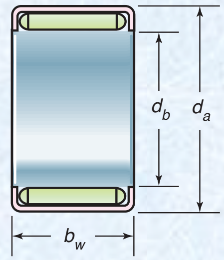


Principal dimensions			Basic load ratings		Speed ratings		Mass	Designation
			Dynamic	Static	Reference	Limiting		
d_b	d_a	b_w	C	C_o				
mm in.	mm in.	mm in.	N lb	N lb	rpm	rpm	kg lbm	—
25 0.9843	52 2.0472	18 0.7078	44,000 9900	40,000 9000	13,000	18,000	0.17 0.40	C2205 TN9
			50,000 11,200	48,000 10,800	—	7000	0.18 0.40	C2205 V[a]
30 1.1811	62 2.4409	20 0.7874	69,500 15,600	62,000 13,900	11,000	15,000	0.27 0.60	C2206 TN9
			76,500 17,200	71,000 16,000	—	6000	0.29 0.64	C2206 V[a]
	55 2.1654	45 1.7717	134,000 30,100	180,000 40,500	—	3000	0.50 1.10	C 6006 V[a]
40 1.5748	80 3.1496	23 0.9055	90,000 20,200	86,500 19,400	8000	11,000	0.50 1.10	C2208 TN9
			102,000 22,900	104,000 23,400	—	4500	0.53 1.17	C2208 V[a]
	62 2,4409	22 0.8661	76,500 17,200	100,000 22,500	—	4300	0.25 0.60	C 4908 V[a]
		30 1.1811	104,000 23,400	143,000 32,100	—	3400	0.35 0.80	C 5908 V[a]
50 1.9685	90 3.5433	23 0.9055	98,000 22,000	100,000 22,500	7000	9500	0.59 1.30	C2210 TN9
			114,000 25,600	122,000 27,400	—	3800	0.62 0.80	C2210 V[a]
	72 2.8346	22 0.8661	86,500 19,400	120,000 28,100	—	3600	0.29 0.60	C 4910 V[a]
		30 1.1811	118,000 26,500	180,000 40,500	—	2800	0.42 0.90	C 5910 V[a]
60 2.3622	110 4.3307	28 1.1024	143,000 32,100	156,000 35,100	5600	7500	1.10 2.40	C 2212 TN9
	110 4.3307	28 1.1024	166,000 37,300	190,000 42,700	—	2800	1.15 2.50	C 2212 V[a]
	85 3.3465	25 0.9843	112,000 25,200	170,000 38,200	—	3000	0.46 1.00	C 4912 V[a]
		34 1.3386	150,000 35,100	240,000 58,400	—	2400	0.64 1.50	C 5912 V[a]
75 2.9528	130 5.1181	31 1.2205	196,000 44,100	208,000 46,800	4800	6700	1.6 3.50	C2215
			220,000 49,500	240,000 54,000	—	2200	1.65 3.60	C2215 V[a]
	105 4.1339	30 1.1811	166,000 37,300	255,000 57,300	—	2400	0.81 1.80	C 4015 V[a]
		40 1.5748	204,000 45,900	325,000 73,100	—	1900	1.10 2.40	C 5915 V[a]
100 3.9370	180 7.0866	46 1.8110	415,000 93,300	465,000 104,500	3600	4800	4.85 10.70	C 2220
	165 6.4961	52 2.0472	415,000 93,300	540,000 121,400	3200	4300	4.40 9.70	C 3120
	140 5.5118	54 2.1260	375,000 84,300	640,000 143,900	—	1400	2.70 6.00	C 5920 V[a]
150 5.9055	270 10.630	73 2.8740	980,000 220,300	1,220,000 274,300	2400	3200	17.5 38.60	C2230
	250 9.8425	80 3.150	880,000 197,800	1,290,000 290,000	2000	2800	15.00 33.10	C 3130
	225 8.8538	75 2.9528	780,000 175,300	1,320,000 296,700	—	750	10.5 23.10	C 4030 V[a]
200 7.8740	340 13.3858	112 4.4094	1,560,000 350,700	2,320,000 521,500	1500	2000	40.00 88.20	C 3140
	310 12.205	109 4.2913	1,630,000 366,400	2,650,000 595,700	—	260	30.50 67.20	C 4060 V[a]
500 19.685	830 32.677	264 10.394	7,500,000 1,686,000	12,700,000 2,855,000	530	750	550.00 1212	C31/500 M
1000 39.370	1580 62.205	462 18.189	22,800,000 5,125,400	45,500,000 10,228,400	220	300	3470 7650	C 31/1000 MB

[a] Full-complement bearing.

Table 13.5: Selected single-row, toroidal (CARB) roller bearing.

