Chapter 11 - Rolling Bearing المحامل المتدحرجة

1- Rolling contact bearings

The term ‘rolling contact bearings’ encompasses the wide variety of bearings that use spherical balls or some type of roller between the stationary and moving elements as illustrated in Figure. 1

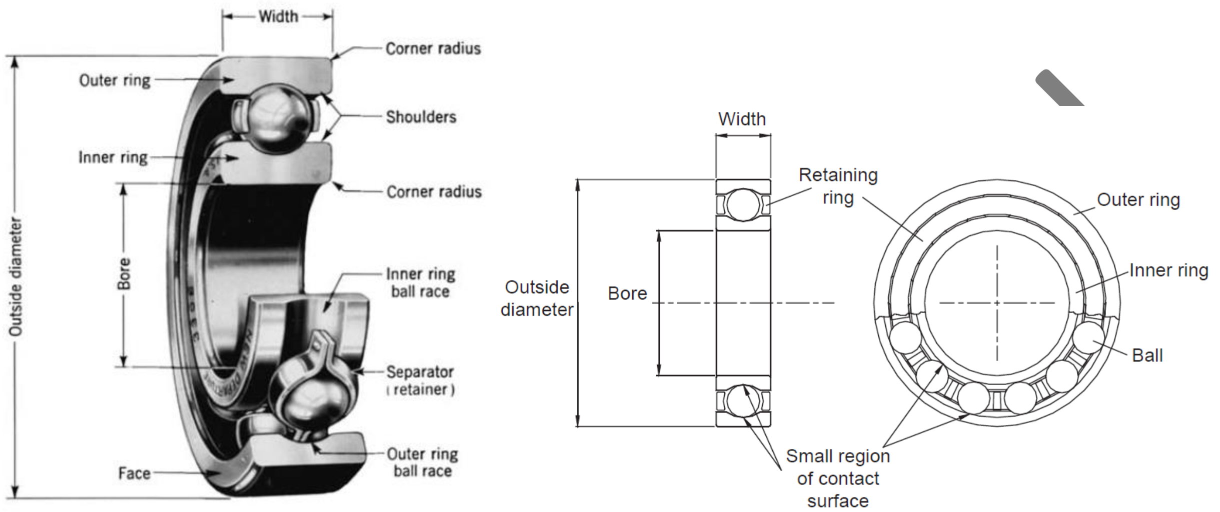


Fig (1) Contact Area for Ball Bearing

The most common type of bearing supports a rotating shaft resisting a combination of radial and axial (or thrust) loads. Some bearings are designed to carry only radial or only thrust loads. See Fig(2) and Fig (3)

