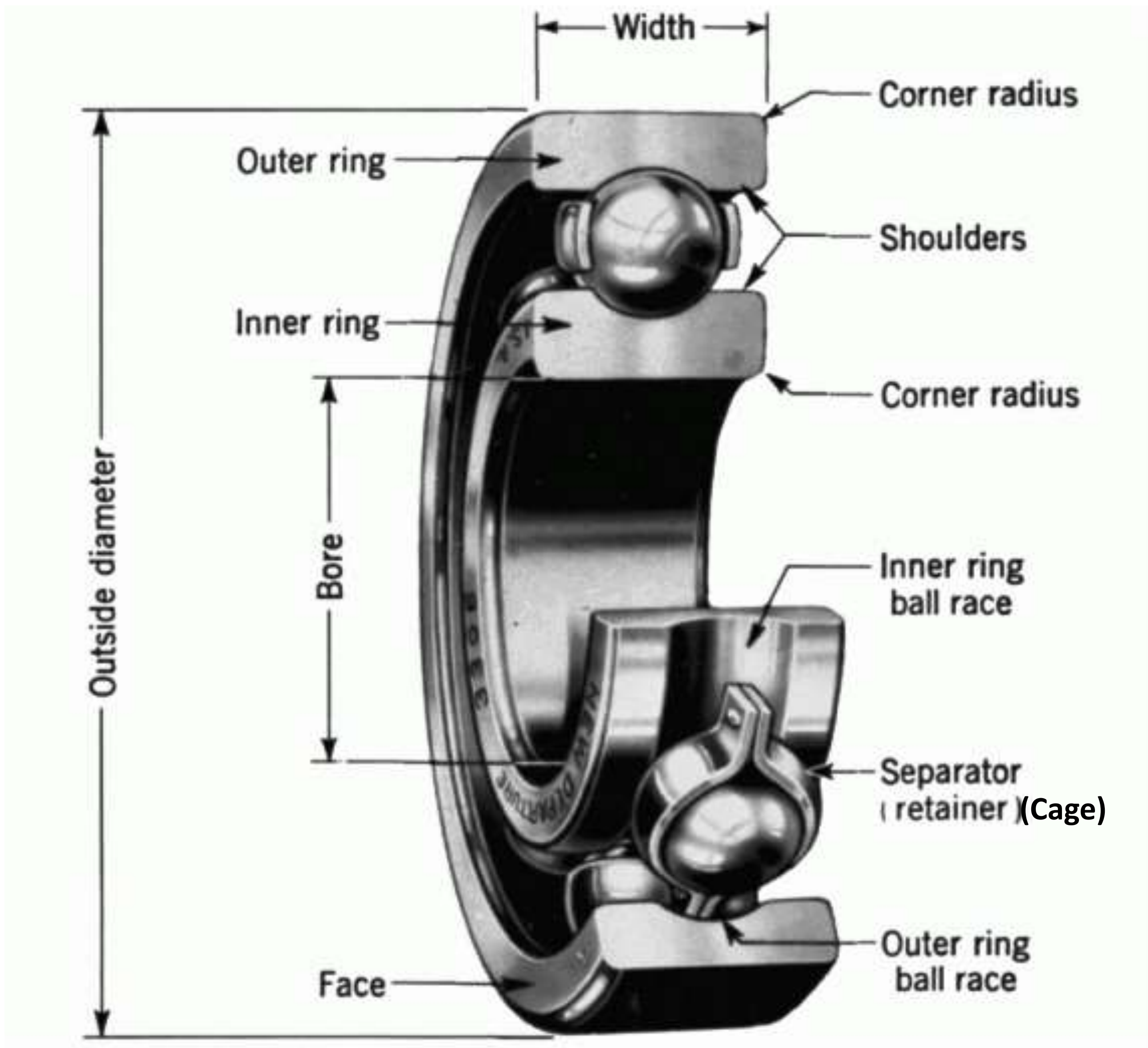
Bearings

A bearing is a key machine element that constrains relative motion between moving parts to only the desired motion.

- Rolling contact bearing (Anti –friction bearing)

- Sliding contact bearing (Journal bearing or sleeve bearing)

Rolling Contact Bearing



- The arrival of the automobile high-speed engines and automatic production machinery provided the impulse for extensive research and development of the rolling bearings, also called the anti-friction bearings.