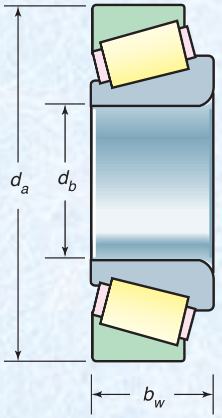
Needle Bearings



Principal dimensions d_b	d_a	b_w	Basic load ratings Dynamic C	Static C_o	Speed ratings Reference	Limiting	Mass	Designation
mm in.	mm in.	mm in.	N lb	N lb	rpm	rpm	g lb	
3 0.1181	7 0.2559	6 0.2362	1230 277	880 198	30,000	43,000	1.00 0.0025	HK 0306 TN[a]
5 0.1969	9 0.3543	9 0.3543	2380 535	2080 468	22,000	34,000	2.00 0.0043	HK 0509[a]
	10 0.3937	10 0.3937	2920 700	2700 700	36,000	40,000	10 0.01	NK 5/12 TN[a]
	15 0.5906	12 0.4724	3800 900	4250 1000	32,000	36,000	10 0.03	NKI 5/12 TN
7 0.2756	11 0.4331	9 0.3543	3030 681	3050 686	18,000	28,000	2.60 0.0056	HK 0709[a]
	14 0.5512	12 0.4724	3580 900	3570 900	32,000	36,000	10 0.02	NK 7/12 TN[a]
	17 0.6693	12 0.4724	4570 1100	5700 1300	28,000	32,000	10 0.03	NKI 7/12 TN
10 0.3937	14 0.5512	10 0.3937	4290 964	5300 1190	16000	24,000	3.00 0.0.875	HK 1010[a]
	22 0.8661	13 0.5118	8800 2000	10,400 2400	24,000	28,000	0.02 0.05	NA 4900
	17 0.6693	16 0.6299	5940 1400	8000 1800	28,000	32,000	10 0.03	NK 10/16 TN[a]
	22 0.8661	16 0.6299	10,200 2300	12,500 2900	24,000	28,000	30 0.06	NKI 10/16
12 0.4724	16 0.6299	10 0.3937	4840 1090	6400 1440	14,000	20,000	4.60 0.16	HK 1210[a]
	24 0.9449	13 0.5118	9900 2300	12,200 2800	22,000	26,000	30 0.06	NA 4901
	19 0.7480	16 0.6299	9130 2100	12,000 2700	26,000	30,000	20 0.04	NK 12/16[a]
	24 0.9449	16 0.6299	11,700 2700	15,300 3500	22,000	26,000	30 0.07	NKI 12/16
15 0.5906	21 0.8268	12 0.4724	7650 1720	9500 2140	11000	17000	11.0 0.024	HK 1512[a]
	28 1.1024	13 0.5118	11,200 2600	15,300 3500	19,000	22,000	30.0 0.07	NA 4902
	23 0.9055	16 0.6299	11,000 2500	14,000 3200	24,000	26,000	20 0.05	NK 15/16[a]
	27 1.0630	16 0.6299	13,400 3100	19,000 4300	20,000	24,000	40 0.09	NKI 15/16
20 0.7874	26 1.0236	10 0.3937	6160 1390	8500 1910	9000	14,000	12.00 0.0375	HK 2010[a]
	37 1.4567	17 0.6693	21,600 4900	28,000 6300	15,000	17,000	80 0.20	NA 4904
	28 1.1024	16 0.6299	13,200 3000	19,300 4400	19,000	22,000	30 0.06	NK 20/16[a]
	32 1.2598	16 0.6299	15,400 3500	24,500 5600	16,000	19,000	50 0.10	NKI 20/16
25 0.9843	32 1.2598	12 0.4724	10,500 2360	15,300 3440	7500	11,000	21 0.046	HK 2512[a]
	42 1.6535	17 0.6693	24,200 5500	34,500 7800	13,000	15,000	90 0.20	NA 4905
	33 1.2992	20 0.7874	19,000 4300	32,500 7400	16,000	18,000	40 0.09	NK 25/20[a]
	38 1.4961	20 0.7874	22,000 5000	36,500 8300	14,000	15,000	80 0.20	NKI 25/20
35 1.3780	42 1.6535	20 0.4724	22,900 2810	46,500 4860	5600	8000	28 0.98	HK 3512[a]
	45 1.7717	20 0.7874	26,400 5600	45,000 10,200	11,000	13,000	70 0.20	NK 35/20[a]
	50 1.9685	20 0.7874	26,400 6000	51,000 11,500	10,000	11,000	130 0.30	NKI 35/20
50 1.9685	58 2.835	20 0.7874	29,200 6560	63,000 14,200	4000	5600	72 0.16	HK 5020[a]
	72 2.8346	22 0.8661	47,300 10,700	85,000 19,200	7000	8000	270 0.60	NA 4910
100 3.9370	140 5.5118	40 1.5748	125,000 28,100	280,000 63,000	3400	4000	1900 4.20	NA 4920

[a] Open end, bearings roll against shaft surface.

Table 13.6: Selected single-row needle roller bearings. Without an inner ring, the load ratings can vary greatly depending on quality of shaft surface preparation, and are expressed for ground and hardened shafts.