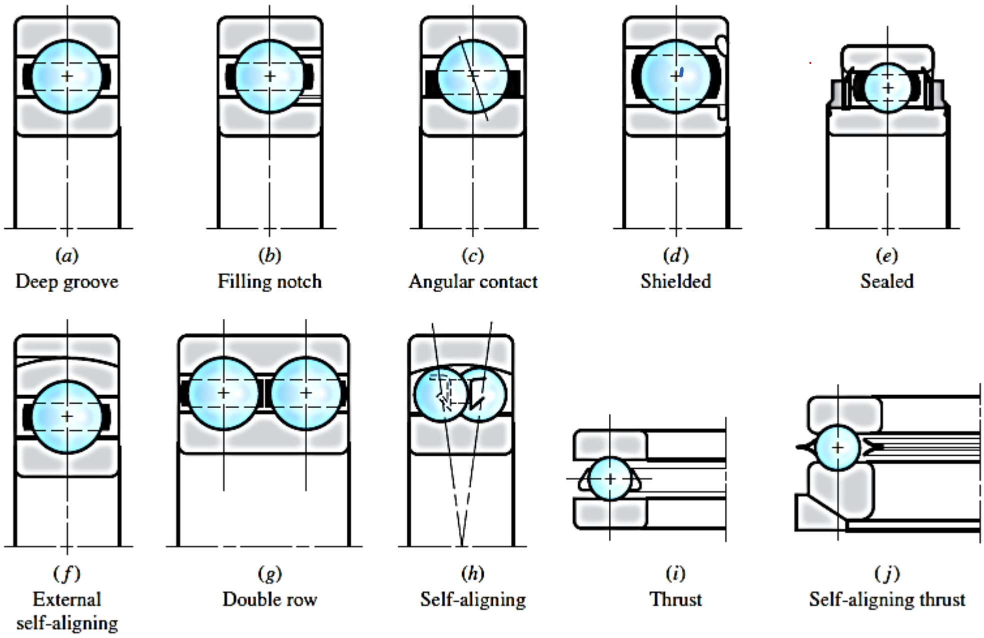


Fig (2) Ball Bearing

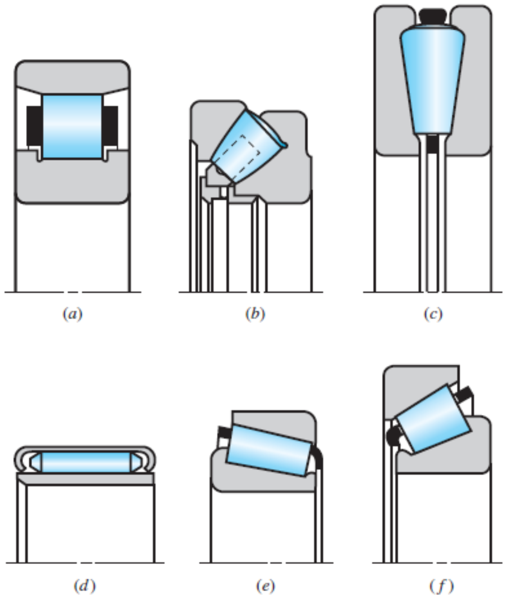


Fig (3): Roller Bearing

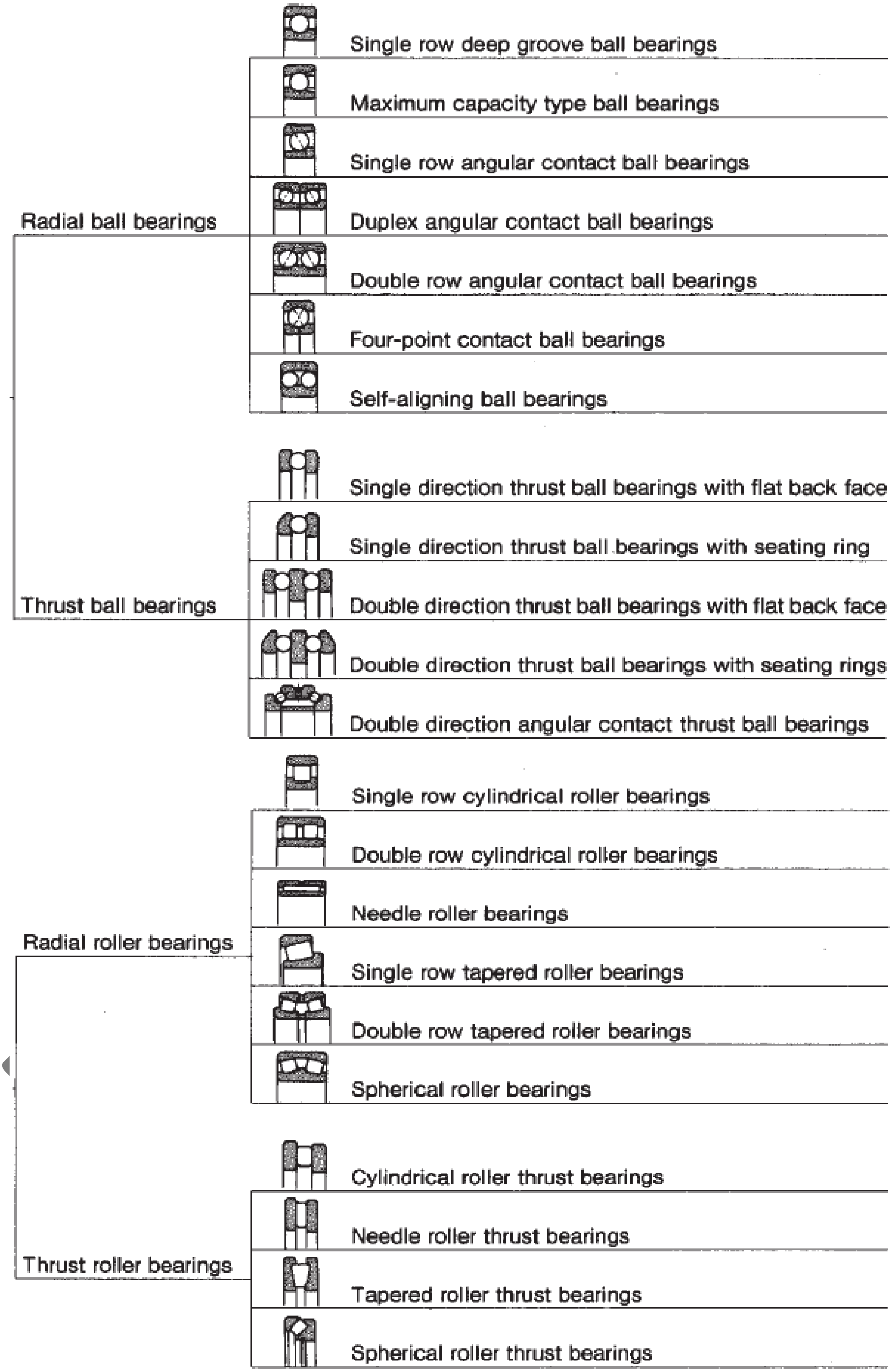
(*a*) straight roller;
(*b*) spherical roller (thrust);
(*c*) tapered roller (thrust);
(*d*) needle
(*e*) tapered roller;
(*f*) steep-angle tapered roller.