- In rolling contact bearings, the contact between the bearing surfaces is rolling instead of sliding as in sliding contact bearings. Sliding contact 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.***

The advantages of rolling bearings compared to journal bearings are:

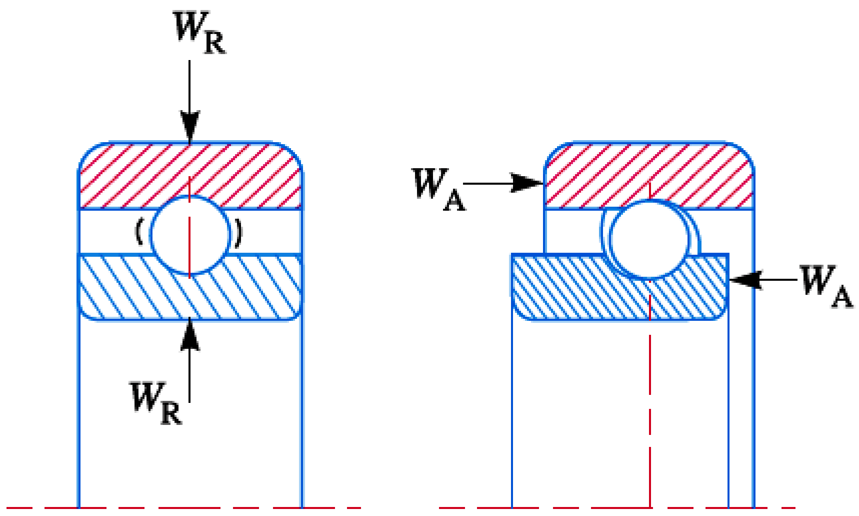
1. Starting friction torque is about twice the running frictional torque, but still it is negligible in comparison to starting friction of a sleeve bearing (Sliding Bearing).
2. Ease of lubrication either with grease or with relatively simple systems.
3. Less axial space for a comparable shaft diameter.
4. Capable of supporting both radial and thrust loads.
5. Early warning of impending failure signaled by increasing noisiness at the same speed of rotation.
6. Standardization and close tolerances make preferable their use in precision machinery.
7. Easy to mount and erect.
8. Cleanliness.

The disadvantages of rolling bearings as compared to journal bearings are:

1. Greater diametrical space required for a comparable shaft diameter.
2. Initial cost is usually higher.
3. Noisier in normal operation.
4. Finite life due to failure by fatigue.
5. Lesser capacity to withstand shock.

Classification

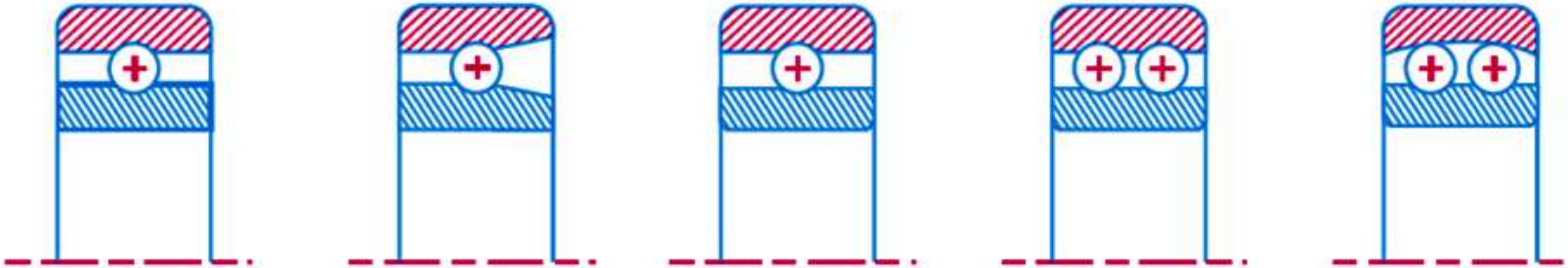
- Ball bearing (Radial and Thrust)
- Roller bearing (Radial and Thrust)



