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CHAPTER

27

Rolling Contact Bearings

27.1 Introduction

In rolling contact bearings, the contact between the bearing surfaces is rolling instead of sliding as in sliding contact bearings. We have already discussed that the ordinary sliding bearing starts from rest with practically metal-to-metal contact and has a high coefficient of friction. It is an outstanding advantage of a rolling contact bearing over a sliding bearing that it has a low starting friction. Due to this low friction offered by rolling contact bearings, these are called ***antifriction bearings.***

27.2 Advantages and Disadvantages of Rolling Contact Bearings Over Sliding Contact Bearings

The following are some advantages and disadvantages of rolling contact bearings over sliding contact bearings.

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Advantages

1. Low starting and running friction except at very high speeds.
2. Ability to withstand momentary shock loads.
3. Accuracy of shaft alignment.
4. Low cost of maintenance, as no lubrication is required while in service.
5. Small overall dimensions.
6. Reliability of service.
7. Easy to mount and erect.
8. Cleanliness.

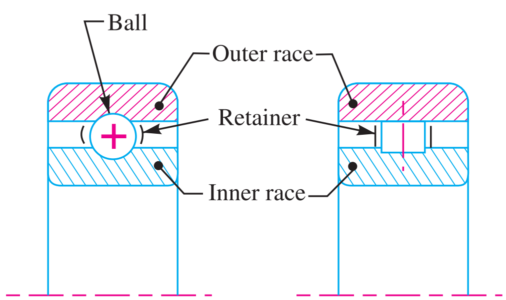
Disadvantages

1. More noisy at very high speeds.
2. Low resistance to shock loading.
3. More initial cost.
4. Design of bearing housing complicated.

27.3 Types of Rolling Contact Bearings

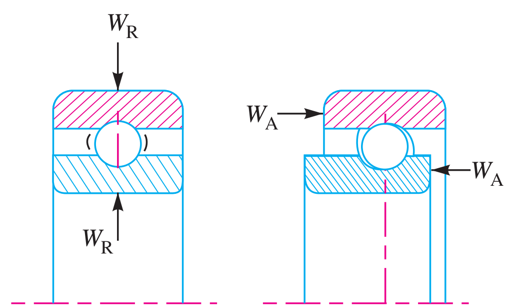
Following are the two types of rolling contact bearings:

1. Ball bearings; and **2.** Roller bearings.



(*a*) Ball bearing. (*b*) Roller bearing.

Fig. 27.1. Ball and roller bearings.



(*a*) Radial ball bearing. (*b*) Thrust ball bearing.

Fig. 27.2. Radial and thrust ball bearings.

The ***ball and roller bearings*** consist of an inner race which is mounted on the shaft or journal and an outer race which is carried by the housing or casing. In between the inner and outer race, there are balls or rollers as shown in Fig. 27.1. A number of balls or rollers are used and these are held at proper distances by retainers so that they do not touch each other. The retainers are thin strips and is usually in two parts which are assembled after the balls have been properly spaced. The ball bearings are used for light loads and the roller bearings are used for heavier loads.

The rolling contact bearings, depending upon the load to be carried, are classified as :

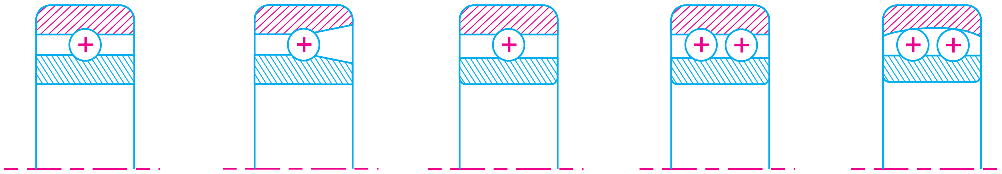
(*a*) Radial bearings, and **(*b*)** Thrust bearings.

The radial and thrust ball bearings are shown in Fig. 27.2 (*a*) and (*b*) respectively. When a ball bearing supports only a radial load (W_R), the plane of rotation of the ball is normal to the centre line of the bearing, as shown in Fig. 27.2 (*a*). The action of thrust load (W_A) is to shift the plane of rotation of the balls, as shown in Fig. 27.2 (*b*). The radial and thrust loads both may be carried simultaneously.

27.4 Types of Radial Ball Bearings

Following are the various types of radial ball bearings:

1. *Single row deep groove bearing.* A single row deep groove bearing is shown in Fig. 27.3 (*a*).



(*a*) Single row deep groove. (*b*) Filling notch. (*c*) Angular contact. (*d*) Double row. (*e*) Self-aligning.

Fig. 27.3. Types of radial ball bearings.

During assembly of this bearing, the races are offset and the maximum number of balls are placed between the races. The races are then centred and the balls are symmetrically located by the use of a retainer or cage. The deep groove ball bearings are used due to their high load carrying capacity and suitability for high running speeds. The load carrying capacity of a ball bearing is related to the size and number of the balls.

Radial ball bearing

2. *Filling notch bearing.* A filling notch bearing is shown in Fig. 27.3 (*b*). These bearings have notches in the inner and outer races which permit more balls to be inserted than in a deep groove ball bearings. The notches do not extend to the bottom of the race way and therefore the balls inserted through the notches must be forced in position. Since this type of bearing contains larger number of balls than a corresponding unnotched one, therefore it has a larger bearing load capacity.

3. *Angular contact bearing.* An angular contact bearing is shown in Fig. 27.3 (*c*). These bearings have one side of the outer race cut away to permit the insertion of more balls than in a deep groove bearing but without having a notch cut into both races. This permits the bearing to carry a relatively large axial load in one direction while also carrying a relatively large radial load. The angular contact bearings are usually used in pairs so that thrust loads may be carried in either direction.

4. *Double row bearing.* A double row bearing is shown in Fig. 27.3 (*d*). These bearings may be made with radial or angular contact between the balls and races. The double row bearing is appreciably narrower than two single row bearings. The load capacity of such bearings is slightly less than twice that of a single row bearing.

5. *Self-aligning bearing.* A self-aligning bearing is shown in Fig. 27.3 (*e*). These bearings permit shaft deflections within 2-3 degrees. It may be noted that normal clearance in a ball bearing are too small to accommodate any appreciable misalignment of the shaft relative to the housing. If the unit is assembled with shaft misalignment present, then the bearing will be subjected to a load that may be in excess of the design value and premature failure may occur. Following are the two types of self-aligning bearings :

(*a*) Externally self-aligning bearing, and **(*b*)** Internally self-aligning bearing.

In an ***externally self-aligning bearing,*** the outside diameter of the outer race is ground to a spherical surface which fits in a mating spherical surface in a housing, as shown in Fig. 27.3 (*e*). In case of ***internally self-aligning bearing,*** the inner surface of the outer race is ground to a spherical surface. Consequently, the outer race may be displaced through a small angle without interfering with the normal operation of the bearing. The internally self-aligning ball bearing is interchangeable with other ball bearings.

27.5 Standard Dimensions and Designations of Ball Bearings

The dimensions that have been standardised on an international basis are shown in Fig. 27.4. These dimensions are a function of the bearing bore and the series of bearing. The standard dimensions are given in millimetres. There is no standard for the size and number of steel balls.

The bearings are designated by a number. In general, the number consists of atleast three digits. Additional digits or letters are used to indicate special features *e.g.* deep groove, filling notch etc. The last three digits give the series and the bore of the bearing. The last two digits from 04 onwards, when multiplied by 5, give the bore diameter in millimetres. The third from the last digit designates the series of the bearing. The most common ball bearings are available in four series as follows :

1. Extra light (100), **2.** Light (200),

3. Medium (300), **4.** Heavy (400)

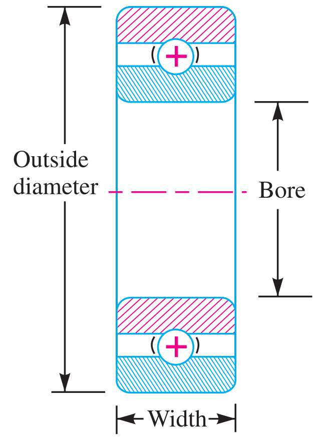


Fig. 27.4. Standard designations of ball bearings.