Selection of the type of bearing to be used for a given application can be aided by the comparison charts, an example of which is given in Table (1)

Table (1) Merits of different rolling contact bearings

Bearing type	Radial load capacity	Axial or thrust load capacity	Misalignment capability
Single row	Good	Fair	Fair
Double row deep groove ball	Excellent	Good	Fair
Angular contact	Good	Excellent	Poor
Cylindrical roller	Excellent	Poor	Fair
Needle roller	Excellent	Poor	Poor
Spherical roller	Excellent	Fair/good	Excellent
Tapered roller	Excellent	Excellent	Poor

Several bearing manufacturers produce excellent catalogues (e.g. NSK/RHP, SKF, FAG, INA) including design guides. The reader is commended to gain access to this information, which is available in web sites.



شكل يوضح تصنيف الركائز الدحروجية Rolling Bearing

		TYPE	SIZE RANGE IN INCHES		AVERAGE RELATIVE RATINGS				AVAILABLE WITH			DIMENSIONS	
			Bore	O.D.	Capacity Radial	Capacity Thrust	Limiting Speed	Permissible Misalignment	Shields	Seals	Snap Rings	Metric	Inch
	BALL BEARINGS	CONRAD TYPE	.1181 to 41.7323	.3750 to 55.1181	Good	Fair ↔	Conrad is basis for comparison 1.00	± 0° 8′ Std. Radial Clearance. ± 0° 12′ C3 Clear	X	X	X	X	X
		MAXIMUM TYPE	.6693 to 4.3307	1.5748 to 8.4646	Excellent	Poor ↔	1.00	± 0° 3′	X		X	X	
Ball		ANGULAR CONTACT 15°/40° (15°, 40°)	.3937 to 7.4803	1.0236 to 15.7480	Good	Good (15°) Excellent (40°) ←	1.00 / 0.70	± 0° 2′				X	
		ANGULAR CONTACT 35°	.3937 to 4.3307	1.1811 to 9.4488	Excellent	Good ←	0.70	0°				X	
		SELF-ALIGNING	.1969 to 4.7244	.7480 to 9.4488	Fair	Fair ↔	1.00	± 4°				X	
	CYLINDRICAL ROLLER BEARINGS	SEPARABLE INNER RING NON-LOCATING	.4724 to 19.6850	1.2598 to 28.3465	Excellent	0	1.00	± 0° 4′				X	
		SEPARABLE INNER RING ONE DIR. LOCATING	.4724 to 12.5984	1.2598 to 22.8346	Excellent	Poor ←	1.00	± 0° 4′				X	
		SELF-CONTAINED TWO DIR. LOCATING	.4724 to 3.9370	1.4567 to 8.4646	Excellent	Poor ↔	1.00	± 0° 4′				X	
	TAPERED ROLLER BEARINGS	SEPARABLE	.6205 to 6.0000	1.5700 to 10.0000	Good	Good →	0.60	± 0° 2′				X	X
	SPHERICAL ROLLER BEARINGS	SELF-ALIGNING	.9843 to 12.5984	2.0472 to 22.8346	Good	Fair ↔	0.50	± 4°				X	
		SELF-ALIGNING	.9843 to 35.4331	2.0472 to 46.4567	Excellent	Good ↔	0.75	± 1°				X	
Roller	NEEDLE BEARINGS	COMPLETE BEARINGS with or without locating rings & lubricating groove	.2362 to 14.1732	.6299 to 17.3228	Good	0	0.60	± 0° 2′		X		X	X
		DRAWN CUP	.1575 to 2.3622	.3150 to 2.6772	Good	0	0.30	± 0° 2′				X	X
	THRUST BEARINGS	SINGLE DIRECTION BALL Grooved Race	.2540 to 46.4567	.8130 to 57.0866	Poor	Excellent →	0.30	0°				X	X
		SINGLE DIRECTION CYL. ROLLER	1.1811 to 23.6220	1.8504 to 31.4960	0	Excellent →	0.20	0°				X	
		SELF-ALIGNING SPHERICAL ROLLER	3.3622 to 14.1732	4.3307 to 22.0472	Poor	Excellent →	0.50	± 3°				X	

شكل يبين معلومات عن الأداء النسبي ، القياسات ، التوفر او المتاحية **availability**

