

WORCESTER POLYTECHNIC INSTITUTE MECHANICAL ENGINEERING DEPARTMENT

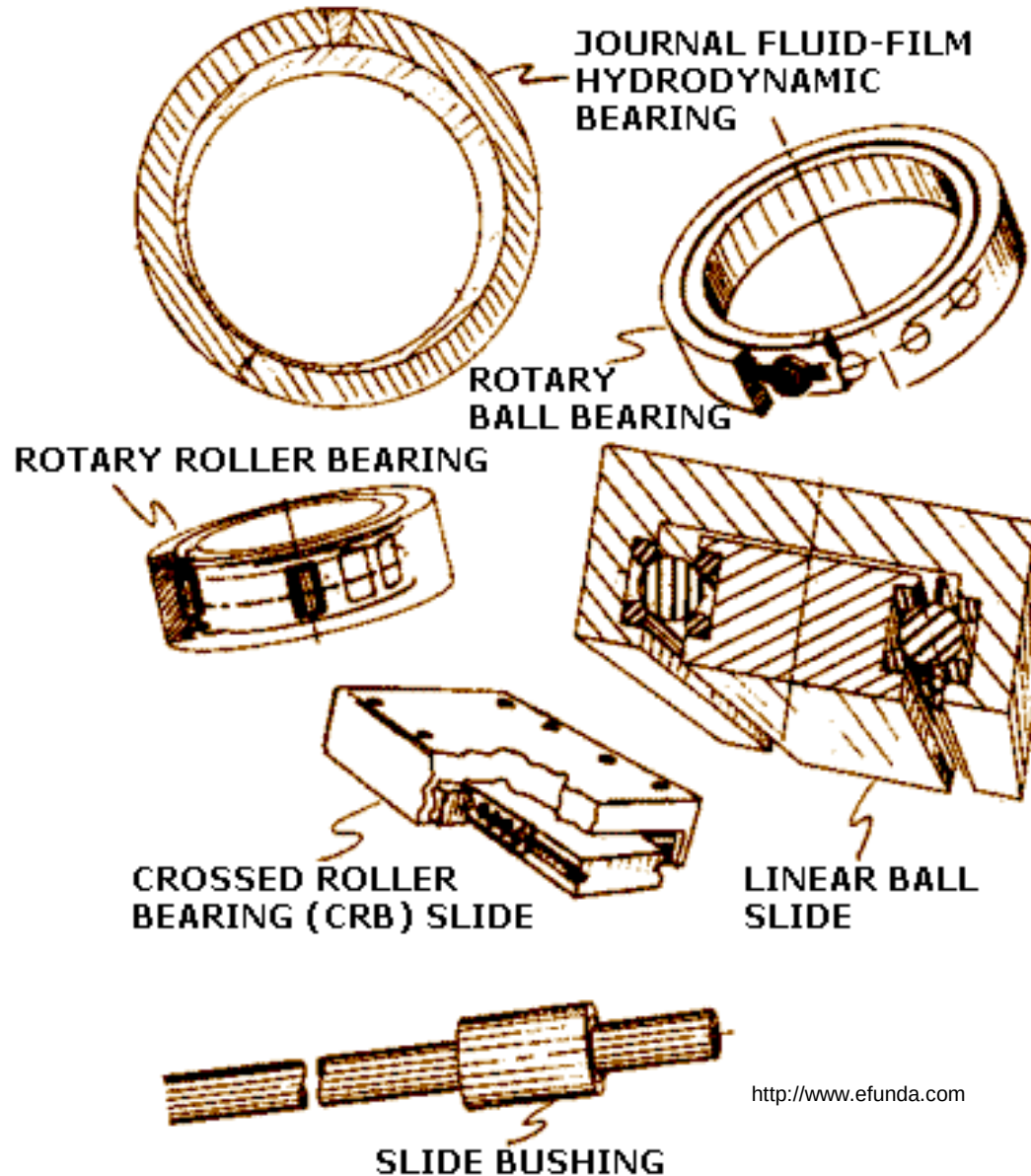
DESIGN OF MACHINE ELEMENTS ME-3320, A'2014