Notes : 1. If a bearing is designated by the number 305, it means that the bearing is of medium series whose bore is 05 × 5, *i.e.*, 25 mm.

2. The extra light and light series are used where the loads are moderate and shaft sizes are comparatively large and also where available space is limited.

3. The medium series has a capacity 30 to 40 per cent over the light series.

4. The heavy series has 20 to 30 per cent capacity over the medium series. This series is not used extensively in industrial applications.

Oilless bearings made using powder metallergy.

The following table shows the principal dimensions for radial ball bearings.

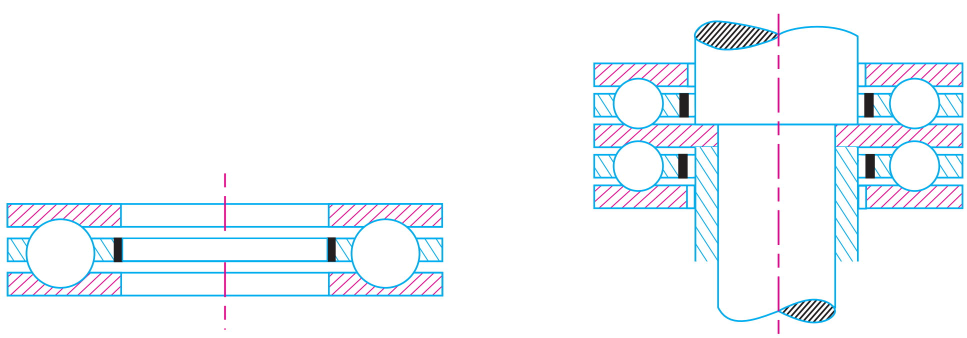
Table 27.1. Principal dimensions for radial ball bearings.

Bearing No.	*Bore (mm)*	*Outside diameter*	*Width (mm)*
200 300	10	30 35	9 11
201 301	12	32 37	10 12
202 302	15	35 42	11 13
203 303 403	17	40 47 62	12 14 17
204 304 404	20	47 52 72	14 14 19
205 305 405	25	52 62 80	15 17 21
206 306 406	30	62 72 90	16 19 23
207 307 407	35	72 80 100	17 21 25
208 308 408	40	80 90 110	18 23 27
209 309 409	45	85 100 120	19 25 29
210 310 410	50	90 110 130	20 27 31
211 311 411	55	100 120 140	21 29 33
212 312 412	60	110 130 150	22 31 35

Bearing No.	Bore (mm)	Outside diameter	Width (mm)
213	65	120	23
313		140	33
413		160	37
214	70	125	24
314		150	35
414		180	42
215	75	130	25
315		160	37
415		190	45
216	80	140	26
316		170	39
416		200	48
217	85	150	28
317		180	41
417		210	52
218	90	160	30
318		190	43
418		225	54

27.6 Thrust Ball Bearings

The thrust ball bearings are used for carrying thrust loads exclusively and at speeds below 2000 r.p.m. At high speeds, centrifugal force causes the balls to be forced out of the races. Therefore at high speeds, it is recommended that angular contact ball bearings should be used in place of thrust ball bearings.



(*a*) Single direction thrust ball bearing.

(*b*) Double direction thrust ball bearing.

Fig. 27.5. Thrust ball bearing.

A thrust ball bearing may be a single direction, flat face as shown in Fig. 27.5 (*a*) or a double direction with flat face as shown in Fig. 27.5 (*b*).

27.7 Types of Roller Bearings

Following are the principal types of roller bearings :

1. *Cylindrical roller bearings.* A cylindrical roller bearing is shown in Fig. 27.6 (*a*). These bearings have short rollers guided in a cage. These bearings are relatively rigid against radial motion

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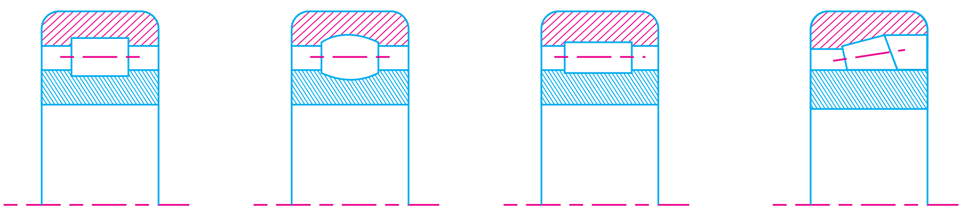
and have the lowest coefficient of friction of any form of heavy duty rolling-contact bearings. Such type of bearings are used in high speed service.

Radial ball bearing

2. *Spherical roller bearings.* A spherical roller bearing is shown in Fig. 27.6 (*b*). These bearings are self-aligning bearings. The self-aligning feature is achieved by grinding one of the races in the form of sphere. These bearings can normally tolerate angular misalignment in the order of $\pm 1\frac{1}{2}^{\circ}$ and when used with a double row of rollers, these can carry thrust loads in either direction.



(*a*) Cylindrical roller. (*b*) Spherical roller. (*c*) Needle roller. (*d*) Tapered roller.

Fig. 27.6. Types of roller bearings.

3. *Needle roller bearings.* A needle roller bearing is shown in Fig. 27.6 (*c*). These bearings are relatively slender and completely fill the space so that neither a cage nor a retainer is needed. These bearings are used when heavy loads are to be carried with an oscillatory motion, *e.g.* piston pin bearings in heavy duty diesel engines, where the reversal of motion tends to keep the rollers in correct alignment.

4. *Tapered roller bearings.* A tapered roller bearing is shown in Fig. 27.6 (*d*). The rollers and race ways of these bearings are truncated cones whose elements intersect at a common point. Such type of bearings can carry both radial and thrust loads. These bearings are available in various combinations as double row bearings and with different cone angles for use with different relative magnitudes of radial and thrust loads.

Cylindrical roller bearings

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Spherical roller bearings

Needle roller bearings

Tapered roller bearings

27.8 Basic Static Load Rating of Rolling Contact Bearings

The load carried by a non-rotating bearing is called a static load. The ***basic static load rating*** is defined as the static radial load (in case of radial ball or roller bearings) or axial load (in case of thrust ball or roller bearings) which corresponds to a total permanent deformation of the ball (or roller) and race, at the most heavily stressed contact, equal to 0.0001 times the ball (or roller) diameter.

In single row angular contact ball bearings, the basic static load relates to the radial component of the load, which causes a purely radial displacement of the bearing rings in relation to each other.

Note : The permanent deformation which appear in balls (or rollers) and race ways under static loads of moderate magnitude, increase gradually with increasing load. The permissible static load is, therefore, dependent upon the permissible magnitude of permanent deformation. Experience shows that a total permanent deformation of 0.0001 times the ball (or roller) diameter, occurring at the most heavily loaded ball (or roller) and race contact can be tolerated in most bearing applications without impairment of bearing operation.

In certain applications where subsequent rotation of the bearing is slow and where smoothness and friction requirements are not too exacting, a much greater total permanent deformation can be permitted. On the other hand, where extreme smoothness is required or friction requirements are critical, less total permanent deformation may be permitted.

According to IS : 3823–1984, the basic static load rating (C_0) in newtons for ball and roller bearings may be obtained as discussed below :

1. For radial ball bearings, the basic static radial load rating (C_0) is given by

$$C_0 = f_0.i.Z.D^2 \cos \alpha$$

where i = Number of rows of balls in any one bearing,

Z = Number of ball per row,

D = Diameter of balls, in mm,

α = Nominal angle of contact *i.e.* the nominal angle between the line of action of the ball load and a plane perpendicular to the axis of bearing, and

f_0 = A factor depending upon the type of bearing.