2- Bearing Mounting

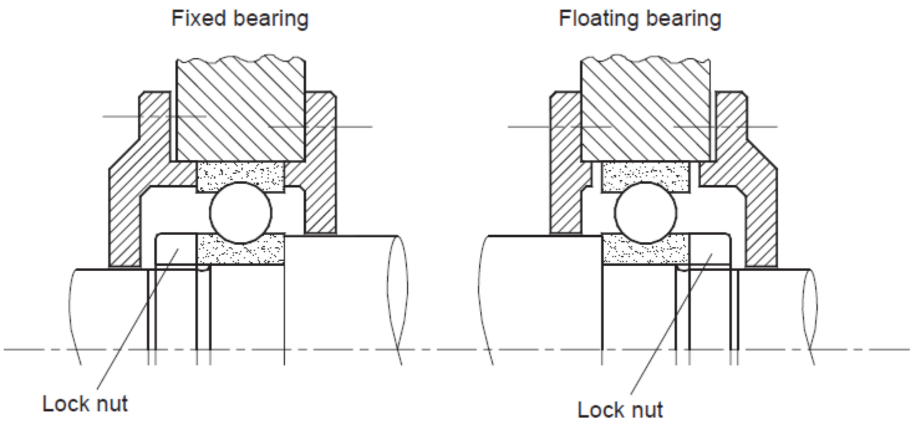


Figure 4.27 Basic bearing mounting using two deep groove ball bearing for a rotating horizontal shaft for moderate radial and axial loading.

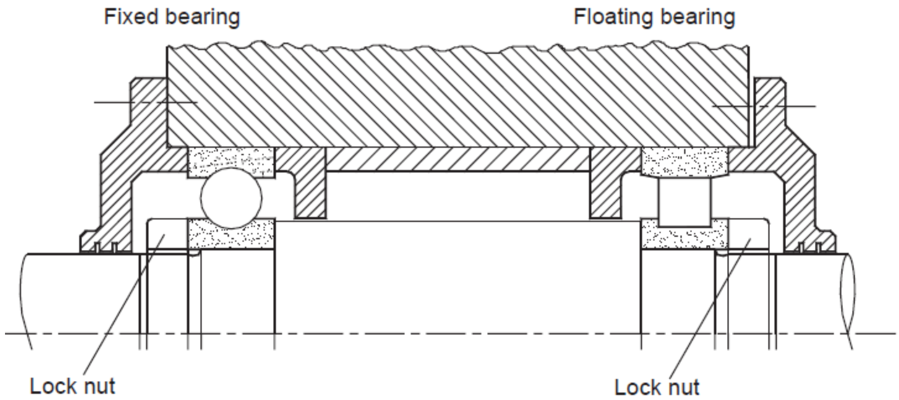


Figure 4.28 Basic bearing mounting using a deep groove and a cylindrical roller bearing for moderate radial loads at the 'locating deep groove bearing' and high radial load capacity at the cylindrical roller bearing.

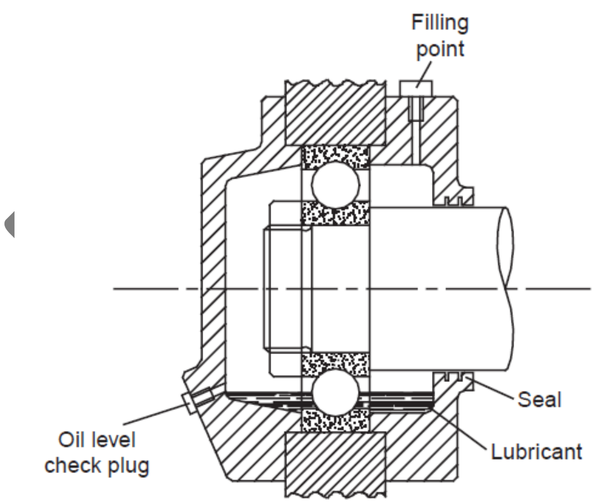


Figure 4.29 Partial submersion lubrication arrangement.

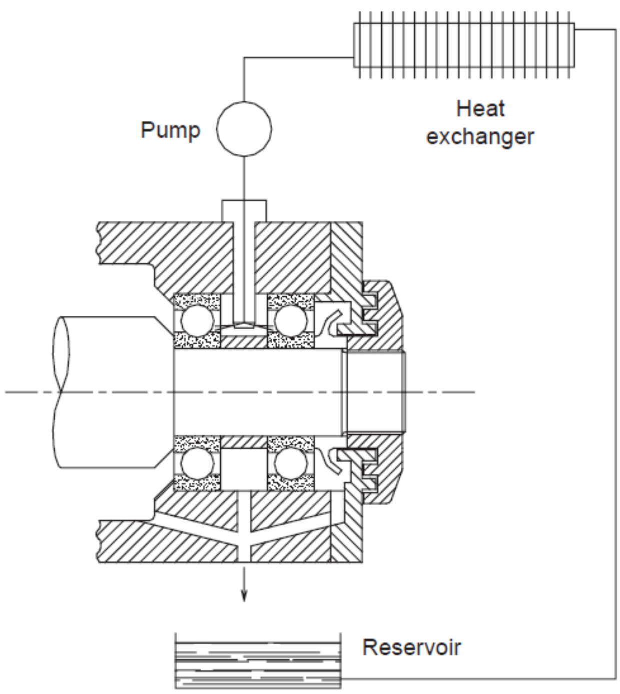


Figure 4.30 Recirculation lubrication system.