Tapered Roller Bearings

Principal dimensions d_b mm in.	d_a mm in.	b_w mm in.	Basic load ratings Dynamic C N lb	Static C_o N lb	Contact angle β deg.	Mass kg lbm	Designation
15 0.5906	42 1.6535	14.25 0.5610	26,000 5850	22,200 4980	10.7	0.11 0.22	30302
17 0.6693	47 1.8504	15.25 0.6004	32,700 7360	28,400 4460	10.7	0.14 0.29	30303
20 0.7874	52 2.0472	16.25 0.6398	38,500 8660	34,500 7760	11.3	0.17 0.37	30304
	52 2.0472	22.5 0.8858	55,200 12,400	55,000 12,400	11.3	0.24 0.53	32304
25 0.9843	52 2.0472	16.25 0.6398	36,90000 8300	38,300 8620	11.3	0.15 0.34	30205
	62 2.4409	25.25 0.9941	72,400 16,300	72,400 16,300	11.3	0.37 0.81	32305
30 1.1811	72 2.8346	20.75 0.8169	67,700 15,200	65,300 14,700	11.9	0.39 0.88	30306
	72 2.8346	28.75 1.1319	87,600 19,700	89,800 20,200	11.9	0.56 1.23	32306
35 1.3780	72 3.1496	24.25 1.2894	74,900 16,800	82,300 18,500	11.9	0.44 0.96	32207
	80 3.1496	22.75 0.8957	87,200 19,600	86,100 19,300	11.9	0.53 1.16	30307
40 1.5748	90 3.5433	25.25 0.9941	117,000 26,300	102,000 23,000	12.9	0.73 1.61	30308
	90 3.5433	35.25 1.3878	157,000 35,300	160,000 36,100	12.9	1.1 2.43	32308-B
45 1.7717	100 3.9370	27.25 1.0728	129,000 29,000	139,000 31,300	12.9	1.01 2.22	30309
	100 3.9370	38.25 1.5059	189,000 42,500	187,000 42,100	12.9	1.42 3.13	32309-B
50 1.9685	110 4.3307	29.25 1.1516	142,000 31,900	150,000 33,800	12.9	1.25 2.77	30310
	110 4.3307	42.25 1.6634	187,000 42,000	211,000 47,500	12.9	1.83 4.03	32310
60 2.3622	130 5.1171	33.5 1.3189	203,000 45,700	188,000 42,200	12.9	1.96 4.32	30312
	130 5.1181	48.5 1.9094	264,000 59,400	310,000 69,800	12.9	2.89 6.35	32312
75 2.9528	115 4.5276	31 1.2205	187,000 42,000	239,000 53,700	11.2	1.15 2.54	33015
	160 6.2992	40 1.5748	248,000 55,800	278,000 62,500	12.9	3.46 7.63	30315
100 3.9370	150 5.9055	39 1.5354	251,000 56,300	393,000 88,300	10.8	2.36 5.22	33020
	180 7.0866	49 1.9291	368,000 82,700	478,000 107,000	15.6	4.92 10.84	32220
120 4.7244	165 6.4961	29 1.1417	172,000 38,800	317,000 71,200	13.1	1.78 3.92	32924
	215 8.4646	43.5 1.7126	396,000 89,100	508,000 114,000	16.2	6.24 13.75	30224
150 5.9055	210 8.2677	38 1.4961	324,000 72,800	573,000 129,000	12.3	3.99 8.82	32930
	270 10.630	49 1.9291	565,000 127,000	735,000 165,000	16.2	11.03 24.29	30230
170 6.6929	230 9.0551	38 1.4961	355,000 79,800	652,000 146,000	14.3	4.40 9.71	32934
200 7.874	280 11.024	51 2.0079	561,000 126,000	1,050,000 235,000	14.7	9.45 20.84	32940
220 8.6614	300 11.811	51 2.0079	561,000 126,000	1,090,000 245,000	15.8	9.90 21.83	32944
	400 15.798	72 2.8346	1,260,000 283,000	1,560,000 350,000	15.6	35.25 77.71	30244
280 11.024	380 14.961	63.5 2.5000	850,000 191,000	1,780,000 401,000	16.0	19.81 43.69	32956
320 12.598	480 18.898	100 3.9370	1,800,000 406,000	3,420,000 768,000	17.0	59.62 131.44	32064X
380 14.173	480 18.898	76 2.9921	1,250,000 281,000	2,780,000 624,000	17.0	45.22 79.84	32972

Table 13.7: Selected single-row, tapered roller bearings.

Radial and Thrust Factors for Statically Loaded Bearings

Bearing type		Single row X_o	Single row Y_o	Double row X_o	Double row Y_o
Radial deep-groove ball		0.6	0.5	0.6	0.5
Radial angular-contact ball	$\beta = 20°$	0.5	0.42	1	0.84
	$\beta = 25°$	0.5	0.38	1	0.76
	$\beta = 30°$	0.5	0.33	1	0.66
	$\beta = 35°$	0.5	0.29	1	0.58
	$\beta = 40°$	0.5	0.26	1	0.52
Radial self-aligning ball		0.5	$0.22 \cot \beta$	1	$0.44 \cot \beta$
Radial spherical roller		0.5	$0.22 \cot \beta$	1	$0.44 \cot \beta$
Radial tapered roller		0.5	$0.22 \cot \beta$	1	$0.44 \cot \beta$

Table 13.8: Radial factor X_o and thrust factor Y_o for statically stressed radial bearings.

Design Procedure 13.1: Evaluation of Ball Bearing Lubricant Film Thickness

1. It will be assumed that the radial load, number of bearings, bearing materials, lubricant properties, and geometry of the bearings are known. Of these, the lubricant properties, especially the pressure exponent of viscosity, are most likely to be unknown or will have the largest uncertainty. Regardless, these properties should be available from the lubricant supplier.
2. For ball bearings, Eq. (13.48) allows calculation of the load on an individual ball. Note that this is a conservative estimate; Eqs. (13.45) and (13.46) can be combined if necessary.
3. The velocities for the ball-inner-race and ball--outer-race contacts can be obtained from Eqs. (13.28) and (13.30). If β is not specified, it can be obtained from Eq. (13.6).