The value of factor (f_0) for bearings made of hardened steel are taken as follows :

f_0 = 3.33, for self-aligning ball bearings

= 12.3, for radial contact and angular contact groove ball bearings.

2. For radial roller bearings, the basic static radial load rating is given by

$$C_0 = f_0.i.Z.l_e.D \cos \alpha$$

where i = Number of rows of rollers in the bearing,

Z = Number of rollers per row,

l_e = Effective length of contact between one roller and that ring (or washer) where the contact is the shortest (in mm). It is equal to the overall length of roller ***minus*** roller chamfers or grinding undercuts,

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D = Diameter of roller in mm. It is the mean diameter in case of tapered rollers,

α = Nominal angle of contact. It is the angle between the line of action of the roller resultant load and a plane perpendicular to the axis of the bearing, and

f_0 = 21.6, for bearings made of hardened steel.

3. For thrust ball bearings, the basic static axial load rating is given by

$$C_0 = f_0.Z.D^2 \sin \alpha$$

where Z = Number of balls carrying thrust in one direction, and

f_0 = 49, for bearings made of hardened steel.

4. For thrust roller bearings, the basic static axial load rating is given by

$$C_0 = f_0.Z.l_e.D.\sin \alpha$$

where Z = Number of rollers carrying thrust in one direction, and

f_0 = 98.1, for bearings made of hardened steel.

27.9 Static Equivalent Load for Rolling Contact Bearings

The static equivalent load may be defined as the static radial load (in case of radial ball or roller bearings) or axial load (in case of thrust ball or roller bearings) which, if applied, would cause the same total permanent deformation at the most heavily stressed ball (or roller) and race contact as that which occurs under the actual conditions of loading.

More cylindrical roller bearings

The static equivalent radial load (W_{0R}) for radial or roller bearings under combined radial and axial or thrust loads is given by the greater magnitude of those obtained by the following two equations, *i.e.*

1. $W_{0R} = X_0.W_R + Y_0.W_A$; and **2.** $W_{0R} = W_R$

where W_R = Radial load,

W_A = Axial or thrust load,

X_0 = Radial load factor, and

Y_0 = Axial or thrust load factor.

According to IS : 3824 – 1984, the values of X_0 and Y_0 for different bearings are given in the following table :

Table 27.2. Values of X_0 and Y_0 for radial bearings.

S.No.	Type of bearing	Single row bearing		Double row bearing	
		X_0	Y_0	X_0	Y_0
1.	Radial contact groove ball bearings	0.60	0.50	0.60	0.50
2.	Self aligning ball or roller bearings and tapered roller bearing	0.50	0.22 cot θ	1	0.44 cot θ
3.	Angular contact groove bearings :				
	$\alpha = 15°$	0.50	0.46	1	0.92
	$\alpha = 20°$	0.50	0.42	1	0.84
	$\alpha = 25°$	0.50	0.38	1	0.76
	$\alpha = 30°$	0.50	0.33	1	0.66
	$\alpha = 35°$	0.50	0.29	1	0.58
	$\alpha = 40°$	0.50	0.26	1	0.52
	$\alpha = 45°$	0.50	0.22	1	0.44

Notes : 1. The static equivalent radial load (W_{0R}) is always greater than or equal to the radial load (W_R).

2. For two similar single row angular contact ball bearings, mounted 'face-to-face' or 'back-to-back', use the values of X_0 and Y_0 which apply to a double row angular contact ball bearings. For two or more similar single row angular contact ball bearings mounted 'in tandem', use the values of X_0 and Y_0 which apply to a single row angular contact ball bearings.

3. The static equivalent radial load (W_{0R}) for all cylindrical roller bearings is equal to the radial load (W_R).

4. The static equivalent axial or thrust load (W_{0A}) for thrust ball or roller bearings with angle of contact $\alpha \neq 90°$, under combined radial and axial loads is given by

$$W_{0A} = 2.3\, W_R.\tan\alpha + W_A$$

This formula is valid for all ratios of radial to axial load in the case of direction bearings. For single direction bearings, it is valid where $W_R / W_A \leq 0.44 \cot\alpha$.

5. The thrust ball or roller bearings with $\alpha = 90°$ can support axial loads only. The static equivalent axial load for this type of bearing is given by

$$W_{0A} = W_A$$

27.10 Life of a Bearing

The ***life*** of an individual ball (or roller) bearing may be defined as the number of revolutions (or hours at some given constant speed) which the bearing runs before the first evidence of fatigue develops in the material of one of the rings or any of the rolling elements.

The ***rating life*** of a group of apparently identical ball or roller bearings is defined as the number of revolutions (or hours at some given constant speed) that 90 per cent of a group of bearings will complete or exceed before the first evidence of fatigue develops (*i.e.* only 10 per cent of a group of bearings fail due to fatigue).

The term ***minimum life*** is also used to denote the rating life. It has been found that the life which 50 per cent of a group of bearings will complete or exceed is approximately 5 times the life which 90 per cent of the bearings will complete or exceed. In other words, we may say that the average life of a bearing is 5 times the rating life (or minimum life). It may be noted that the longest life of a single bearing is seldom longer than the 4 times the average life and the maximum life of a single bearing is about 30 to 50 times the minimum life.

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The life of bearings for various types of machines is given in the following table.

Table 27.3. Life of bearings for various types of machines.

S. No.	*Application of bearing*	*Life of bearing, in hours*
1.	Instruments and apparatus that are rarely used	
	(*a*) Demonstration apparatus, mechanism for operating sliding doors	500
	(*b*) Aircraft engines	1000 – 2000
2.	Machines used for short periods or intermittently and whose breakdown would not have serious consequences *e.g.* hand tools, lifting tackle in workshops, and operated machines, agricultural machines, cranes in erecting shops, domestic machines.	4000 – 8000
3.	Machines working intermittently whose breakdown would have serious consequences *e.g.* auxillary machinery in power stations, conveyor plant for flow production, lifts, cranes for piece goods, machine tools used frequently.	8000 – 12 000
4.	Machines working 8 hours per day and not always fully utilised *e.g.* stationary electric motors, general purpose gear units.	12 000 – 20 000
5.	Machines working 8 hours per day and fully utilised *e.g.* machines for the engineering industry, cranes for bulk goods, ventilating fans, counter shafts.	20 000 – 30 000
6.	Machines working 24 hours per day *e.g.* separators, compressors, pumps, mine hoists, naval vessels.	40 000 – 60 000
7.	Machines required to work with high degree of reliability 24 hours per day *e.g.* pulp and paper making machinery, public power plants, mine-pumps, water works.	100 000 – 200 000

27.11 Basic Dynamic Load Rating of Rolling Contact Bearings

The basic dynamic load rating is defined as the constant stationary radial load (in case of radial ball or roller bearings) or constant axial load (in case of thrust ball or roller bearings) which a group of apparently identical bearings with stationary outer ring can endure for a rating life of one million revolutions (which is equivalent to 500 hours of operation at 33.3 r.p.m.) with only 10 per cent failure.

The basic dynamic load rating (C) in newtons for ball and roller bearings may be obtained as discussed below :

1. According to IS: 3824 (Part 1)– 1983, the basic dynamic radial load rating for radial and angular contact ball bearings, except the filling slot type, with balls not larger than 25.4 mm in diameter, is given by

$$C = f_c (i \cos \alpha)^{0.7} Z^{2/3} . D^{1.8}$$

and for balls larger than 25.4 mm in diameter,

$$C = 3.647 f_c (i \cos \alpha)^{0.7} Z^{2/3} . D^{1.4}$$

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where f_c = A factor, depending upon the geometry of the bearing components, the accuracy of manufacture and the material used.

and *i*, *Z*, *D* and α have usual meanings as discussed in Art. 27.8.