3- Bearing life and selection

The load on a rolling contact bearing is exerted on a very small area as illustrated in Figure 2. The resulting contact stresses are very high and of the order of 2000MPa.

Despite very strong steels (e.g. BS 970 534 A99, AISI 52100) all bearings have a finite life and will eventually fail due to fatigue.

For two groups of apparently identical bearings tested under loads F_1 and F_2, the respective lives L_1 and L_2 are related by:

$$\frac{L_1}{L_2} = \left(\frac{F_2}{F_1}\right)^3 \qquad \textbf{for ball bearings} \ldots\ldots\ldots\ldots (\mathbf{1a})$$

$$\frac{L_1}{L_2} = \left(\frac{F_2}{F_1}\right)^{10/3} \qquad \textbf{for roller bearings} \ldots\ldots\ldots\ldots (\mathbf{1b})$$

The various commonly used definitions for rolling element bearing life specification are outlined and illustrated by the example below.

The basic dynamic load rating, C, is the constant radial load which a bearing can endure for 1×10^6 revolutions without evidence of the development of fatigue in any of the bearing components.

The life of a ball bearing, L, is the number of revolutions (or hours at some constant speed), which the bearing runs before the development of fatigue in any of the bearing components.

If in Eq. (1), $P_2 = C$ and the corresponding life $L_2 = 1 \times 10^6$, then the life of a bearing L, with basic dynamic load rating C with a load P is given by:

$$L = \left(\frac{C}{P}\right)^3 \textbf{ million revolutions} \qquad \textbf{for ball bearings} \ldots\ldots\ldots (\mathbf{2a})$$

$$L = \left(\frac{C}{P}\right)^{10/3} \textbf{ million revolutions} \qquad \textbf{for roller bearings} \ldots\ldots (\mathbf{2b})$$

where:
L = life (millions of revolutions);
C = basic dynamic load rating (N);
P= load (N).
When selecting a particular bearing from a manufacturer's catalogue, it is useful to know the required basic dynamic load rating C for a given load P and life L, which is given by:

$$C = PL^{1/3} \qquad \textbf{for ball bearings} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (\mathbf{3a})$$

$$C = PL^{0.3} \qquad \textbf{for roller bearings} \ldots\ldots\ldots\ldots\ldots\ldots\ldots (\mathbf{3b})$$

Many bearing manufacturers publish ratings for bearings corresponding to particular number of hours at aspecified rotational speed

The designer's task is to determine which value of catalogue rating to use given a set of particular values of P_d, L_d, n_d

$$C_{cat} = P_d \left(\frac{L_d n_d}{L_{cat} n_{cat}}\right)^{1/k} \dots\dots\dots\dots\dots\dots\dots\dots\dots (4)$$

Where

$$k = \begin{cases} 3 & \dots\dots\dots\dots\dots\dots\dots\dots \text{ for ball bearings} \\ 10/3 & \dots\dots\dots\dots \text{ for cylindrical roller bearings.} \end{cases}$$

C_{cat} = catalogue radial rating (N)
P_d = required radial design load (N)
L_d = required design life (revolutions or hours)
L_{cat} = rated catalogue life (revolutions or hours)
n_d = required design speed (rpm)
n_{cat} = catalogue rated speed (rpm)

The life in hours may be found from the life in revolutions as:

$$L_h = \frac{L_d \times 10^6}{n_d \times 60} \dots\dots\dots\dots\dots\dots\dots\dots\dots (5)$$

Example 1

A straight cylindrical roller bearing operates with a load of 7.5 kN. The required life is 8760 hours at 1000 rpm. What load rating should be used for selection from the catalogue?

Solution:

From eq. 5

$$L_d = \frac{L_h \times n_d \times 60}{10^6} = \frac{8760 \times 1000 \times 60}{10^6}$$

$$= 525.6 \text{ million revolutions}$$

Using Eq. 3,

$$C = P_d \times {L_d}^{1/k} = 7500(525.6)^{0.3} = 49.1 \text{ kN}$$

Example 2

A catalogue lists the basic dynamic load rating for a ball bearing to be 33800 N for a rated life of 1 million revolutions.

a- What would be the expected L_{10} life of the bearing if it were subjected to 15000 N

b- Determine the life in hours that this corresponds to if the speed of rotation is 2000 rpm. Comment on the value obtained and its suitability for a machine.

Solution:

C_{cat}=33800 N,

P_d=15000 N,

L_{cat}=10^6 (L_{10} life at load C),

K=3 (ball).