Design Procedure 13.1 (concluded)

4. R_x and R_y can be calculated from Eqs. (8.6) and (8.7). Equation (13.64) then allows calculation of E'.
5. The parameters k_e, W, U, and G are then calculated from Eqs. (8.12) and (13.67) through (13.69).
6. Equation (13.70) then allows calculation of the minimum film thickness.
7. The adequacy of the lubricant film can be evaluated with respect to the film parameter, Λ, given by Eq. (13.27). A reasonable design goal is to require the bearing to operate in a partial film lubrication regime (see Section 8.7.3). This would require $\Lambda = 3$. Alternatively, Fig. 13.25 can be used to assess the adequacy of the lubricant film and modify the catalog ratings for the bearing according to Eq. (13.87).

Fatigue Spall

(a)

(b)

Figure 13.20: Typical fatigue spall. (a) Spall on tapered roller bearing. (b) Detail of fatigue spall. *Source:* Courtesy of Timken, Inc.

Fatigue Failure

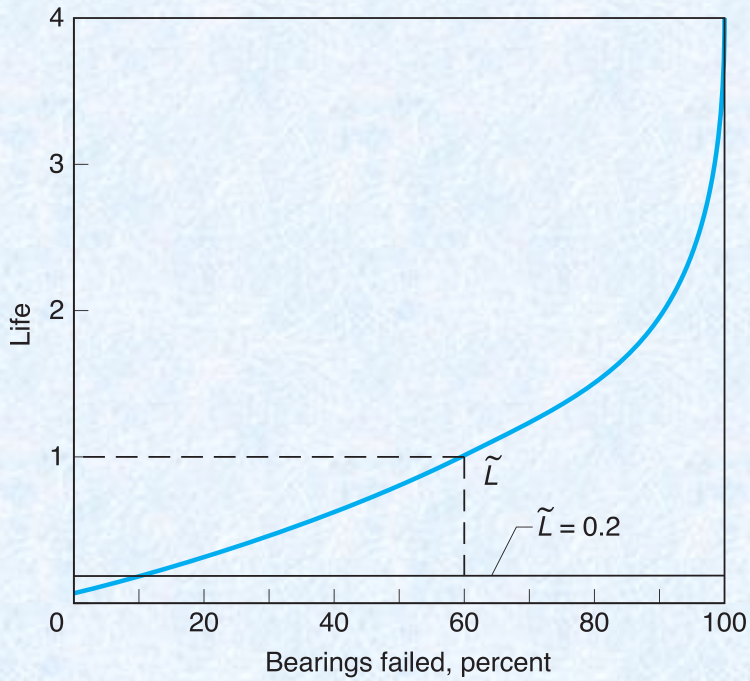


Figure 13.21: Distribution of bearing fatigue failures.

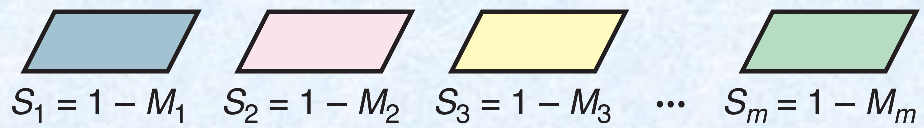


Figure 13.22: Representation of m similar stressed volumes.

$\tilde{L}_{10}$ life:

$$\tilde{L}_{10} = \left(\frac{\bar{C}}{P}\right)^{m_k}$$

Weibull Plot of Failures

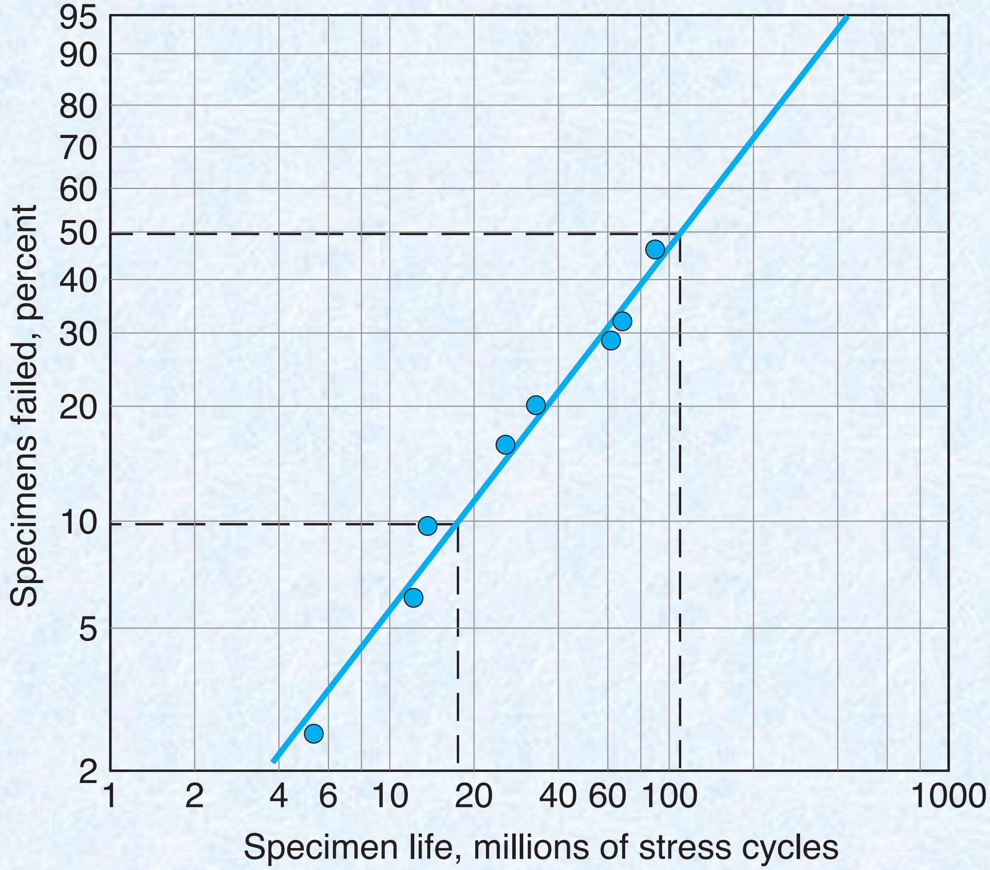


Figure 13.23: Typical Weibull plot of bearing fatigue failures for clean and filtered lubricants. *Source:* From Hamrock and Anderson [1983].