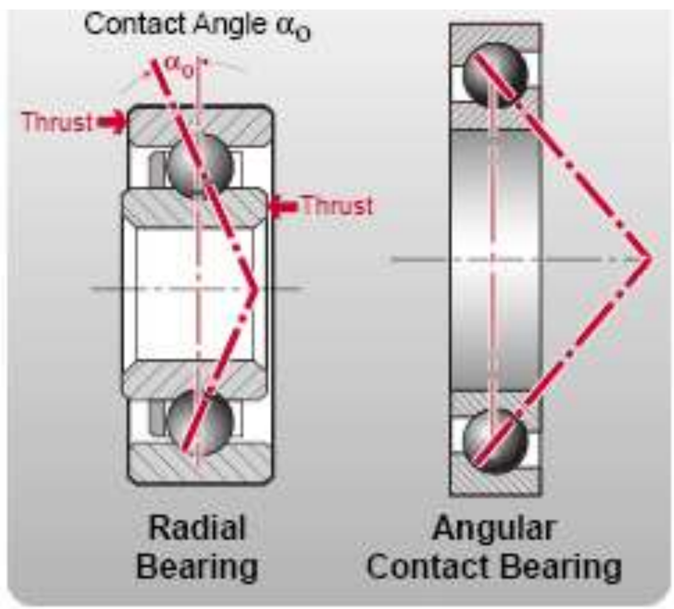
(*a*) Radial bearing.   (*b*) Thrust bearing.

Ball Bearing

- Radial Ball Bearing (When radial load is severe)



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



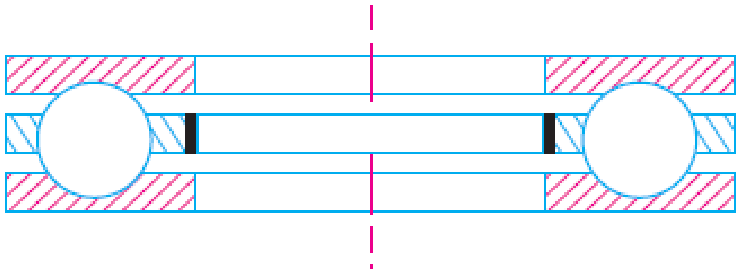
(a) Angular contact bearing

(b) Self aligning

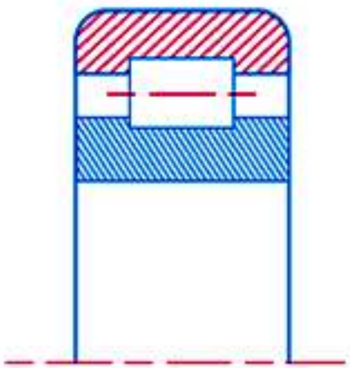
- The balls are inserted into the grooves by moving the inner ring to the eccentric position in deep groove ball bearing.
- Radial load capacity of filling notch bearing can be increased be inserting balls, but thrust load capacity decreases due to bumping of the balls against the edge of the notch.
- Sealed bearing - lubricated at factory.
- Shielded bearing – protect against the dirt.

Thrust Ball Bearing (When thrust load is severe)

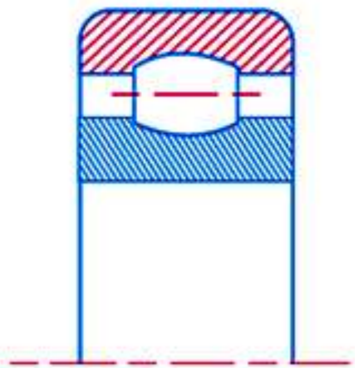
- The thrust ball bearings are used for carrying **thrust loads exclusively and at speeds below 2000 r.p.m**. At high speeds, centrifugal force causes the balls to be forced out of the races. Therefore **at high speeds**, it is recommended that **angular contact ball bearings** should be used in place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



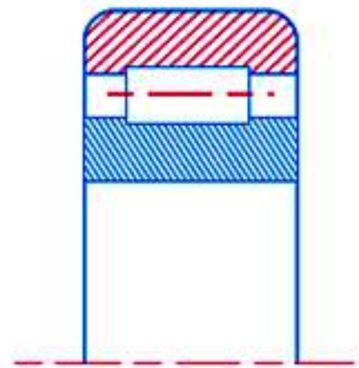
Roller Bearing



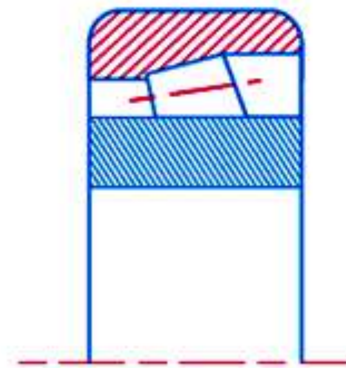
(*a*) Cylindrical roller.