Using Eq. (2), the life is given by:

$$L = \left(\frac{33800}{15000}\right)^3 = 11.44 \text{ million revolutions}$$

$$= \text{life at 15000 N}$$

If the rotational speed is 2000 rpm,

From eq. 5

$$L_h = \frac{L_d \times 10^6}{n_d \times 60}$$

$$L_h = 11.44 \times \frac{10^6}{2000 \times 60} = 95 \text{ hours operation}$$

This is not very long and illustrates the need to use a bearing with a high basic dynamic load rating.

The basic static load rating, C_o, is the load the bearing can withstand without any permanent deformation of any component. If this load is exceeded it is likely the bearing races will be indented by the rolling elements (called Brinelling).

The equivalent load, P, is defined as the constant radial load which if applied to a bearing would give the same life as that which the bearing would attain under the actual conditions of load and rotation.

When both radial and thrust loads are exerted on a bearing the equivalent load is the constant radial load that would produce the same rated life for the bearing as the combined loading. Normally,

$$\boldsymbol{P = VXF_r + YF_a} \quad \dots\dots\dots\dots (\mathbf{5})$$

where
P = the equivalent load (N);
V = 1.2 if mounting rotates is recommended,
V = 1.0 if shaft rotates;
X = radial factor (given in bearing catalogues, see Table 2 for example data);
F_r = applied radial load (N);
Y = thrust factor (given in bearing catalogues, see Table 2 for example data);
F_a = applied thrust load (N).

Tables 3 to 5 give an overview of the information typically available in bearing manufacturers' catalogues and the example given below illustrates their basic use.

Example 3

A bearing is required to carry a radial load of 2.8 kN and provide axial location for a shaft of 30 mm diameter rotating at 1500 rpm. An L_{10} life of 10000 hours is required. Select and specify an appropriate bearing.

Solution

Axial shaft location is required, so a deep groove ball bearing, which provides axial location capability in both directions,would be suitable.

The total number of revolutions in life is

$$10000 \times 1500 \times 60 = 900 \text{ million}$$

so L=900. The load is purely radial, so

$$P = 2800 \text{ N}$$

The required dynamic loading is given b

$$C = PL^{1/3} = 2800 \times 900^{1/3} = 27034 \text{ N}$$

Reference to the deep groove bearing chart (Table 3) shows a suitable bearing could be:

- ISO designation 6306
- bore diameter 30 mm, outer diameter 72 mm
- width 19 mm

$$C = 28200 \text{ N}$$

$$C_0 = 16000 \text{ N}$$

- speed limit (using grease) 9000 rpm
- speed limit (using oil) 11000 rpm.

4- Variable Loads:

a. If the loads are constant for peiods of time then the mean effective load is given by

$$\boldsymbol{F_m = \left(\frac{F_1^3 N_1 + F_2^3 N_2 + F_3^3 N_3 + \cdots}{L_n}\right)^{1/3}} \quad \dots\dots\dots (\mathbf{6})$$

F_m: is the mean cubic load
F_i: is the force acting for N_i revolutions
L_n : is the total number of revolutions

b. If the speed of rotation is constant but the load varies with time, then

$$\boldsymbol{F_m = \left(\frac{F_1^3 t_1 + F_2^3 t_2 + F_3^3 t_3 + \cdots}{T}\right)^{1/3}} \quad \dots\dots\dots (\mathbf{7})$$

F_i: is the force at an instant of time t_i and T is the time for one cycle of the load variaton.

Example 4

A radial load $F_1 = 3.2$ kN acts for 2 hours of a rolling bearing and then reduced to $F_2 = 2.9$ kN for 1 hour. The cycle repeats itself. The shaft rotates at 430 rpm. Calculate the mean cubic load which shoud be used in rating the bearing for 9000 hours life.

Solution: using Eq. 7

$$F_m = \left(\frac{F_1^3 t_1 + F_2^3 t_2}{T}\right)^{\frac{1}{3}} = \left(\frac{3200^3(2) + 2900^3(1)}{3}\right)^{\frac{1}{3}} = 3106 \text{ N}$$

5- Bearing Reliability

A knowledge of the reliability of a bearing or bearing combination is critical to the design of a product . An idea of the impact of using bearings with a reliability only a few points less than 100 per cent can be gained by considering the example of a double reduction gear box with six bearings . If the reliability of each bearing is 90 per cent and if the probability of failure of any one bearing is independent , the overall reliability of the bearing combination is $(0.9)^6 = 0.5314$ or 53 per cent. This is a very poor level of reliability and indicates the need to use bearings with a high reliability. The distribution of bearing failures at constant load can be approximated by the Weibull distribution which for bearings can be approximated by (Mischke, 1990)

$$\boldsymbol{R = \exp\left[-\left(\frac{L/L_{10} - 0.02}{4.439}\right)^{1.483}\right]} \quad \dots\dots\dots\dots (\mathbf{8})$$

Rearranging equation 8 in terms of the desired life L and the desired reliability R gives

$$\boldsymbol{L_{10} = \frac{L}{0.02 + 4.439[\ln(1/R)]^{1/1.483}}} \quad \dots\dots\dots\dots (\mathbf{9})$$

Example 5

A small fan application requires a bearing to last for 2100 hours with a reliability of 95 %. What should the rated life of the bearing be?