Lecture 20-22-23a

October 2014

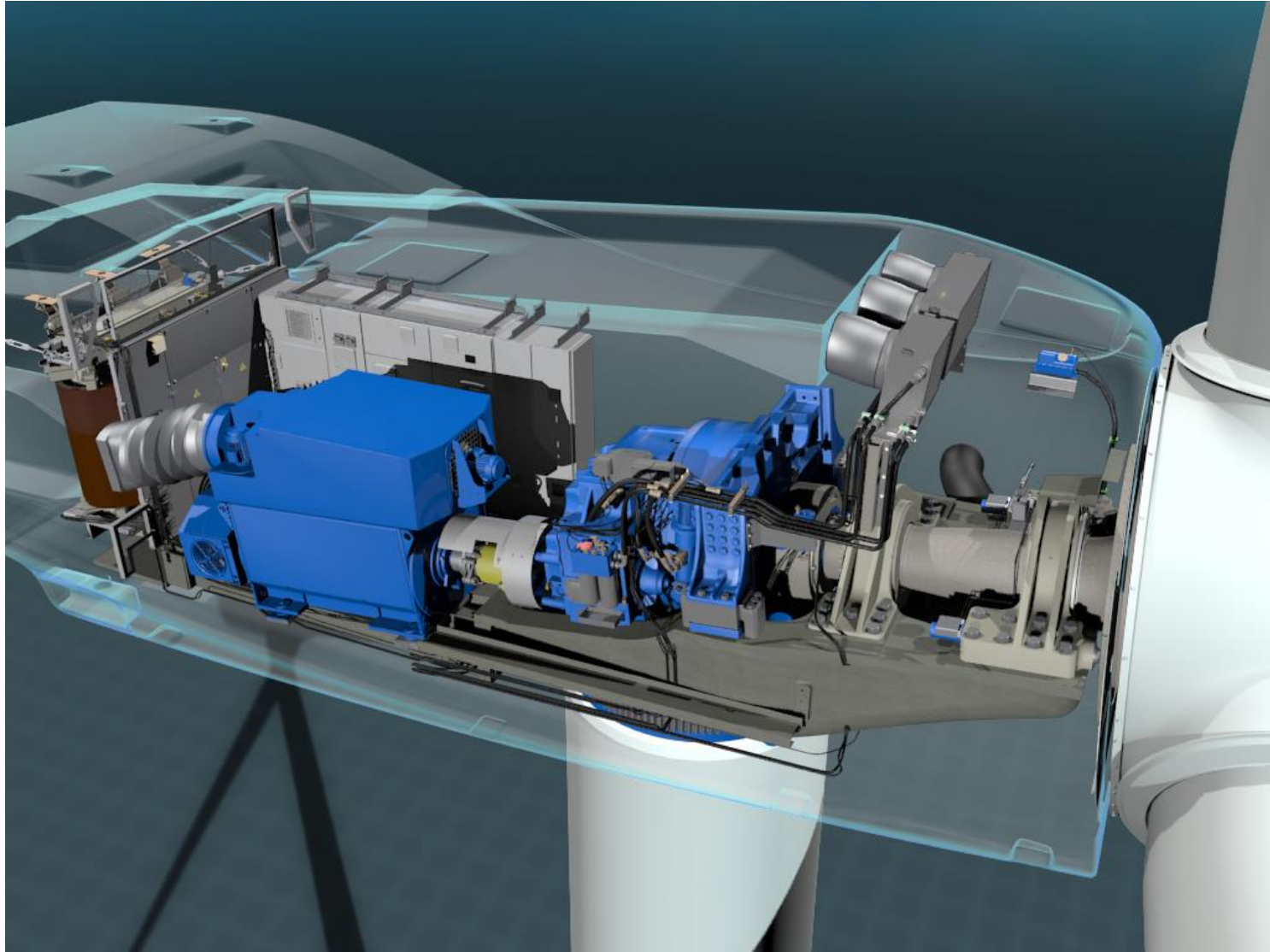


Bearings and lubrication



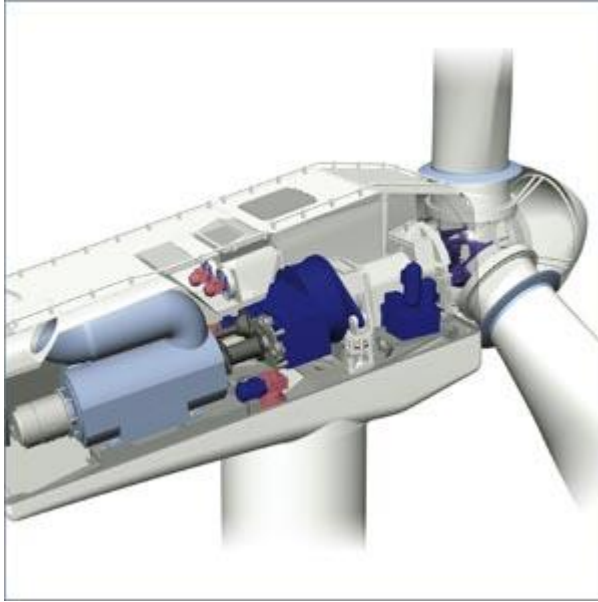
Bearings and lubrication

Wind turbine - bearings



Bearings and lubrication

Wind turbine - bearings



Bearings and lubrication

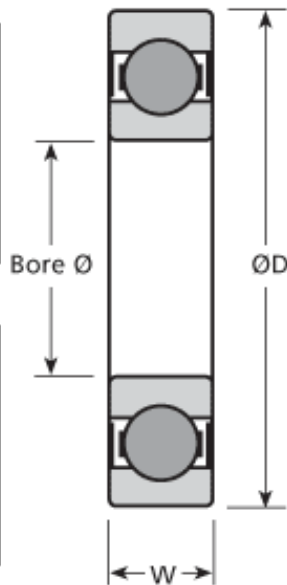
With Rolling elements: high-speed applications