Design Procedure 13.2: Design of Rolling Element Bearings Based on Dynamic Load Rating

1. It will be assumed that the radial and thrust/axial loads are known, as well as the required reliability.
2. Selection of the bearing type is important; Table 13.1 and Example 13.1 address this issue and serve as useful guides. Ultimately, selection of a type of bearing depends on the loading condition, speed, space available, and, perhaps most importantly, cost. It will be assumed that a bearing type can be selected, or a number of candidates selected for further analysis and comparison.
3. Some dimensions of the bearing may be restricted by geometry considerations not associated with the bearing. For example, a shaft may have its diameter specified by deflection considerations; a smaller bearing may be used by machining a shoulder into the shaft per manufacturer's recommendations. However, excessively small diameters with shoulders transitioning to large diameters introduce large stress concentrations (see Section 6.2). Alternatively, the bearing width or outer diameter may be constrained. Such considerations may further reduce the number of suitable bearing candidates.
4. Equivalent static load can be obtained from Eq. (13.60) using factors X_o and Y_o from Table 13.8. Bearings with a static load rating lower than the equivalent static load can be eliminated from consideration. Any other bearing can be considered.

Design Procedure 13.2 (concluded)

5. A bearing for consideration can be selected from Tables 13.2 through 13.7, or from a manufacturer's catalog or website.
6. Equivalent dynamic load can be obtained from Eq. (13.85), using factors X and Y determined according to the bearing type:
   a. For deep groove or angular contact ball bearings, the factors X and Y are obtained from Table 13.9. This requires calculation of P_a/C_o to obtain an estimate of e, then comparison of P_a/P_r with e to obtain the factors.
   b. For thrust bearings, the factors are obtained in similar fashion from Table 13.10.
   c. For tapered roller bearings, the factors can be obtained from Table 13.9 using the contact angle β from Table 13.7.
7. The L_{10} life can be obtained from the bearing's dynamic load rating and equivalent dynamic load according to Eq. (13.82). The L_{10} that results is in millions of revolutions.
8. Life at any other reliability can be estimated from Fig. 13.23 or from Eq. (13.83).

Capacities of Rolling Element Bearings

Bearing type		e	Single-row bearings				Double-row bearings			
			$\frac{P_a}{P_r} \le e$		$\frac{P_a}{P_r} > e$		$\frac{P_a}{P_r} \le e$		$\frac{P_a}{P_r} > e$	
			X	Y	X	Y	X	Y	X	Y
Deep-groove	$P_a/C_o = 0.025$	0.22	1	0	0.56	2.0				
ball bearings	$P_a/C_o = 0.04$	0.24	1	0	0.56	1.8				
	$P_a/C_o = 0.07$	0.27	1	0	0.56	1.6				
	$P_a/C_o = 0.13$	0.31	1	0	0.56	1.4				
	$P_a/C_o = 0.25$	0.37	1	0	0.56	1.2				
	$P_a/C_o = 0.50$	0.44	1	0	0.56	1				
Angular-	$\beta = 20°$	0.57	1	0	0.43	1	1	1.09	0.70	1.63
contact ball	$\beta = 25°$	0.68	1	0	0.41	0.87	1	0.92	0.67	1.41
bearings	$\beta = 30°$	0.80	1	0	0.39	0.76	1	0.78	0.63	1.24
	$\beta = 35°$	0.95	1	0	0.37	0.66	1	0.66	0.60	1.07
	$\beta = 40°$	1.14	1	0	0.35	0.57	1	0.55	0.57	0.93
	$\beta = 45°$	1.33	1	0	0.33	0.50	1	0.47	0.54	0.81
Self-aligning ball bearings		$1.5 \tan \beta$					1	$0.42 \cot \beta$	0.65	$0.65 \cot \beta$
Spherical roller bearings		$1.5 \tan \beta$					1	$0.45 \cot \beta$	0.67	$0.67 \cot \beta$
Tapered-roller bearings		$1.5 \tan \beta$	1	0	0.40	$0.4 \cot \beta$	1	$0.42 \cot \beta$	0.67	$0.67 \cot \beta$

Figure 13.9: Capacity formulae for rectangular and elliptical conjunctions for radial and angular bearings.

Radial and Thrust Factors

Bearing type		e	Single acting		Double acting			
			$\frac{P_a}{P_r} > e$		$\frac{P_a}{P_r} \le e$		$\frac{P_a}{P_r} > e$	
			X	Y	X	Y	X	Y
Thrust ball	$\beta = 45°$	1.25	0.66	1	1.18	0.59	0.66	1
	$\beta = 60°$	2.17	0.92	1	1.90	0.55	0.92	1
	$\beta = 75°$	4.67	1.66	1	3.89	0.52	1.66	1
Spherical roller thrust		1.5 tan β	tan β	1	1.5 tan β	0.67	tan β	1
Tapered roller		1.5 tan β	tan β	1	1.5 tan β	0.67	tan β	1

Figure 13.10: Radial factor X and thrust factor Y for thrust bearings.