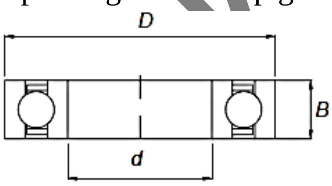
$$L_{10} = \frac{L}{0.02 + 4.439[\ln(1/R)]^{1/1.483}}$$

$$L_{10} = \frac{2100}{0.02 + 4.439[\ln(1/0.95)]^{1/1.483}} = 3392 \text{ hours}$$

Table (2) Values for the radial and thrust factors for determining the equivalent load for deep groove ball single bearings and bearing pairs arranged in tandem

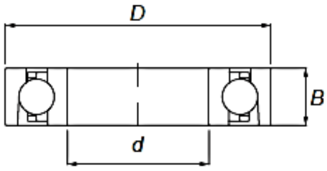
	Normal clearance			C3 clearance			C4 clearance		
F_a/C_0	e	X	Y	e	X	Y	e	X	Y
0.025	0.22	0.56	2	0.31	0.46	1.75	0.4	0.44	1.42
0.04	0.24	0.56	1.8	0.33	0.46	1.62	0.42	0.44	1.36
0.07	0.27	0.56	1.6	0.36	0.46	1.46	0.44	0.44	1.27
0.13	0.31	0.56	1.4	0.41	0.46	1.3	0.48	0.44	1.16
0.25	0.37	0.56	1.2	0.46	0.46	1.14	0.53	0.44	1.05
0.5	0.44	0.56	1	0.54	0.46	1	0.56	0.44	1

Table (3) Selected example single row deep groove ball bearing ratings



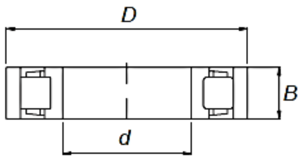
d (mm)	D (mm)	B (mm)	Basic dynamic load rating C (N)	Basic static load rating C_o (N)	Speed limit for grease lubrication (rpm)	Speed limit for oil lubrication (rpm)	Code
15	24	5	1570	800	28 000	34 000	61802
	32	8	5600	2850	22 000	28 000	16002
	32	9	5600	2850	22 000	28 000	6002
	35	11	7850	3750	19 000	24 000	6202
	42	13	11 500	5400	17 000	20 000	6302
17	26	5	1690	930	24 000	30 000	61803
	35	8	6060	3250	19 000	24 000	16003
	35	10	6060	3250	19 000	24 000	6003
	40	12	9550	4750	17 000	20 000	6203
	47	14	13 600	6550	16 000	19 000	6303
	62	17	23 000	10 800	12 000	15 000	6403
20	32	7	2750	1500	19 000	24 000	61804
	42	8	6900	4050	17 000	20 000	16004
	42	12	9400	5000	17 000	20 000	6004
	47	14	12 800	6550	15 000	18 000	6204
	52	15	16 000	7800	13 000	16 000	6304
	72	19	30 800	15 000	10 000	13 000	6404
25	37	7	4400	2600	17 000	20 000	61805
	47	8	7600	4750	14 000	17 000	16005
	47	12	11 300	6550	15 000	18 000	6005
	52	15	14 050	7800	12 000	15 000	6205
	62	17	22 600	11 600	11 000	14 000	6305
	80	21	36 000	19 300	9000	11 000	6405
30	42	7	4500	2900	15 000	18 000	61806
	55	9	11 300	7350	12 000	15 000	16006
	55	13	13 400	8300	12 000	15 000	6006
	62	16	19 600	11 200	10 000	13 000	6206
	72	19	28 200	16 000	9000	11 000	6306
	90	23	43 700	23 600	8500	10 000	6406