Ball bearings

2. According to IS: 3824 (Part 2)–1983, the basic dynamic radial load rating for radial roller bearings is given by

$$C = f_c\,(i.l_e \cos\alpha)^{7/9}\, Z^{3/4}.\, D^{29/27}$$

3. According to IS: 3824 (Part 3)–1983, the basic dynamic axial load rating for single row, single or double direction thrust ball bearings is given as follows :

(*a*) For balls not larger than 25.4 mm in diameter and α = 90º,

$$C = f_c \,.\, Z^{2/3} \,.\, D^{1.8}$$

(*b*) For balls not larger than 25.4 mm in diameter and α ≠ 90º,

$$C = f_c\,(\cos\alpha)^{0.7} \tan\alpha.\, Z^{2/3} \,.\, D^{1.8}$$

(*c*) For balls larger than 25.4 mm in diameter and α = 90º

$$C = 3.647\, f_c \,.\, Z^{2/3} \,.\, D^{1.4}$$

(*d*) For balls larger than 25.4 mm in diameter and α ≠ 90º,

$$C = 3.647\, f_c\,(\cos\alpha)^{0.7} \tan\alpha \,.\, Z^{2/3} \,.\, D^{1.4}$$

4. According to IS: 3824 (Part 4)–1983, the basic dynamic axial load rating for single row, single or double direction thrust roller bearings is given by

$$C = f_c \,.\, l_e^{7/9} \,.\, Z^{3/4} \,.\, D^{29/27} \quad \text{... (when } \alpha = 90^\circ)$$

$$= f_c\,(l_e \cos\alpha)^{7/9} \tan\alpha.Z^{3/4}.\, D^{29/27} \quad \text{... (when } \alpha \neq 90^\circ)$$

27.12 Dynamic Equivalent Load for Rolling Contact Bearings

The dynamic equivalent load may be defined as the constant stationary radial load (in case of radial ball or roller bearings) or axial load (in case of thrust ball or roller bearings) which, if applied to a bearing with rotating inner ring and stationary outer ring, would give the same life as that which the bearing will attain under the actual conditions of load and rotation.

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The dynamic equivalent radial load (W) for radial and angular contact bearings, except the filling slot types, under combined constant radial load (W_R) and constant axial or thrust load (W_A) is given by

$$W = X \cdot V \cdot W_R + Y \cdot W_A$$

where V = A rotation factor,

= 1, for all types of bearings when the inner race is rotating,

= 1, for self-aligning bearings when inner race is stationary,

= 1.2, for all types of bearings except self-aligning, when inner race is stationary.

The values of radial load factor (X) and axial or thrust load factor (Y) for the dynamically loaded bearings may be taken from the following table:

Table 27.4. Values of *X* and *Y* for dynamically loaded bearings.

Type of bearing	*Specifications*	$\frac{W_A}{W_R} \le e$		$\frac{W_A}{W_R} > e$		*e*
		X	*Y*	*X*	*Y*	
Deep groove	$\frac{W_A}{C_0} = 0.025$				2.0	0.22
ball bearing	= 0.04				1.8	0.24
	= 0.07				1.6	0.27
	= 0.13	1	0	0.56	1.4	0.31
	= 0.25				1.2	0.37
	= 0.50				1.0	0.44
Angular contact ball bearings	Single row		0	0.35	0.57	1.14
	Two rows in tandem		0	0.35	0.57	1.14
	Two rows back to back	1	0.55	0.57	0.93	1.14
	Double row		0.73	0.62	1.17	0.86
Self-aligning bearings	Light series : for bores					
	10 – 20 mm		1.3		2.0	0.50
	25 – 35	1	1.7	6.5	2.6	0.37
	40 – 45		2.0		3.1	0.31
	50 – 65		2.3		3.5	0.28
	70 – 100		2.4		3.8	0.26
	105 – 110		2.3		3.5	0.28
	Medium series : for bores					
	12 mm		1.0	0.65	1.6	0.63
	15 – 20		1.2		1.9	0.52
	25 – 50		1.5		2.3	0.43
	55 – 90		1.6		2.5	0.39
Spherical roller bearings	For bores :					
	25 – 35 mm		2.1		3.1	0.32
	40 – 45	1	2.5	0.67	3.7	0.27
	50 – 100		2.9		4.4	0.23
	100 – 200		2.6		3.9	0.26
Taper roller bearings	For bores :					
	30 – 40 mm				1.60	0.37
	45 – 110	1	0	0.4	1.45	0.44
	120 – 150				1.35	0.41

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27.13 Dynamic Load Rating for Rolling Contact Bearings under Variable Loads

The approximate rating (or service) life of ball or roller bearings is based on the fundamental equation,

$$L = \left(\frac{C}{W}\right)^k \times 10^6 \text{ revolutions}$$

or
$$C = W\left(\frac{L}{10^6}\right)^{1/k}$$

where L = Rating life,

C = Basic dynamic load rating,

W = Equivalent dynamic load, and

k = 3, for ball bearings,

= 10/3, for roller bearings.

Roller bearing

The relationship between the life in revolutions (L) and the life in working hours (L_H) is given by

$$L = 60\, N \,.\, L_H \text{ revolutions}$$

where N is the speed in r.p.m.

Now consider a rolling contact bearing subjected to variable loads. Let W_1, W_2, W_3 etc., be the loads on the bearing for successive n_1, n_2, n_3 etc., number of revolutions respectively.

If the bearing is operated exclusively at the constant load W_1, then its life is given by

$$L_1 = \left(\frac{C}{W_1}\right)^k \times 10^6 \text{ revolutions}$$

∴ Fraction of life consumed with load W_1 acting for n_1 number of revolutions is

$$\frac{n_1}{L_1} = n_1\left(\frac{W_1}{C}\right)^k \times \frac{1}{10^6}$$

Similarly, fraction of life consumed with load W_2 acting for n_2 number of revolutions is

$$\frac{n_2}{L_2} = n_2\left(\frac{W_2}{C}\right)^k \times \frac{1}{10^6}$$

and fraction of life consumed with load W_3 acting for n_3 number of revolutions is

$$\frac{n_3}{L_3} = n_3\left(\frac{W_3}{C}\right)^k \times \frac{1}{10^6}$$

But
$$\frac{n_1}{L_1} + \frac{n_2}{L_2} + \frac{n_3}{L_3} + \ldots = 1$$

or
$$n_1\left(\frac{W_1}{C}\right)^k \times \frac{1}{10^6} + n_2\left(\frac{W_2}{C}\right)^k \times \frac{1}{10^6} + n_3\left(\frac{W_3}{C}\right)^k \times \frac{1}{10^6} + \ldots = 1$$

$$\therefore\; n_1(W_1)^k + n_2(W_2)^k + n_3(W_3)^k + \ldots = C^k \times 10^6 \qquad \ldots(i)$$

If an equivalent constant load (W) is acting for n number of revolutions, then

$$n = \left(\frac{C}{W}\right)^k \times 10^6$$

$$\therefore \qquad n\,(W)^k = C^k \times 10^6 \qquad ...(ii)$$

where $\qquad n = n_1 + n_2 + n_3 + ...$

From equations (*i*) and (*ii*), we have

$$n_1\,(W_1)^k + n_2\,(W_2)^k + n_3\,(W_3)^k + ... = n\,(W)^k$$

$$\therefore \qquad W = \left[\frac{n_1\,(W_1)^k + n_2\,(W_2)^k + n_3\,(W_3)^k + ...}{n}\right]^{1/k}$$

Substituting $n = n_1 + n_2 + n_3 + ...$, and $k = 3$ for ball bearings, we have

$$W = \left[\frac{n_1\,(W_1)^3 + n_2\,(W_2)^3 + n_3\,(W_3)^3 + ...}{n_1 + n_2 + n_3 + ...}\right]^{1/3}$$

Note : The above expression may also be written as

$$W = \left[\frac{L_1\,(W_1)^3 + L_2\,(W_2)^3 + L_3\,(W_3)^3 + ...}{L_1 + L_2 + L_3 + ...}\right]^{1/3}$$

See Example 27.6.