(*b*) Spherical roller.



(*c*) Needle roller.



(*d*) Tapered roller.

Angle of taper is 25^{o}

- Needle bearings are very useful where radial space is limited. They may be used without separators and races.

Selection of Bearing type

- For low and medium radial loads, ball bearings are used, whereas for heavy loads and large shaft diameters, roller bearings are selected.
- Self-aligning ball bearings and spherical roller bearings are used in applications where a misalignment between the axes of shaft and housing is likely to exist.
- Thrust ball bearings are used for medium thrust loads whereas for heavy thrust loads, cylindrical roller thrust bearings are recommended.
- Deep groove ball bearings, angular contact bearings and spherical roller bearings are suitable in applications where the loads acting on the bearing consists of two components- radial and thrust.
- Rigidity controls the selection of bearing in certain applications like machine tool spindles. Double row cylindrical roller bearings or taper roller bearings are used under these conditions. The line of contact of these bearings, as compared with the point of contact in ball bearings, improves the rigidity of the system.
- Noise becomes the criterion of selection in applications like household appliances. Under these circumstances, deep groove ball bearings are recommended.

Designations of Ball Bearings

- The bearings are designated by a **number.** In general, **the number consists of at least 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 millimeters. 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)

*e.g. If a bearing is designated by the number **305k,** it means that the bearing is of **medium series** whose **bore is** 05 × 5, i.e., **25 mm**. k means it is a taper roller bearing*

Static Load Rating or static load carrying capacity (C_0)

- The load carried by a non-rotating bearing is called a static load.
- The permanent deformation which appear in balls (or rollers) and race ways under static loads of moderate magnitude, increase gradually with increasing load. Therefore the permissible static load is 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.
- 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.
- It is given by ***Stribeck's equation***.

1. For radial ball bearings,

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

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,

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

i = Number of rows of rollers in the bearing

Z = Number of rollers per row,

l_e = Effective length of contact

It is equal to the overall length of roller ***minus*** roller chamfers or grinding undercuts,

f_0 = 21.6, for bearings made of hardened steel.

3. For thrust ball bearings,

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

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

f_0 = 49, for bearings made of hardened steel.

4. For thrust roller bearings,

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

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

f_0 = 98.1, for bearings made of hardened steel.

Static Equivalent radial Load (W_{0R})

- Greater of the two equations

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

W_R = Radial load,

W_A = Axial or thrust load,

X_0 = Radial load factor, and

Y_0 = Axial or thrust load factor.

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

Static Equivalent thrust Load (W_{0A})

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

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 percent** 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.