Material Factors

Material	Material factor, $\bar{D}$
52100	2.0
M-1	0.6
M-2	0.6
M-10	2.0
M-50	2.0
T-1	0.6
Halmo	2.0
M-42	0.2
WB 49	0.6
440C	0.6-0.8

Table 13.11: Material factors for through-hardened bearing materials. *Source:* From Bamberger [1971].

Film Parameter Effect

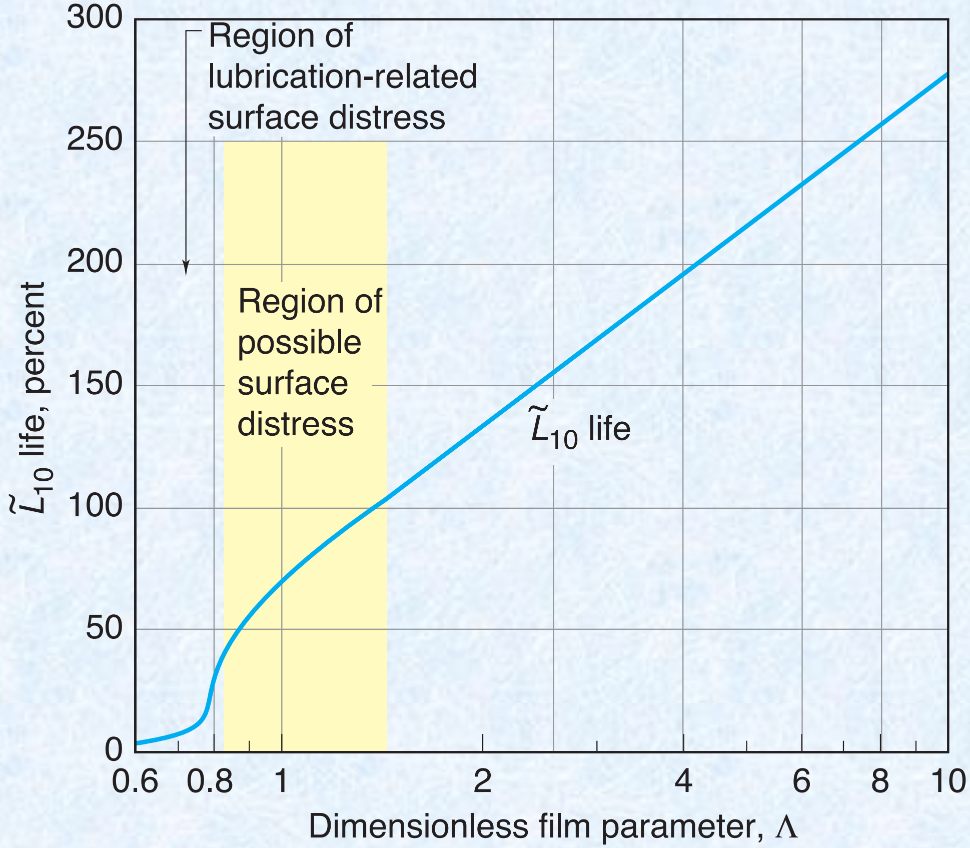


Figure 13.24: Group fatigue life as function of dimensionless film parameter. *Source:* From Tallian [1967].