27.14 Reliability of a Bearing

We have already discussed in the previous article that the rating life is the life that 90 per cent of a group of identical bearings will complete or exceed before the first evidence of fatigue develops. The reliability (R) is defined as the ratio of the number of bearings which have successfully completed L million revolutions to the total number of bearings under test. Sometimes, it becomes necessary to select a bearing having a reliability of more than 90%. According to Wiebull, the relation between the bearing life and the reliability is given as

$$\log_e\left(\frac{1}{R}\right) = \left(\frac{L}{a}\right)^b \qquad \text{or} \qquad \frac{L}{a} = \left[\log_e\left(\frac{1}{R}\right)\right]^{1/b} \qquad ...(i)$$

where L is the life of the bearing corresponding to the desired reliability R and a and b are constants whose values are

$$a = 6.84, \quad \text{and} \quad b = 1.17$$

If L_{90} is the life of a bearing corresponding to a reliability of 90% (*i.e.* R_{90}), then

$$\frac{L_{90}}{a} = \left[\log_e\left(\frac{1}{R_{90}}\right)\right]^{1/b} \qquad ...(ii)$$

Dividing equation (*i*) by equation (*ii*), we have

$$\frac{L}{L_{90}} = \left[\frac{\log_e\,(1/R)}{\log_e\,(1/R_{90})}\right]^{1/b} = {}^{*}6.85\,[\log_e\,(1/R)]^{1/1.17} \qquad ...(\because\ b = 1.17)$$

This expression is used for selecting the bearing when the reliability is other than 90%.

Note : If there are n number of bearings in the system each having the same reliability R, then the reliability of the complete system will be

$$R_S = R_p$$

where R_S indicates the probability of one out of p number of bearings failing during its life time.

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* $[\log_e\,(1/R_{90})]^{1/b} = [\log_e\,(1/0.90)]^{1/1.17} = (0.10536)^{0.8547} = 0.146$

$$\therefore \qquad \frac{L}{L_{90}} = \frac{[\log_e(1/R)]^{1/b}}{0.146} = 6.85\,[\log_e\,(1/R)]^{1/1.17}$$

Example 27.1. *A shaft rotating at constant speed is subjected to variable load. The bearings supporting the shaft are subjected to stationary equivalent radial load of 3 kN for 10 per cent of time, 2 kN for 20 per cent of time, 1 kN for 30 per cent of time and no load for remaining time of cycle. If the total life expected for the bearing is 20 × 10⁶ revolutions at 95 per cent reliability, calculate dynamic load rating of the ball bearing.*

Solution. Given : $W_1 = 3$ kN ; $n_1 = 0.1\,n$; $W_2 = 2$ kN ; $n_2 = 0.2\,n$; $W_3 = 1$ kN ; $n_3 = 0.3\,n$; $W_4 = 0$; $n_4 = (1 - 0.1 - 0.2 - 0.3)\,n = 0.4\,n$; $L_{95} = 20 \times 10^6$ rev

Let L_{90} = Life of the bearing corresponding to reliability of 90 per cent,

L_{95} = Life of the bearing corresponding to reliability of 95 per cent

$= 20 \times 10^6$ revolutions ... (Given)

We know that

$$\frac{L_{95}}{L_{90}} = \left[\frac{\log_e (1/R_{95})}{\log_e (1/R_{90})}\right]^{1/b} = \left[\frac{\log_e (1/0.95)}{\log_e (1/0.90)}\right]^{1/1.17} \quad \text{... } (\because b = 1.17)$$

$$= \left(\frac{0.0513}{0.1054}\right)^{0.8547} = 0.54$$

$\therefore$ $L_{90} = L_{95} / 0.54 = 20 \times 10^6 / 0.54 = 37 \times 10^6$ rev

We know that equivalent radial load,

$$W = \left[\frac{n_1 (W_1)^3 + n_2 (W_2)^3 + n_3 (W_3)^3 + n_4 (W_4)^3}{n_1 + n_2 + n_3 + n_4}\right]^{1/3}$$

$$= \left[\frac{0.1n \times 3^3 + 0.2\,n \times 2^3 + 0.3n \times 1^3 + 0.4\,n \times 0^3}{0.1\,n + 0.2n + 0.3n + 0.4n}\right]^{1/3}$$

$$= (2.7 + 1.6 + 0.3 + 0)^{1/3} = 1.663 \text{ kN}$$

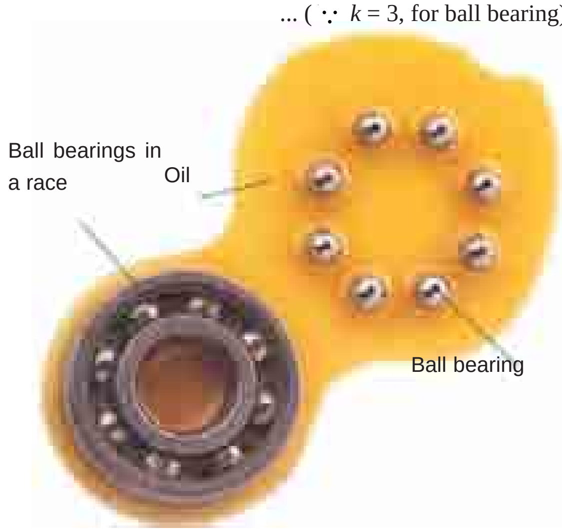
We also know that dynamic load rating,

$$C = W\left(\frac{L_{90}}{10^6}\right)^{1/k} = 1.663\left(\frac{37 \times 10^6}{10^6}\right)^{1/3} = 5.54 \text{ kN } \textbf{Ans.}$$

... ($\because$ $k = 3$, for ball bearing)

Example 27.2. *The rolling contact ball bearing are to be selected to support the overhung countershaft. The shaft speed is 720 r.p.m. The bearings are to have 99% reliability corresponding to a life of 24 000 hours. The bearing is subjected to an equivalent radial load of 1 kN. Consider life adjustment factors for operating condition and material as 0.9 and 0.85 respectively. Find the basic dynamic load rating of the bearing from manufacturer's catalogue, specified at 90% reliability.*

Solution. Given : $N = 720$ r.p.m. ; $L_H = 24\,000$ hours ; $W = 1$ kN



Another view of ball-bearings

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We know that life of the bearing corresponding to 99% reliability,

$$L_{99} = 60\ N.\ L_H = 60 \times 720 \times 24\ 000 = 1036.8 \times 10^6 \text{ rev}$$

Let L_{90} = Life of the bearing corresponding to 90% reliability.

Considering life adjustment factors for operating condition and material as 0.9 and 0.85 respectively, we have

$$\frac{L_{99}}{L_{90}} = \left[\frac{\log_e (1/R_{99})}{\log_e (1/R_{90})}\right]^{1/b} \times 0.9 \times 0.85 = \left[\frac{\log_e (1/0.99)}{\log_e (1/0.9)}\right]^{1/1.17} \times 0.9 \times 0.85$$

$$= \left[\frac{0.01005}{0.1054}\right]^{0.8547} \times 0.9 \times 0.85 = 0.1026$$

$$\therefore \quad L_{90} = L_{99} / 0.1026 = 1036.8 \times 10^6 / 0.1026 = 10\ 105 \times 10^6 \text{ rev}$$

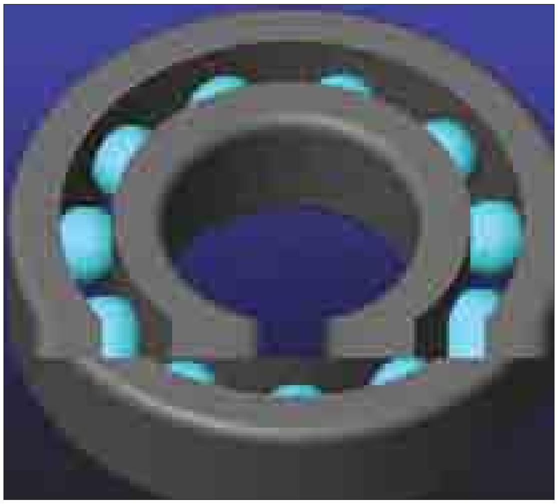
We know that dynamic load rating,

$$C = W\left(\frac{L_{90}}{10^6}\right)^{1/k}$$

$$= 1\left(\frac{10\ 105 \times 10^6}{10^6}\right)^{1/3} \text{ kN}$$

... ($\because$ k = 3, for ball bearing)

= 21.62 kN **Ans.**



Radial ball bearings

27.15 Selection of Radial Ball Bearings

In order to select a most suitable ball bearing, first of all, the basic dynamic radial load is calculated. It is then multiplied by the service factor (K_S) to get the design basic dynamic radial load capacity. The service factor for the ball bearings is shown in the following table.