Table (4) Selected example angular contact ball bearing ratings



d (mm)	D (mm)	B (mm)	Basic dynamic load rating C (N)	Basic static load rating C_o (N)	Speed limit for grease lubrication (rpm)	Speed limit for oil lubrication (rpm)	Code
15	35	11	8850	4800	17 000	24 000	7202B
	42	13	13 050	6700	15 000	20 000	7302B
17	40	12	11 200	6100	15 000	20 000	7203B
	47	14	16 000	8300	13 000	18 000	7303B
20	47	14	14 050	8300	12 000	17 000	7204B
	52	15	19 050	10 400	11 000	16 000	7304B
25	52	15	15 500	10 200	10 000	15 000	7205B
	62	17	26 100	15 600	9000	13 000	7305B
30	62	16	23 900	15 600	8500	12 000	7206B
	72	19	34 600	21 200	8000	11 000	7306B
40	80	18	36 500	26 000	7000	9500	7208B
	90	23	49 500	33 500	6700	9000	7308B
50	90	20	39 050	30 500	6000	8000	7210B
	110	27	74 000	51 000	5300	7000	7310B
55	100	21	48 850	38 000	5600	7500	7211B
	120	29	85 300	60 000	4800	6300	7311B
60	110	22	57 250	45 500	5000	6700	7212B
	130	31	95 700	69 500	4500	6000	7312B
65	120	23	66 400	54 000	4500	6000	7213B
	140	33	109 000	80 000	4300	5600	7313B
70	125	24	71 600	60 000	4300	5600	7214B

Table (5) Selected example cylindrical roller bearing ratings



d (mm)	D (mm)	B (mm)	Basic dynamic load rating C (N)	Basic static load rating C_o (N)	Speed limit for grease lubrication (rpm)	Speed limit for oil lubrication (rpm)	Code
15	35	11	12 600	10 200	18 000	22 000	NU202E
	42	13	19 500	15 300	16 000	19 000	NU302E
25	52	15	28 700	27 000	11 000	14 000	NU205E
	62	17	40 300	36 500	9500	12 000	NU305E
30	62	16	38 100	36 500	9500	12 000	NU206E
	72	19	51 300	48 000	9000	11 000	NU306E
50	90	20	64 500	69 500	6300	7500	NU210E
	110	27	111 000	112 000	5000	6000	NU310E
	130	31	131 000	127 000	5000	6000	NU410
100	180	34	252 000	305 000	3200	3800	NU220E
	250	58	430 000	475 000	2400	3000	NU420
200	360	58	766 000	1 060 000	1500	1800	NU240E
	420	80	990 000	1 320 000	1300	1600	NU340
600	870	118	2 750 000	510 000	600	700	NU10/600

PROBLEMS:

1- A bearing is required to support a radial load of 3200 N for a shaft of 50 mm nominal diameter spinning at 700 rpm. The desired life is 10000 hours. Select and specify an appropriate bearing.

Ans. [NU210E, d = 50 mm, D = 90 mm, B = 20 mm, Grease limit 6300 rpm]

2- A straight cylindrical roller bearing operates with a load of 14.2kN.The required life is 3800 hours at 925 rpm. What load rating should be used for selection from a bearing manufacturer's catalogue.

Ans.[70.7 kN]

3- A bearing is required for the floating end of a heavy-duty lathe to carry a radial load of up to 9kN.The shaft diameter is 50 mm and rotates at 3000 rpm.A life of 7500 hours for the bearings is desired. Select and specify an appropriate bearing.

[C = 78.2 kN. No unique solution]

4- A bearing is required to support a radial load of 2800 N for a shaft of 30 mm nominal diameter spinning at 750 rpm. The desired life is 10 000 hours. From the limited range available in Tables 3 to 5, select and specify an appropriate bearing, justifying the choice.

[NU206E, d = 30 mm, D = 62 mm, B = 16 mm, C = 38 100 N. Grease limit 9500 rpm.]

5- A bearing is required to provide axial location and support a radial load of 940 N for a shaft of 17 mm nominal diameter spinning at 570 rpm. The desired life is 10 years continuous operation. From the limited range available in Tables 3 to 5, select and specify an appropriate bearing, justifying the choice.

[6403, d = 17 mm, D = 62 mm, B = 17 mm, C = 23000 N. Grease limit 12000 rpm.]

6- A bearing is required to support an equivalent radial load of 1290N. The nominal diameter of the shaft is 25 mm and its design speed is 730 rpm. The desired life is 2 years continuous operation. If the bearing should support the load and provide axial location, then from the limited range available in Tables 3 to 5, select and specify an appropriate bearing, justifying the choice.

[6205, d = 25 mm, D = 52 mm, B = 15 mm, C = 14050 N. Grease limit 12000 rpm.]

7- A bearing is required to support an equivalent radial load of 1130N. The nominal diameter of the shaft is 20 mm and its design speed is 7000 rpm. The desired life is 1 year continuous operation. If the bearing should support the load and provide axial location, then from the limited range available in Tables 3 to 5, select and specify, detailing the bore, width and outer diameter an appropriate bearing, justifying the choice.

[6404, d = 20 mm, D = 72 mm, B = 19 mm]

1- The bearing for a power transmission arrangement is required to carry an equivalent radial load of 2.4 kN at 3000 rpm.The nominal shaft diameter at the bearing is 30mm. A life of 8760 hours is required. Select and specify an appropriate bearing from the limited range available in Tables 3 to 5.

[6306, d = 30 mm, D = 72 mm, B = 19 mm. Grease limit 9000 rpm].