Radial ball bearings

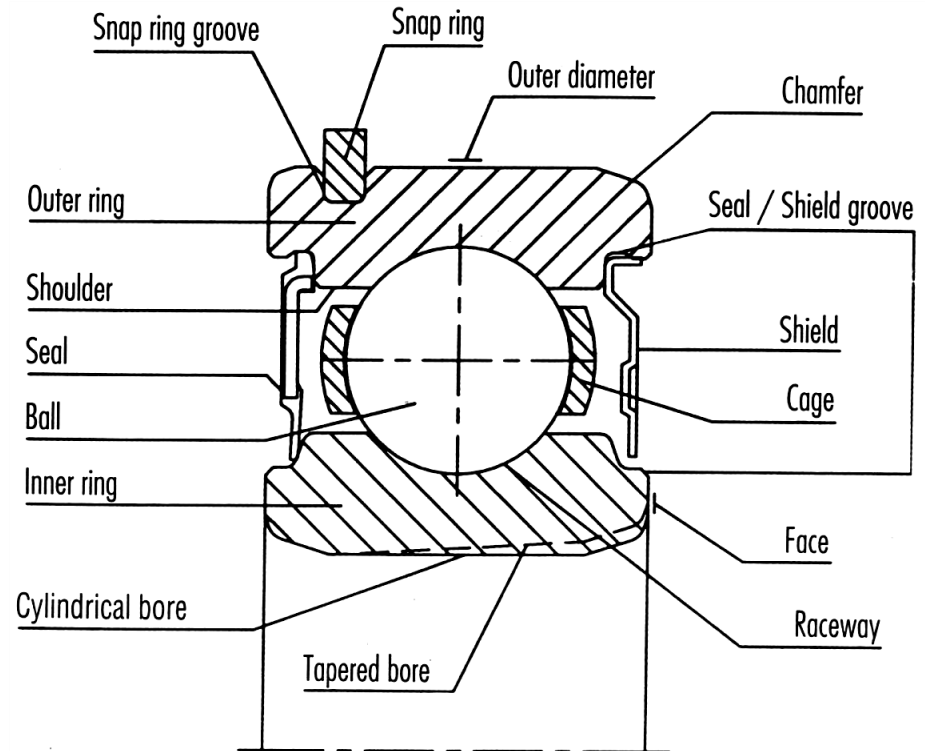
S Type Open



S-ZZ Type Shielded

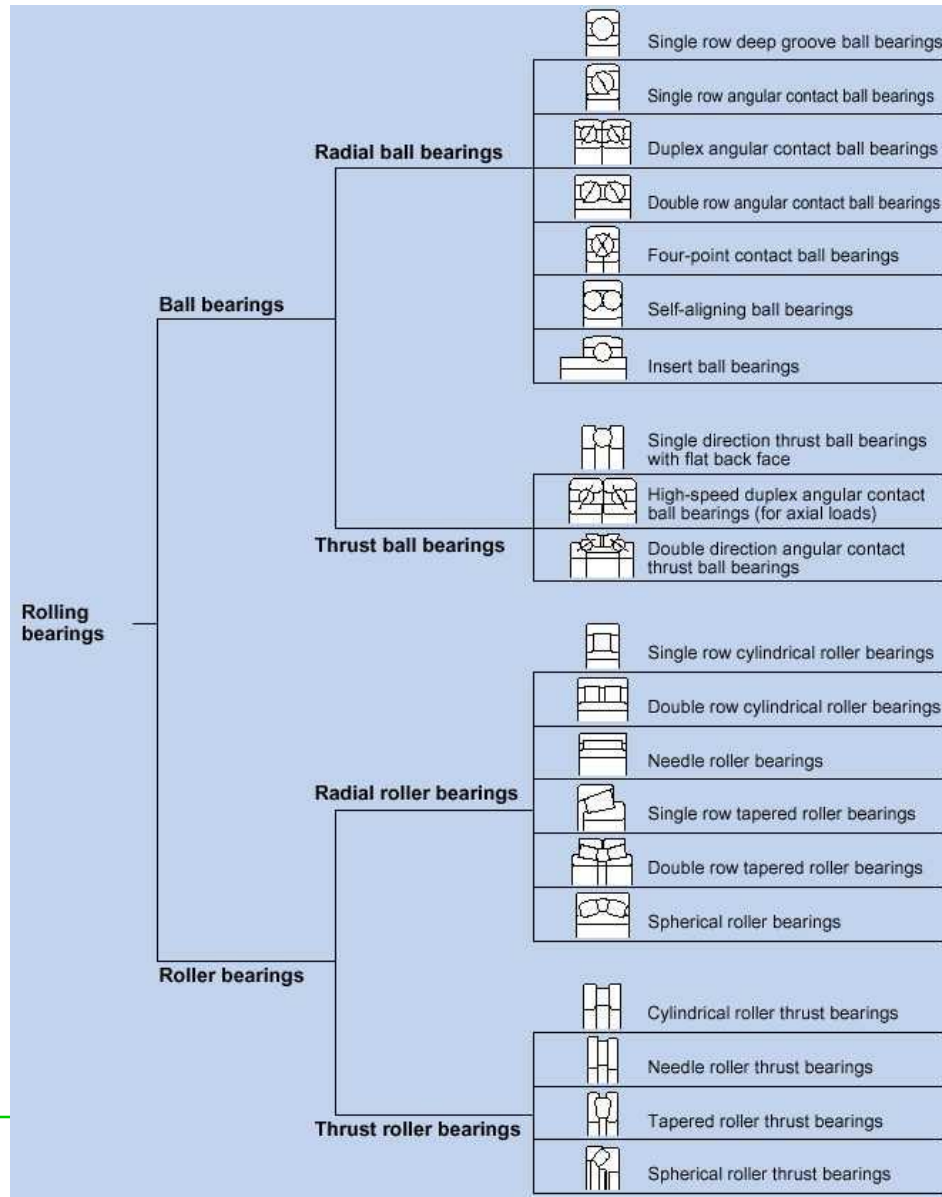


Cross-section of a radial ball-bearing



Bearings and lubrication

Rolling-element bearings



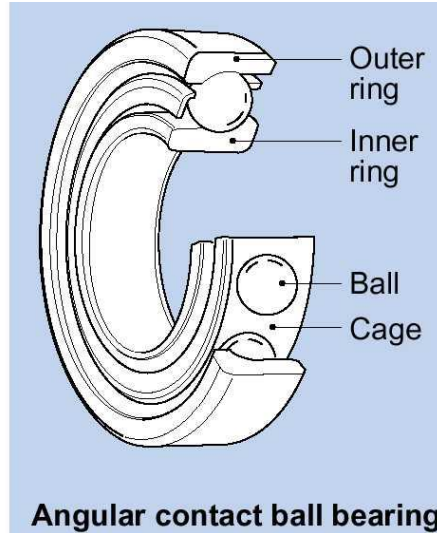
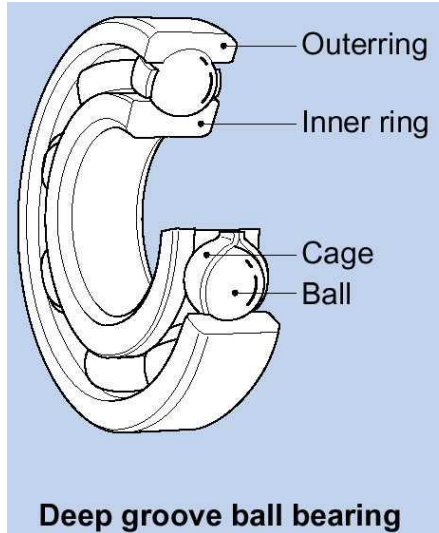
General classification and comments

- ➡ Ball and