Table 27.5. Values of service factor (K_S).

S.No.	*Type of service*	*Service factor (K_S) for radial ball bearings*
1.	Uniform and steady load	1.0
2.	Light shock load	1.5
3.	Moderate shock load	2.0
4.	Heavy shock load	2.5
5.	Extreme shock load	3.0

After finding the design basic dynamic radial load capacity, the selection of bearing is made from the catalogue of a manufacturer. The following table shows the basic static and dynamic capacities for various types of ball bearings.

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Table 27.6. Basic static and dynamic capacities of various types of radial ball bearings.

Bearing No.	Basic capacities in kN							
	Single row deep groove ball bearing		Single row angular contact ball bearing		Double row angular contact ball bearing		Self-aligning ball bearing	
	Static (C_0)	Dynamic (C)	Static (C_0)	Dynamic (C)	Static (C_0)	Dynamic (C)	Static (C_0)	Dynamic (C)
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
200	2.24	4	—	—	4.55	7.35	1.80	5.70
300	3.60	6.3	—	—	—	—	—	—
201	3	5.4	—	—	5.6	8.3	2.0	5.85
301	4.3	7.65	—	—	—	—	3.0	9.15
202	3.55	6.10	3.75	6.30	5.6	8.3	2.16	6
302	5.20	8.80	—	—	9.3	14	3.35	9.3
203	4.4	7.5	4.75	7.8	8.15	11.6	2.8	7.65
303	6.3	10.6	7.2	11.6	12.9	19.3	4.15	11.2
403	11	18	—	—	—	—	—	—
204	6.55	10	6.55	10.4	11	16	3.9	9.8
304	7.65	12.5	8.3	13.7	14	19.3	5.5	14
404	15.6	24	—	—	—	—	—	—
205	7.1	11	7.8	11.6	13.7	17.3	4.25	9.8
305	10.4	16.6	12.5	19.3	20	26.5	7.65	19
405	19	28	—	—	—	—	—	—
206	10	15.3	11.2	16	20.4	25	5.6	12
306	14.6	22	17	24.5	27.5	35.5	10.2	24.5
406	23.2	33.5	—	—	—	—	—	—
207	13.7	20	15.3	21.2	28	34	8	17
307	17.6	26	20.4	28.5	36	45	13.2	30.5
407	30.5	43	—	—	—	—	—	—
208	16	22.8	19	25	32.5	39	9.15	17.6
308	22	32	25.5	35.5	45.5	55	16	35.5
408	37.5	50	—	—	—	—	—	—
209	18.3	25.5	21.6	28	37.5	41.5	10.2	18
309	30	41.5	34	45.5	56	67	19.6	42.5
409	44	60	—	—	—	—	—	—
210	21.2	27.5	23.6	29	43	47.5	10.8	18
310	35.5	48	40.5	53	73.5	81.5	24	50
410	50	68	—	—	—	—	—	—

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(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
211 311 411	26 42.5 60	34 56 78	30 47.5 —	36.5 62 —	49 80 —	53 88 —	12.7 28.5 —	20.8 58.5 —
212 312 412	32 48 67	40.5 64 85	36.5 55 —	44 71 —	63 96.5 —	65.5 102 —	16 33.5 —	26.5 68 —
213 313 413	35.5 55 76.5	44 72 93	43 63 —	50 80 —	69.5 112 —	69.5 118 —	20.4 39 —	34 75 —
214 314 414	39 63 102	48 81.5 112	47.5 73.5 —	54 90 —	71 129 —	69.5 137 —	21.6 45 —	34.5 85 —
215 315 415	42.5 72 110	52 90 120	50 81.5 —	56 98 —	80 140 —	76.5 143 —	22.4 52 —	34.5 95 —
216 316 416	45.5 80 120	57 96.5 127	57 91.5 —	63 106 —	96.5 160 —	93 163 —	25 58.5 —	38 106 —
217 317 417	55 88 132	65.5 104 134	65.5 102 —	71 114 —	100 180 —	106 180 —	30 62 —	45.5 110 —
218 318 418	63 98 146	75 112 146	76.5 114 —	83 122 —	127 — —	118 — —	36 69.5 —	55 118 —
219 319	72 112	85 120	88 125	95 132	150 —	137 —	43 —	65.5 —
220 320	81.5 132	96.5 137	93 153	102 150	160 —	146 —	51 —	76.5 —
221 321	93 143	104 143	104 166	110 160	— —	— —	56 —	85 —
222 322	104 166	112 160	116 193	120 176	— —	— —	64 —	98 —

Note: The reader is advised to consult the manufacturer's catalogue for further and complete details of the bearings.

Example 27.3. *Select a single row deep groove ball bearing for a radial load of 4000 N and an axial load of 5000 N, operating at a speed of 1600 r.p.m. for an average life of 5 years at 10 hours per day. Assume uniform and steady load.*

Solution. Given : W_R = 4000 N ; W_A = 5000 N ; N = 1600 r.p.m.

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Since the average life of the bearing is 5 years at 10 hours per day, therefore life of the bearing in hours,

$$L_H = 5 \times 300 \times 10 = 15\,000 \text{ hours} \quad \text{... (Assuming 300 working days per year)}$$

and life of the bearing in revolutions,

$$L = 60\, N \times L_H = 60 \times 1600 \times 15\,000 = 1440 \times 10^6 \text{ rev}$$

We know that the basic dynamic equivalent radial load,

$$W = X.V.W_R + Y.W_A \quad \text{...}(i)$$

In order to determine the radial load factor (X) and axial load factor (Y), we require W_A / W_R and W_A / C_0. Since the value of basic static load capacity (C_0) is not known, therefore let us take $W_A / C_0 = 0.5$. Now from Table 27.4, we find that the values of X and Y corresponding to $W_A / C_0 = 0.5$ and $W_A/W_R = 5000 / 4000 = 1.25$ (which is greater than $e = 0.44$) are

$$X = 0.56 \quad \text{and} \quad Y = 1$$

Since the rotational factor (V) for most of the bearings is 1, therefore basic dynamic equivalent radial load,

$$W = 0.56 \times 1 \times 4000 + 1 \times 5000 = 7240 \text{ N}$$

From Table 27.5, we find that for uniform and steady load, the service factor (K_S) for ball bearings is 1. Therefore the bearing should be selected for $W = 7240$ N.