Lubrication Factor

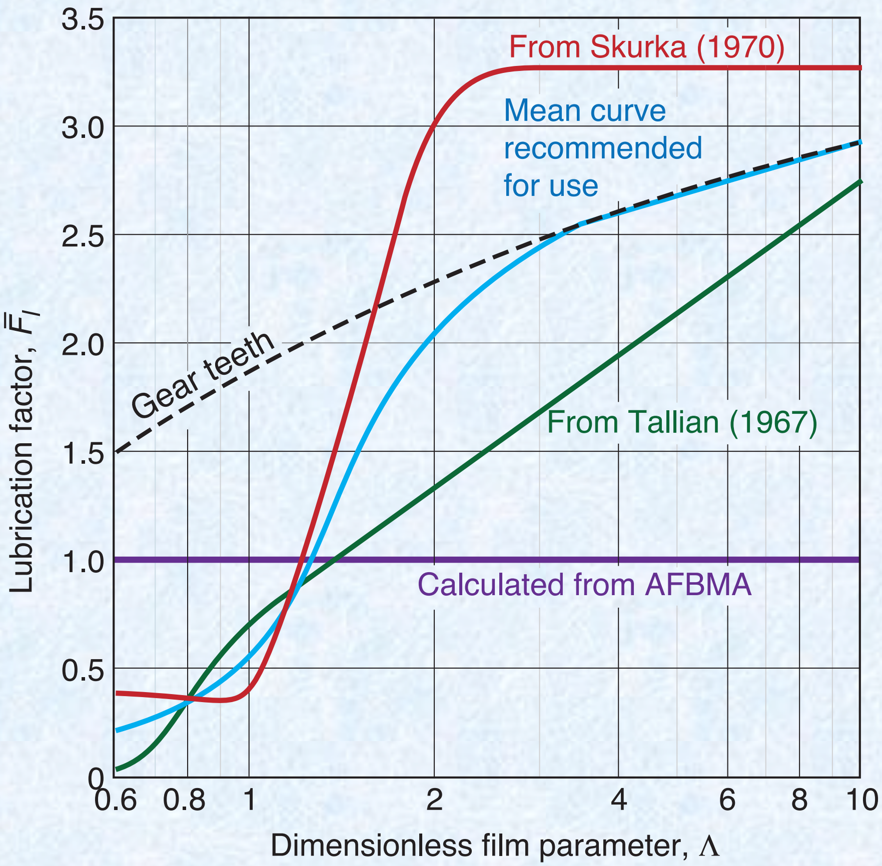
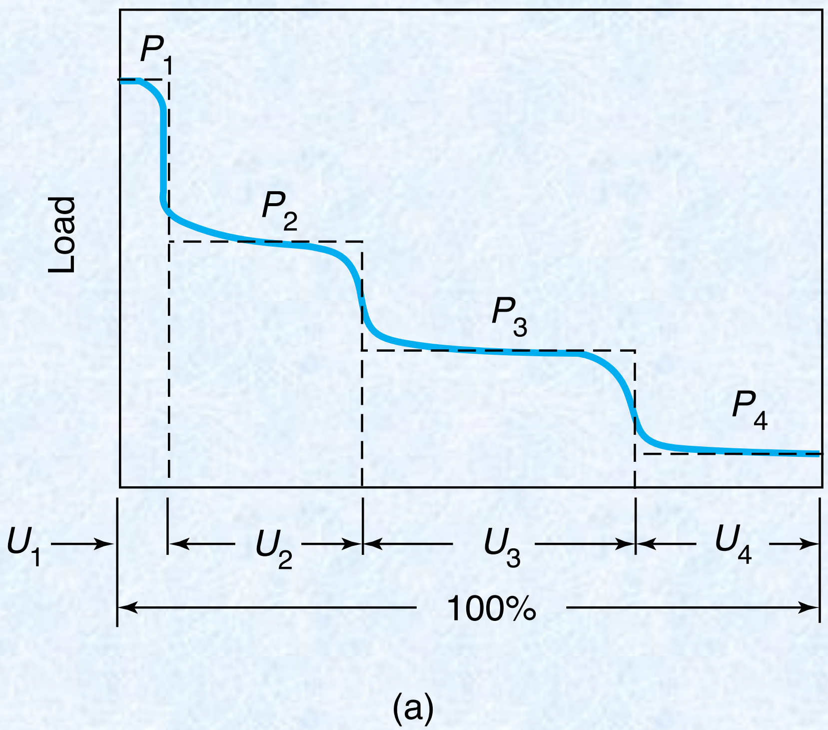


Figure 13.25: Lubrication factor as function of dimensionless film parameter.

Duty Cycle



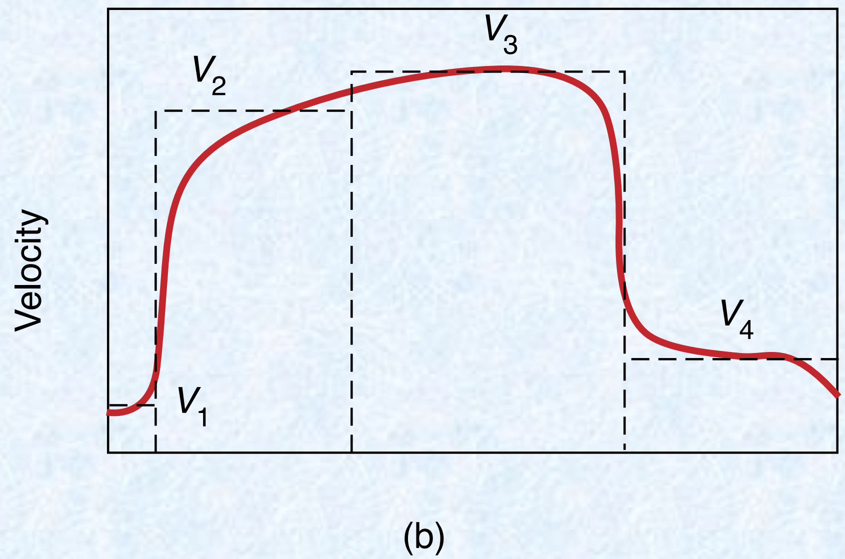
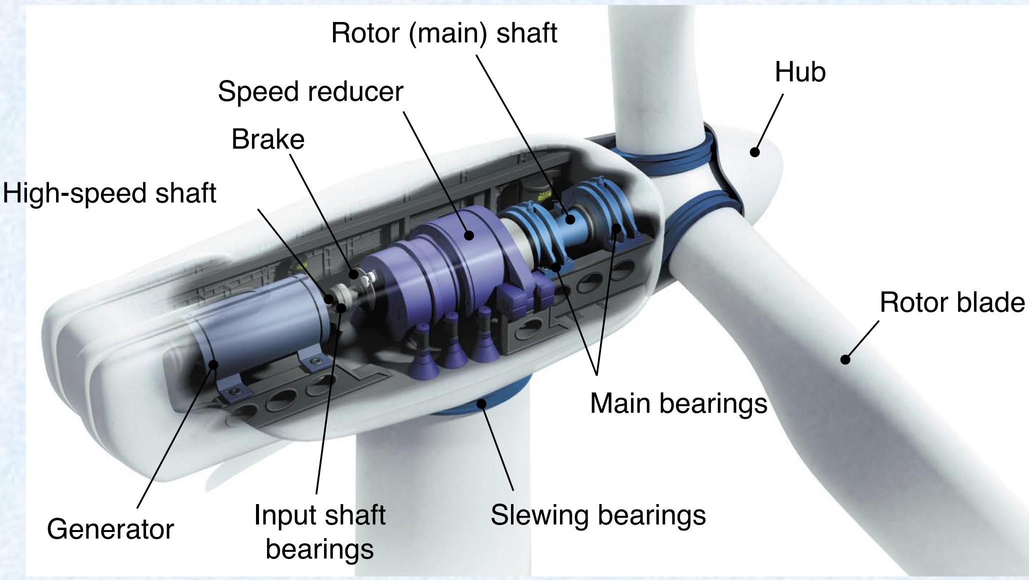