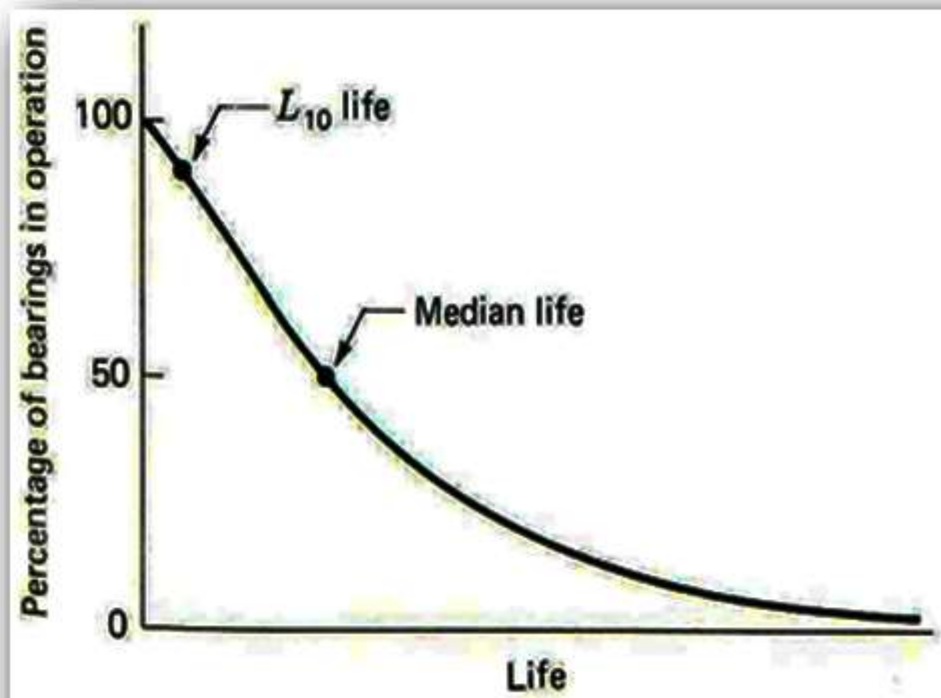


FIGURE Typical curve of bearing life expectancy.

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

Basic Dynamic Load Rating or load carrying capacity (C)

1. For radial ball bearings,

When balls are not larger than 25.4 mm in diameter.

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

for balls larger than 25.4 mm in diameter,

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

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

2. For radial roller bearings,

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

3. For thrust ball bearings,

(*a*) For balls not larger than 25.4 mm in diameter and $\alpha = 90°$,

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

(*b*) For balls not larger than 25.4 mm in diameter and $\alpha \neq 90°$,

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

(*c*) For balls larger than 25.4 mm in diameter and $\alpha = 90°$

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

(*d*) For balls larger than 25.4 mm in diameter and $\alpha \neq 90°$,

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

4. For thrust roller bearings,

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

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

Dynamic Equivalent Load (*W*)

$$W = X \, . \, V \, . \, W_R + Y \, . \, W_A$$

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.

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 ball bearing	$\frac{W_A}{C_0} = 0.025$	1	0	0.56	2.0	0.22
	$= 0.04$				1.8	0.24
	$= 0.07$				1.6	0.27
	$= 0.13$				1.4	0.31
	$= 0.25$				1.2	0.37
	$= 0.50$				1.0	0.44
Angular contact ball bearings	Single row	1	0	0.35	0.57	1.14
	Two rows in tandem		0	0.35	0.57	1.14
	Two rows back to back		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	1.3	6.5	2.0	0.50
	25 – 35		1.7		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

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*	
Spherical roller bearings	For bores :					
	25 – 35 mm	1	2.1	0.67	3.1	0.32
	40 – 45		2.5		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	0	0.4	1.60	0.37
	45 – 110				1.45	0.44
	120 – 150				1.35	0.41

Load-Life relationship

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

where

L = Rating life,

C = Basic dynamic load rating,

W = Equivalent dynamic load, and

k = 3, for ball bearings,

= 10/3, for roller bearings.

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

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

Service factor (K_s)

- The dynamic radial load is multiplied by the service factor (K_S) *to get the basic* dynamic radial load . The service factor for the ball bearings is shown in the following table.

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

Selection (Design)

- Calculate the basic dynamic load (W x K_s)
- Calculate the basic dynamic load capacity.
- Select the bearing from the catalogue.

Equivalent Dynamic Load for Rolling Contact Bearings under **Variable** Loads

Consider a rolling contact bearing subjected to variable loads W_1, W_2, W_3 *etc.* for successive *n1, n2, n3 etc. number of revolutions respectively.* If the bearing is operated at the constant load *W1, 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,

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

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

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

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

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

for equivalent load

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

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

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

From equation (i) and (ii)

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

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

and also

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

Reliability (Probability of survival)

- 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.*

According to Wiebull, the relation between the bearing life and the reliability is given as