We know that basic dynamic load rating,

$$C = W\left(\frac{L}{10^6}\right)^{1/k} = 7240\left(\frac{1440 \times 10^6}{10^6}\right)^{1/3} = 81\,760 \text{ N}$$

$$= 81.76 \text{ kN} \quad \text{... } (\because k = 3, \text{ for ball bearings})$$

From Table 27.6, let us select the bearing No. 315 which has the following basic capacities,

$$C_0 = 72 \text{ kN} = 72\,000 \text{ N} \quad \text{and} \quad C = 90 \text{ kN} = 90\,000 \text{ N}$$

Now $\quad W_A / C_0 = 5000 / 72\,000 = 0.07$

∴ From Table 27.4, the values of X and Y are

$$X = 0.56 \quad \text{and} \quad Y = 1.6$$

Substituting these values in equation (*i*), we have dynamic equivalent load,

$$W = 0.56 \times 1 \times 4000 + 1.6 \times 5000 = 10\,240 \text{ N}$$

∴ Basic dynamic load rating,

$$C = 10\,240\left(\frac{1440 \times 10^6}{10^6}\right)^{1/3} = 115\,635 \text{ N} = 115.635 \text{ kN}$$

From Table 27.6, the bearing number 319 having $C = 120$ kN, may be selected. **Ans.**

Example 27.4. *A single row angular contact ball bearing number 310 is used for an axial flow compressor. The bearing is to carry a radial load of 2500 N and an axial or thrust load of 1500 N. Assuming light shock load, determine the rating life of the bearing.*

Solution. Given : $W_R = 2500$ N ; $W_A = 1500$ N

From Table 27.4, we find that for single row angular contact ball bearing, the values of radial factor (X) and thrust factor (Y) for $W_A / W_R = 1500 / 2500 = 0.6$ are

$$X = 1 \quad \text{and} \quad Y = 0$$

Since the rotational factor (V) for most of the bearings is 1, therefore dynamic equivalent load,

$$W = X.V.W_R + Y.W_A = 1 \times 1 \times 2500 + 0 \times 1500 = 2500 \text{ N}$$

From Table 27.5, we find that for light shock load, the service factor (K_S) is 1.5. Therefore the design dynamic equivalent load should be taken as

$$W = 2500 \times 1.5 = 3750 \text{ N}$$

From Table 27.6, we find that for a single row angular contact ball bearing number 310, the basic dynamic capacity,

$$C = 53 \text{ kN} = 53\ 000 \text{ N}$$

We know that rating life of the bearing in revolutions,

$$L = \left(\frac{C}{W}\right)^k \times 10^6 = \left(\frac{53\ 000}{3750}\right)^3 \times 10^6 = 2823 \times 10^6 \text{ rev} \quad \textbf{Ans.}$$

... ($\because$ k = 3, for ball bearings)

Example 27.5. *Design a self-aligning ball bearing for a radial load of 7000 N and a thrust load of 2100 N. The desired life of the bearing is 160 millions of revolutions at 300 r.p.m. Assume uniform and steady load,*

Solution. Given : W_R = 7000 N ; W_A = 2100 N ; $L = 160 \times 10^6$ rev ; N = 300 r.p.m.

From Table 27.4, we find that for a self-aligning ball bearing, the values of radial factor (X) and thrust factor (Y) for W_A / W_R = 2100 / 7000 = 0.3, are as follows :

$$X = 0.65 \quad \text{and} \quad Y = 3.5$$

Since the rotational factor (V) for most of the bearings is 1, therefore dynamic equivalent load,

$$W = X.V.W_R + Y.W_A = 0.65 \times 1 \times 7000 + 3.5 \times 2100 = 11\ 900 \text{ N}$$

From Table 27.5, we find that for uniform and steady load, the service factor K_S for ball bearings is 1. Therefore the bearing should be selected for W = 11 900 N.

We know that the basic dynamic load rating,

$$C = W\left(\frac{L}{10^6}\right)^{1/k} = 11\ 900\left(\frac{160 \times 10^6}{10^6}\right)^{1/3} = 64\ 600 \text{ N} = 64.6 \text{ kN}$$

... ($\because$ k = 3, for ball bearings)

From Table 27.6, let us select bearing number 219 having C = 65.5 kN **Ans.**

Example 27.6. *Select a single row deep groove ball bearing with the operating cycle listed below, which will have a life of 15 000 hours.*

Fraction of cycle	*Type of load*	*Radial (N)*	*Thrust (N)*	*Speed (R.P.M.)*	*Service factor*
1/10	*Heavy shocks*	*2000*	*1200*	*400*	*3.0*
1/10	*Light shocks*	*1500*	*1000*	*500*	*1.5*
1/5	*Moderate shocks*	*1000*	*1500*	*600*	*2.0*
3/5	*No shock*	*1200*	*2000*	*800*	*1.0*

Assume radial and axial load factors to be 1.0 and 1.5 respectively and inner race rotates.

Solution. Given : L_H = 15 000 hours ; W_{R1} = 2000 N ; W_{A1} = 1200 N ; N_1 = 400 r.p.m. ; K_{S1} = 3 ; W_{R2} = 1500 N ; W_{A2} = 1000 N ; N_2 = 500 r.p.m. ; K_{S2} = 1.5 ; W_{R3} = 1000 N ; W_{A3} = 1500 N ; N_3 = 600 r.p.m. ; K_{S3} = 2 ; W_{R4} = 1200 N ; W_{A4} = 2000 N ; N_4 = 800 r.p.m. ; K_{S4} = 1 ; X = 1 ; Y = 1.5

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We know that basic dynamic equivalent radial load considering service factor is

$$W = [X.V.W_R + Y.W_A]\,K_S \qquad ...(i)$$

It is given that radial load factor (X) = 1 and axial load factor (Y) = 1.5. Since the rotational factor (V) for most of the bearings is 1, therefore equation (*i*) may be written as

$$W = (W_R + 1.5\,W_A)\,K_S$$

Now, substituting the values of W_R, W_A and K_S for different operating cycle, we have

$$W_1 = (W_{R1} + 1.5\,W_{A1})\,K_{S1} = (2000 + 1.5 \times 1200)\,3 = 11\,400 \text{ N}$$

$$W_2 = (W_{R2} + 1.5\,W_{A2})\,K_{S2} = (1500 + 1.5 \times 1000)\,1.5 = 4500 \text{ N}$$

$$W_3 = (W_{R3} + 1.5\,W_{A3})\,K_{S3} = (1000 + 1.5 \times 1500)\,2 = 6500 \text{ N}$$

and

$$W_4 = (W_{R4} + 1.5\,W_{A4})\,K_{S4} = (1200 + 1.5 \times 2000)\,1 = 4200 \text{ N}$$

We know that life of the bearing in revolutions

$$L = 60\,N.L_H = 60\,N \times 15\,000 = 0.9 \times 10^6\,N \text{ rev}$$

∴ Life of the bearing for 1/10 of a cycle,

$$L_1 = \frac{1}{10} \times 0.9 \times 10^6\,N_1 = \frac{1}{10} \times 0.9 \times 10^6 \times 400 = 36 \times 10^6 \text{ rev}$$

Similarly, life of the bearing for the next 1/10 of a cycle,

$$L_2 = \frac{1}{10} \times 0.9 \times 10^6\,N_2 = \frac{1}{10} \times 0.9 \times 10^6 \times 500 = 45 \times 10^6 \text{ rev}$$

Life of the bearing for the next 1/5 of a cycle,

$$L_3 = \frac{1}{5} \times 0.9 \times 10^6\,N_3 = \frac{1}{5} \times 0.9 \times 10^6 \times 600 = 108 \times 10^6 \text{ rev}$$

and life of the bearing for the next 3/5 of a cycle,

$$L_4 = \frac{3}{5} \times 0.9 \times 10^6\,N_4 = \frac{3}{5} \times 0.9 \times 10^6 \times 800 = 432 \times 10^6 \text{ rev}$$

We know that equivalent dynamic load,

$$W = \left[\frac{L_1 (W_1)^3 + L_2 (W_2)^3 + L_3 (W_3)^3 + L_4 (W_4)^3}{L_1 + L_2 + L_3 + L_4}\right]^{1/3}$$

$$= \left[\frac{36 \times 10^6 (11\,400)^3 + 45 \times 10^6 (4500)^3 + 108 \times 10^6 (6500)^3 + 432 \times 10^6\ (4200)^3}{36 \times 10^6 + 45 \times 10^6 + 108 \times 10^6 + 423 \times 10^6}\right]^{1/3}$$

$$= \left[\frac{1.191 \times 10^8 \times 10^{12}}{621 \times 10^6}\right]^{1/3} = (0.1918 \times 10^{12})^{1/3} = 5767 \text{ N}$$

and

$$L = L_1 + L_2 + L_3 + L_4$$

$$= 36 \times 10^6 + 45 \times 10^6 + 108 \times 10^6 + 432 \times 10^6 = 621 \times 10^6 \text{ rev}$$