Figure 13.26: Example of duty cycles for variable operating conditions. (a) Load and (b) velocity duty cycles.

Wind Mill and Bearings

(a)



(b)

Figure 13.27: (a) Modern wind farm installation, showing multiple wind powered turbines. (b) Schematic illustration of a modern windmill and rolling-element bearings. *Source:* Courtesy SKF USA, Inc.

Duty Cycle for Windmill

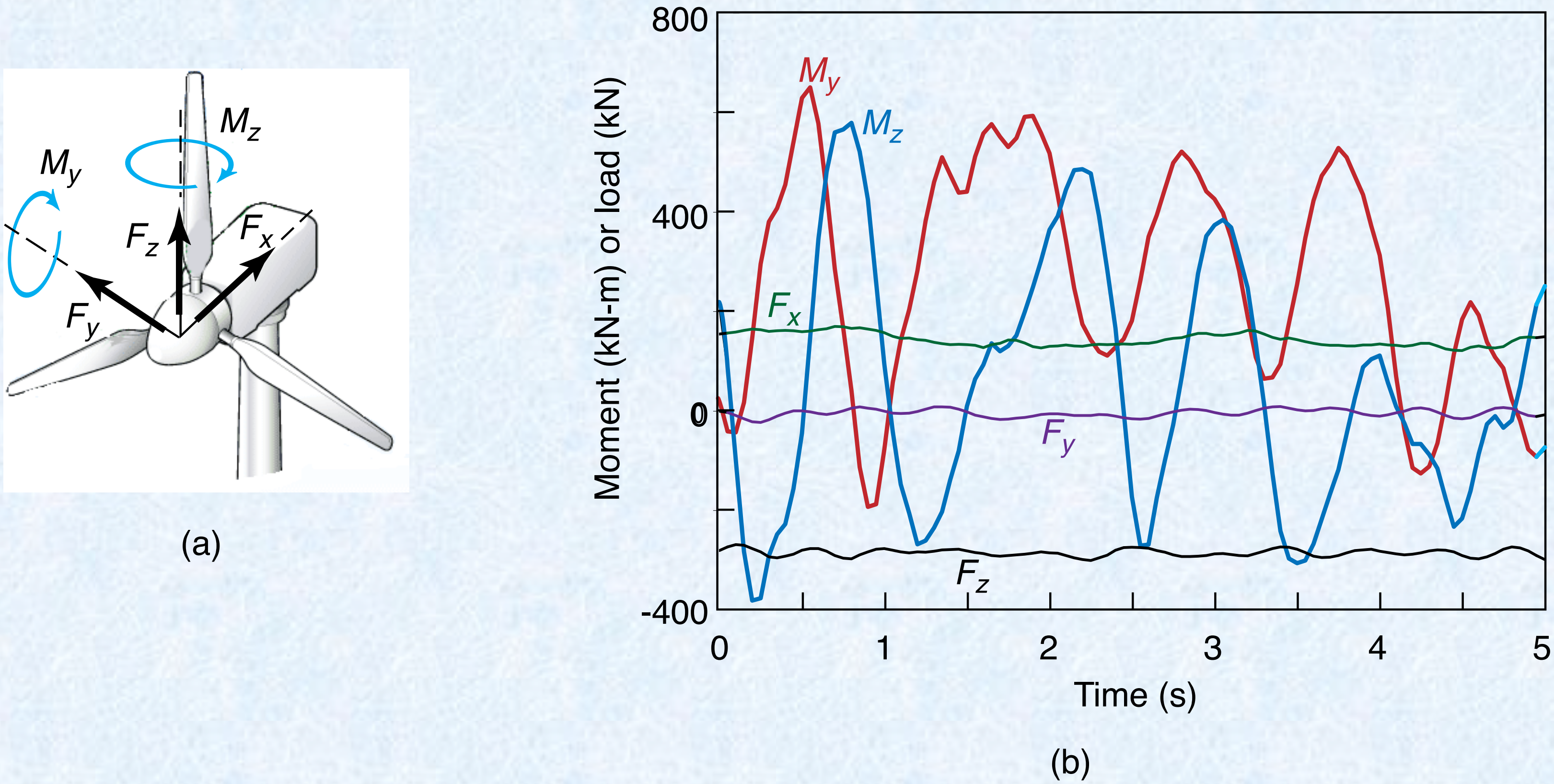


Figure 13.28: Portion of a loading for a windmill, used to develop a complicated duty cycle. (a) Illustration of rotor to demonstrate nomenclature; (b) five second loading excerpt. *Source:* Courtesy Timken, Inc.