- ➡ Roller type bearings
- ➡ Sizes and capacities of ball and roller bearings are standardized
- ➡ However, depending on the type of machine they are to be used in, and expected application and function, a non-standard or specially design bearing may be preferred (*very expensive*)



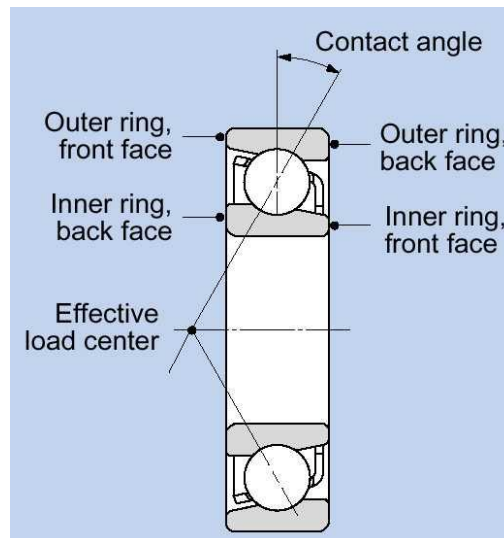
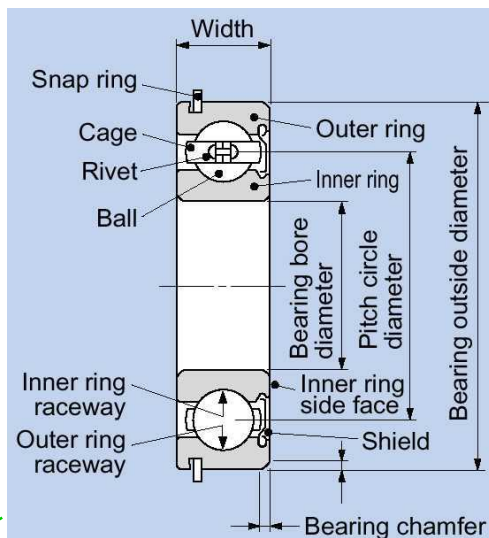
Bearings and lubrication