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

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

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

$a = 6.84$, and $b = 1.17$

$$\frac{L}{L_{90}} = \left[\frac{\log_e(1/R)}{\log_e(1/R_{90})}\right]^{1/b}$$

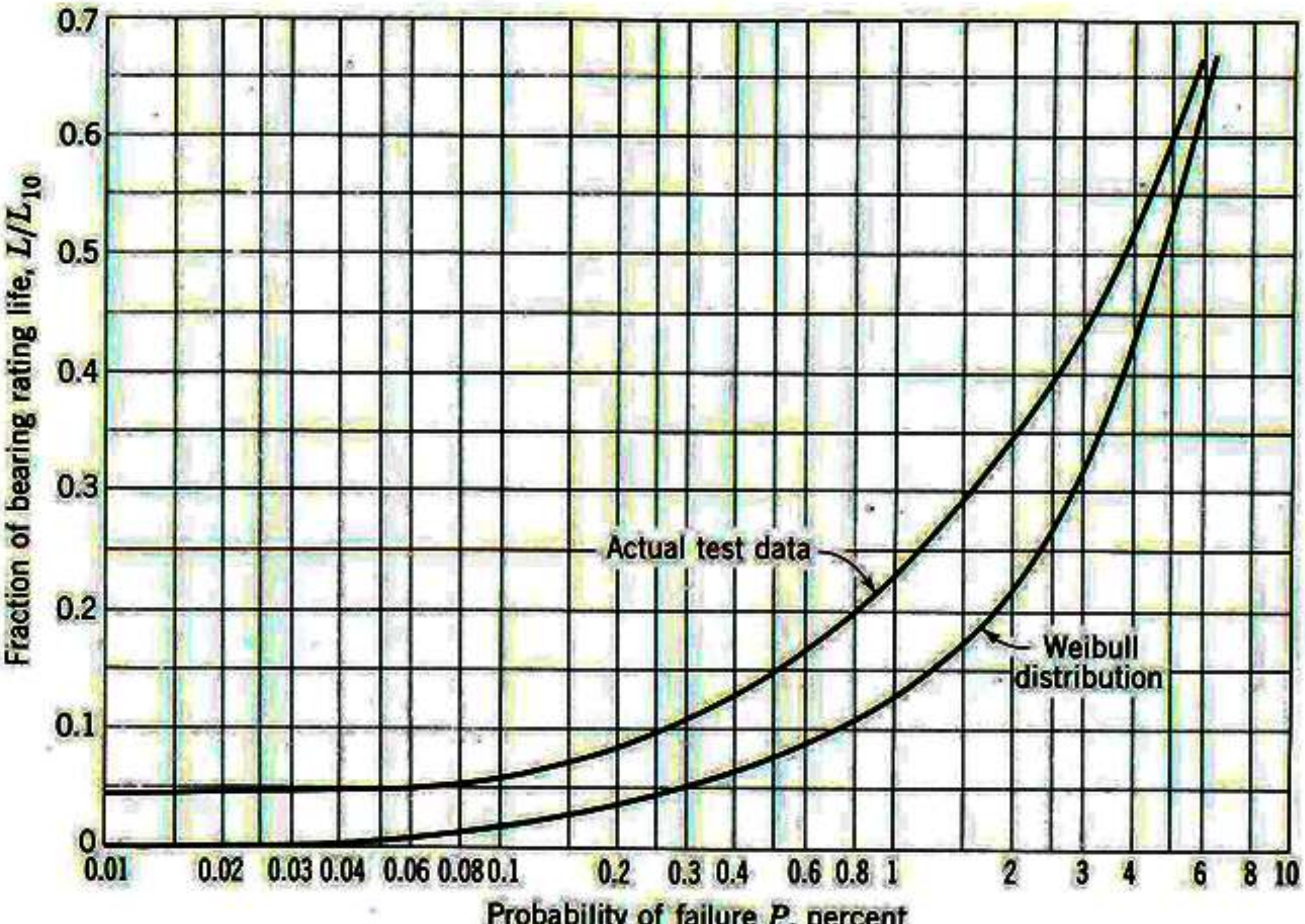


FIGURE 11-5 Reduction in life for reliabilities greater than 90 percent. Note that the abscissa is the probability of failure $P = 100 - R$ in percent. *(By permission from Tedric A. Harris, "Predicting Bearing Reliability," Machine Design, vol. 35, no. 1, Jan. 3, 1963, pp. 129–132.)*

Home Assignment

- Material used
- Manufacturing
- Lubrication
- Mounting of Bearings