We know that dynamic load rating,

$$C = W \left(\frac{L}{10^6}\right)^{1/k} = 5767 \left(\frac{621 \times 10^6}{10^6}\right)^{1/3}$$

$$= 5767 \times 8.53 = 49\,193 \text{ N} = 49.193 \text{ kN}$$

From Table 27.6, the single row deep groove ball bearing number 215 having C = 52 kN may be selected. **Ans.**

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27.16 Materials and Manufacture of Ball and Roller Bearings

Since the rolling elements and the races are subjected to high local stresses of varying magnitude with each revolution of the bearing, therefore the material of the rolling element (*i.e.* steel) should be of high quality. The balls are generally made of high carbon chromium steel. The material of both the balls and races are heat treated to give extra hardness and toughness.

Ball and Roller Bearings

The balls are manufactured by hot forging on hammers from steel rods. They are then heat-treated, ground and polished. The races are also formed by forging and then heat-treated, ground and polished.

27.17 Lubrication of Ball and Roller Bearings

The ball and roller bearings are lubricated for the following purposes :

1. To reduce friction and wear between the sliding parts of the bearing,

2. To prevent rusting or corrosion of the bearing surfaces,

3. To protect the bearing surfaces from water, dirt etc., and

4. To dissipate the heat.

In general, oil or light grease is used for lubricating ball and roller bearings. Only pure mineral oil or a calcium-base grease should be used. If there is a possibility of moisture contact, then potassium or sodium-base greases may be used. Another additional advantage of the grease is that it forms a seal to keep out dirt or any other foreign substance. It may be noted that too much oil or grease cause the temperature of the bearing to rise due to churning. The temperature should be kept below 90ºC and in no case a bearing should operate above 150ºC.

EXERCISES

1. The ball bearings are to be selected for an application in which the radial load is 2000 N during 90 per cent of the time and 8000 N during the remaining 10 per cent. The shaft is to rotate at 150 r.p.m. Determine the minimum value of the basic dynamic load rating for 5000 hours of operation with not more than 10 per cent failures. **[Ans. 13.8 kN]**

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2. A ball bearing subjected to a radial load of 5 kN is expected to have a life of 8000 hours at 1450 r.p.m. with a reliability of 99%. Calculate the dynamic load capacity of the bearing so that it can be selected from the manufacturer's catalogue based on a reliability of 90%. **[Ans. 86.5 kN]**
3. A ball bearing subjected to a radial load of 4000 N is expected to have a satisfactory life of 12 000 hours at 720 r.p.m. with a reliability of 95%. Calculate the dynamic load carrying capacity of the bearing, so that it can be selected from manufacturer's catalogue based on 90% reliability. If there are four such bearings each with a reliability of 95% in a system, what is the reliability of the complete system? **[Ans. 39.5 kN ; 81.45%]**
4. A rolling contact bearing is subjected to the following work cycle :

   (*a*) Radial load of 6000 N at 150 r.p.m. for 25% of the time; (*b*) Radial load of 7500 N at 600 r.p.m. for 20% of the time; and (*c*) Radial load of 2000 N at 300 r.p.m. for 55% of the time.

   The inner ring rotates and loads are steady. Select a bearing for an expected average life of 2500 hours.
5. A single row deep groove ball bearing operating at 2000 r.p.m. is acted by a 10 kN radial load and 8 kN thrust load. The bearing is subjected to a light shock load and the outer ring is rotating. Determine the rating life of the bearing. **[Ans. 15.52 × 10^6 rev]**
6. A ball bearing operates on the following work cycle :

Element No.	*Radial load (N)*	*Speed (R.P.M.)*	*Element time (%)*
1	3000	720	30
2.	7000	1440	40
3.	5000	900	30

The dynamic load capacity of the bearing is 16 600 N. Calculate 1. the average speed of rotation ; 2. the equivalent radial load ; and 3. the bearing life.

[Ans. 1062 r.p.m. ; 6.067 kN ; 20.5 × 10^6 rev]

QUESTIONS

1. What are rolling contact bearings? Discuss their advantages over sliding contact bearings.
2. Write short note on classifications and different types of antifriction bearings.
3. Where are the angular contact and self-aligning ball bearings used? Draw neat sketches of these bearings.
4. How do you express the life of a bearing? What is an average or median life?
5. Explain how the following factors influence the life of a bearing:

   (*a*) Load (*b*) Speed (*c*) Temperature (*d*) Reliability
6. Define the following terms as applied to rolling contact bearings:

   (*a*) Basic static load rating (*b*) Static equivalent load

   (c) Basic dynamic load rating (*d*) Dynamic equivalent load.
7. Derive the following expression as applied to rolling contact bearings subjected to variable load cycle

$$W_e = \sqrt[3]{\frac{N_1 (W_1)^3 + N_2 (W_2)^3 + N_3 (W_3)^3 + ...}{N_1 + N_2 + N_3 + ...}}$$

where W_e = Equivalent cubic load,

W_1, W_2 and W_3 = Loads acting respectively for N_1, N_2, N_3 ....

8. Select appropriate type of rolling contact bearing under the following condition of loading giving reasons for your choice.
   1. Light radial load with high rotational speed.
   2. Heavy axial and radial load with shock.
   3. Light load where radial space is very limited.
   4. Axial thrust only with medium speed.

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OBJECTIVE TYPE QUESTIONS

1. The rolling contact bearings are known as
   (*a*) thick lubricated bearings (*b*) plastic bearings
   (*c*) thin lubricated bearings (*d*) antifriction bearings
2. The bearings of medium series have capacity .... over the light series.
   (*a*) 10 to 20% (*b*) 20 to 30%
   (*c*) 30 to 40% (*d*) 40 to 50%
3. The bearings of heavy series have capacity .... over the medium series.
   (*a*) 10 to 20% (*b*) 20 to 30%
   (*c*) 30 to 40% (*d*) 40 to 50%
4. The ball bearings are usually made from
   (*a*) low carbon steel
   (*b*) medium carbon steel
   (*c*) high speed steel
   (*d*) chrome nickel steel
5. The tapered roller bearings can take
   (*a*) radial load only
   (*b*) axial load only
   (*c*) both radial and axial loads
   (*d*) none of the above
6. The piston pin bearings in heavy duty diesel engines are
   (*a*) needle roller bearings
   (*b*) tapered roller bearings
   (*c*) spherical roller bearings
   (*d*) cylindrical roller bearings
7. Which of the following is antifriction bearing?
   (*a*) journal bearing
   (*b*) pedestal bearing
   (*c*) collar bearing
   (*d*) needle bearing

Ball bearing

8. Ball and roller bearings in comparison to sliding bearings have
   (*a*) more accuracy in alignment (*b*) small overall dimensions
   (*c*) low starting and running friction (*d*) all of these
9. A bearing is designated by the number 405. It means that a bearing is of
   (*a*) light series with bore of 5 mm (*b*) medium series with bore of 15 mm
   (*c*) heavy series with bore of 25 mm (*d*) light series with width of 20 mm
10. The listed life of a rolling bearing, in a catalogue, is the
   (*a*) minimum expected life (*b*) maximum expected life
   (*c*) average life (*d*) none of these

ANSWERS

1. (*d*)	**2.** (*c*)	**3.** (*b*)	**4.** (*d*)	**5.** (*c*)
6. (*a*)	**7.** (*d*)	**8.** (*d*)	**9.** (*c*)	**10.** (*a*)