Rolling-element bearings: ball bearings



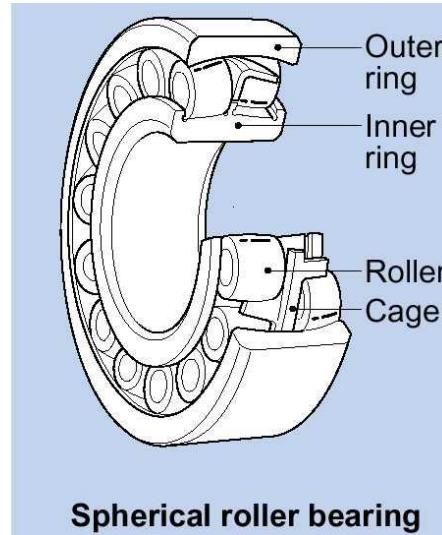
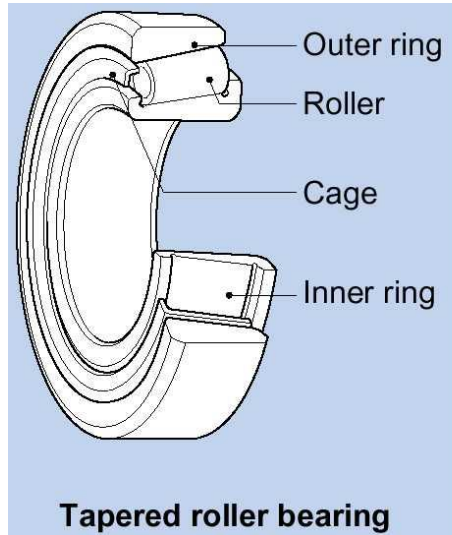
Typical applications:

- ➡ High-speed
- ➡ High-precision
- ➡ Low torque
- ➡ Low vibration
- ➡ Deep groove ball bearings are selected for radial load and moderate thrust (axial) load
- ➡ Angular contact ball bearings are selected for radial load and larger thrust (axial) loads in only one direction



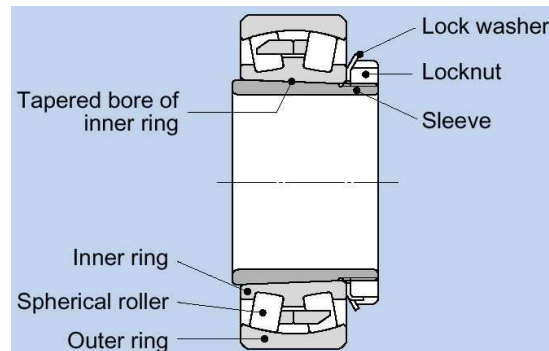
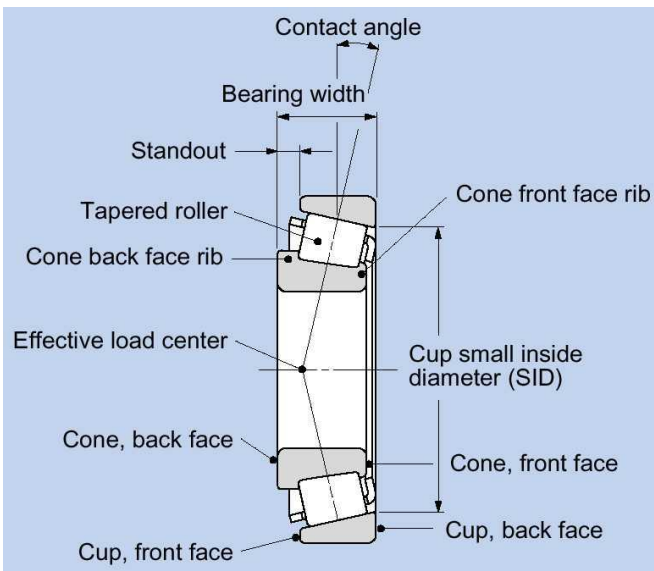
Bearings and lubrication

Rolling-element bearings: roller bearings



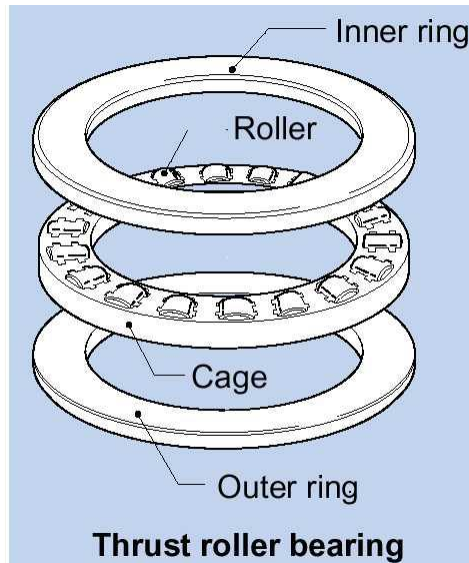
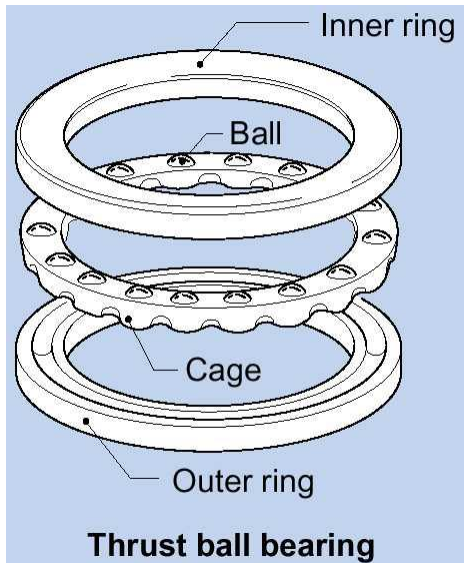
Typical applications:

- ➡ Large capacity
- ➡ Long-life requirements
- ➡ Long endurance for heavy loads
- ➡ Long endurance for shock forces
- ➡ Unless rollers are contoured, they can support load in only one direction (radial or thrust according to bearing design)
- ➡ Most roller bearings support, both radial and thrust loads
- ➡ If contact angle is less than 45° , bearing has larger radial capacity



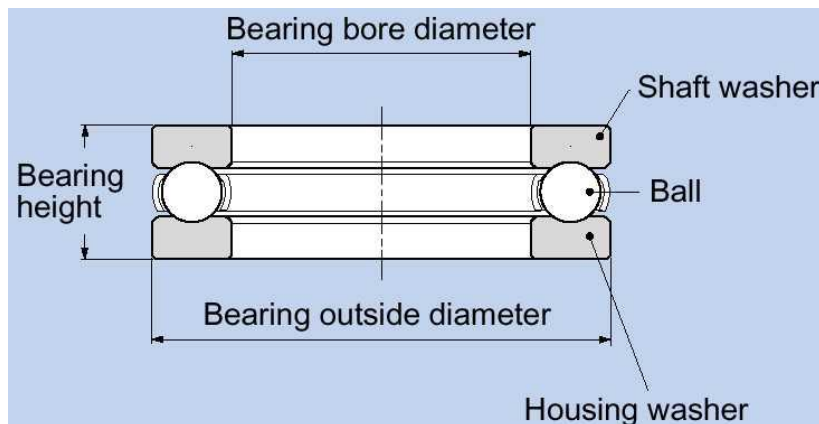
Bearings and lubrication

Rolling-element bearings: thrust bearings



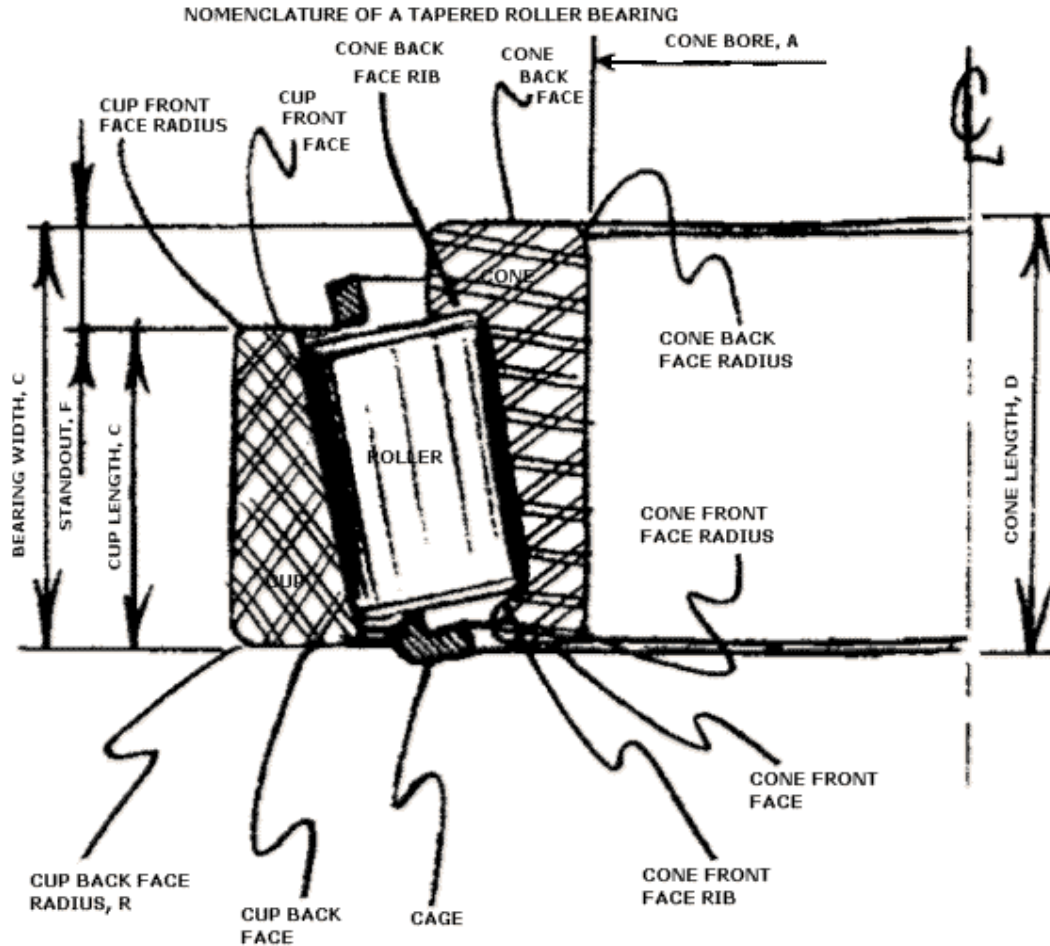
Typical applications:

- ➡ Large capacity
- ➡ Designed to support thrust (axial) load only
- ➡ Some roller bearings with a contact angle larger than 45° can be used for thrust (axial) load and moderate radial load



Bearings and lubrication

With Rolling elements: high-speed applications



<http://www.efunda.com>

Tapered roller bearings



Selection of rolling-element bearings

Basic dynamic load rating, C (defined as the load that will give a life of 1 million revolutions of the inner race):

$$\text{Ball bearings: } L_{10} = \left(\frac{C}{P}\right)^3$$

$$L_P = K_R \left(\frac{C}{P}\right)^3$$

$$\text{Roller bearings: } L_{10} = \left(\frac{C}{P}\right)^{10/3}$$

$$L_P = K_R \left(\frac{C}{P}\right)^{10/3}$$

Fatigue life in millions of revolution: L_{10}

Fatigue life in P -millions of revolution: L_P

Dynamic load rating: C

Applied load: P

Reliability factor: K_R
(Table 10-5)

Table 10-5

Reliability Factors R
for a Weibull Distribution
Corresponding to the
Probability of Failure P

P%	R%	K_R
50	50	5.0
10	90	1.0
5	95	0.62
4	96	0.53
3	97	0.44
2	98	0.33
1	99	0.21



Selection of rolling-element bearings



OPEN



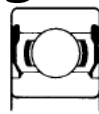
ONE SHIELD



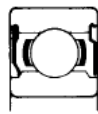
TWO SHIELDS



ONE SEAL



TWO SEALS



SEAL & SHIELD



OPEN, WITH SNAP RING†



RADIAL SEAL & SHIELD

Suffix

.Z

.2Z

.RS

.2RS

.RSZ

.NR

.RSRZR

This configuration only shown to illustrate new standard enclosures. Some bearings are now being converted.

BEARING NUMBER*	BOUNDARY DIMENSIONS						SNAP RING DIMENSIONS inches			MAX. FILLET RADIUS Shaft & Hsg. inch	APPROX. WEIGHT lb.	S _L LIMITING SPEED † rpm	C DYNAMIC LOAD RATING lb.	C ₀ STATIC LOAD RATING lb.
	BORE		O. DIAM.		WIDTH		H	S	t					
	mm	inch	mm	inch	mm	inch								
6300	10	.3937	35	1.3780	11	.4331	.125	1.562	.044	.025	.13	22000	1400	850
6301	12	.4724	37	1.4567	12	.4724	.125	1.625	.044	.040	.15	20000	1700	1040
6302	15	.5906	42	1.6535	13	.5118	.125	1.821	.044	.040	.20	18000	1930	1200
6303	17	.6693	47	1.8504	14	.5512	.141	2.074	.044	.040	.25	16000	2320	1460
6304	20	.7874	52	2.0472	15	.5906	.141	2.276	.044	.040	.34	14000	3000	1930
6305	25	.9843	62	2.4409	17	.6693	.195	2.665	.067	.040	.58	11000	3800	2550
6306	30	1.1811	72	2.8346	19	.7480	.195	3.091	.067	.040	.83	9500	5000	3400
6307	35	1.3780	80	3.1496	21	.8268	.195	3.406	.067	.060	1.07	8500	5700	4000
6308	40	1.5748	90	3.5433	23	.9055	.226	3.799	.097	.060	1.41	7500	7350	5300
6309	45	1.7717	100	3.9370	25	.9843	.226	4.193	.097	.060	1.95	6700	9150	6700
6310	50	1.9685	110	4.3307	27	1.0630	.226	4.587	.097	.080	2.50	6000	10600	8150
6311	55	2.1654	120	4.7244	29	1.1417	.271	5.104	.111	.080	3.30	5300	12900	10000
6312	60	2.3622	130	5.1181	31	1.2205	.271	5.498	.111	.080	3.81	5000	14000	10800
6313	65	2.5591	140	5.5118	33	1.2992	.304	5.892	.111	.080	4.64	4500	16000	12500
6314	70	2.7559	150	5.9055	35	1.3780	.304	6.286	.111	.080	5.68	4300	18000	14000
6315	75	2.9528	160	6.2992	37	1.4567	.304	6.679	.111	.080	6.60	4000	19300	16300
6316	80	3.1496	170	6.6929	39	1.5354	.346	7.198	.122	.080	9.53	3800	21200	18000
6317	85	3.3465	180	7.0866	41	1.6142	.346	7.593	.122	.100	11.00	3400	21600	18600
6318	90	3.5433	190	7.4803	43	1.6929	.346	7.986	.122	.100	11.60	3400	23200	20000
6319	95	3.7402	200	7.8740	45	1.7717	.346	8.380	.122	.100	13.38	3200	24500	22400
6320	100	3.9370	215	8.4646	47	1.8504	—	—	—	.100	16.34	3000	28500	27000
6321	105	4.1338	225	8.8582	49	1.9291	—	—	—	.100	17.8	2800	30500	30000
6322	110	4.3307	240	9.4488	50	1.9685	—	—	—	.100	21.0	2600	32500	32500
6324	120	4.7244	260	10.2362	55	2.1654	—	—	—	.100	32.3	2400	36000	38000
6326	130	5.1181	280	11.0236	58	2.2835	—	—	—	.12	40.1	2200	39000	43000
6328	140	5.5118	300	11.8110	62	2.4409	—	—	—	.12	48.1	2000	44000	50000
6330	150	5.9055	320	12.5984	65	2.5590	—	—	—	.12	57.8	1900	49000	60000

*Bearing numbers listed are for open bearings only. For shields, seals and snap rings, add suffix or prefix indicated below bearing diagram. Eg. **6300.Z**, **6300.RS**, **6300.NR**, etc. Check availability of closures for larger sizes.

†Snap ring bearings available with shields or seals. Add both suffixes. Eg. **6300.ZNR**, etc.

‡For grease lubricated bearings without seals. For other conditions, see Page 114.

For mounting data, shaft and housing fits and shoulder diameters, see Pages 124-132.

Dimensions and Load Ratings for 6300 Series, Medium, Metric, Deep-Groove (Conrad-type) Ball Bearings Courtesy of FAG Bearings Corporation, Stamford Conn.



Selection of rolling-element bearings

Review and Master: Example 10-3. Ball bearings for a designed shaft

Select radial ball bearings for the shaft shown in Fig. 9-5, which was designed in Example 9-1

Given The maximum transverse loads on the shaft at the bearings are 16 lb at R_1 and 54 lb at R_2 . Since the load at R_2 is 4X that at R_1 , one design can be created for R_2 and used also at R_1 . Shaft diameter at both R_1 and R_2 is 0.591 in, based on the tentative choice of a 15-mm-ID bearing in Example 9-1. The shaft speed is 1 725 rpm.

Assumptions Thrust loads are negligible. A 5% failure rate is desired.

Find The bearing fatigue lives at both shaft locations.

Solution

- From Figure 10-23 (p. 615), choose a #6302 bearing with 15-mm inside diameter. Its dynamic load rating factor is $C = 1\,930$ lb. The static load rating $C_0 = 1\,200$ lb. The static applied load of 54 lb is obviously well below the bearing's static rating.
- From Table 10-5 (p. 614), choose the factor for a 5% failure rate: $K_R = 0.62$.
- Calculate the projected life with equations 10.20a (p. 614) and 10.19 (p. 612) or their combination, equation 10.20c (p. 615). Note that the equivalent load in this case is simply the applied radial load due to the absence of any thrust load. For the larger reaction load of 54 lb at R_2 :

$$L_{10} = \left(\frac{C}{P} \right)^3 = \left(\frac{1\,930}{54} \right)^3 = 45E3 \text{ millions of revs} = 45E9 \text{ revs}$$

$$L_P = K_R L_{10} = 0.62(45E9) = 27.9E9 \text{ revs}$$

$K_R = \text{probab. of failure;}$
 $\Rightarrow \text{reliability factors}$
 (Weibull distribution)
 pg. 614

- For the smaller reaction load of 16 lb at R_1 :

$$L_{10} = \left(\frac{C}{P} \right)^3 = \left(\frac{1\,930}{16} \right)^3 = 1.75E6 \text{ millions of revs} = 1.75E12 \text{ revs}$$

$$L_P = K_R L_{10} = 0.62(1.75E12) = 1.09E12 \text{ revs}$$

This shows the nonlinear relationship between load and life. A 3.5X reduction in load results in a 38X increase in fatigue life. These bearings are obviously very lightly loaded, but their size was dictated by considerations of stresses in the shaft that defined the shaft diameters.

- From Figure 10-23, this bearing's limiting speed is 18 000 rpm, well above the operating speed of 1 725 rpm.



Examples

☞ **Review and Master:** Example 11-3 and 11-4



Reading

- ☞ Chapters 10 of textbook: **Sections 11.8 to 11.10**
- ☞ Review notes and text: **ES2501, ES2502, ES2503**

Homework assignment

- ☞ Author's: **11-1**
- ☞ Solve: **11-1e, 11-3**

