به نام خداوند جان و خرد

کزین برتر اندیشه برنگذرد

دانشگاه صنعتی خواجه نصیرالدین طوسی

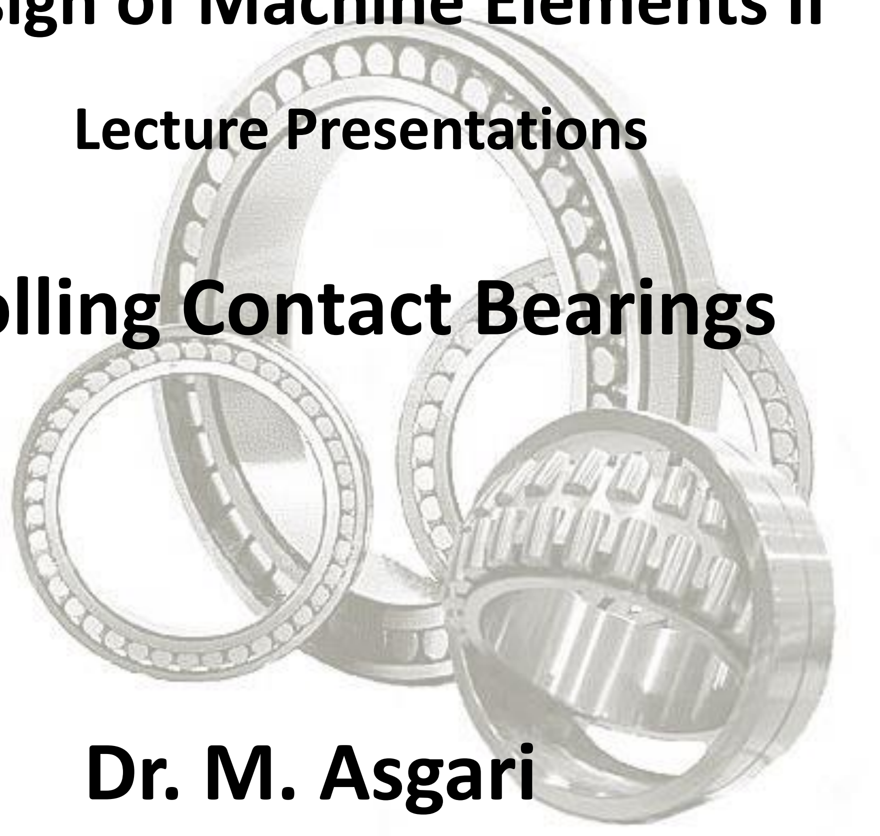
K. N. Toosi Univ. of Technology,

Faculty of Mechanical Engineering

Design of Machine Elements II

Lecture Presentations

Rolling Contact Bearings



Dr. M. Asgari

Introduction

- The term ‘bearing’ typically refers to contacting surfaces through which a load is transmitted.
- The purpose of a bearing is to support a load, whilst allowing relative motion between two elements of a machine.
- Bearings may roll or slide or do both simultaneously.

- They can be broadly split into two categories:

  – sliding bearings, where the motion is facilitated by a thin layer or film of lubricant,

  – rolling element bearings, where the motion is aided by a combination of rolling motion and lubrication.

- Lubrication is often required in a bearing to reduce friction between surfaces and to remove heat.

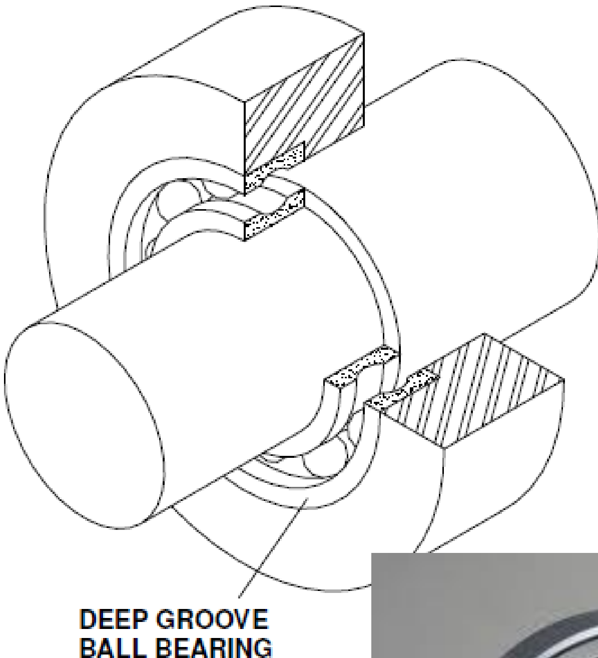
Learning objectives

- The aims of this section are to describe the range of bearing technology, to outline the identification of which type of bearing to use for a given application, to describe the selection of standard rolling element bearings.

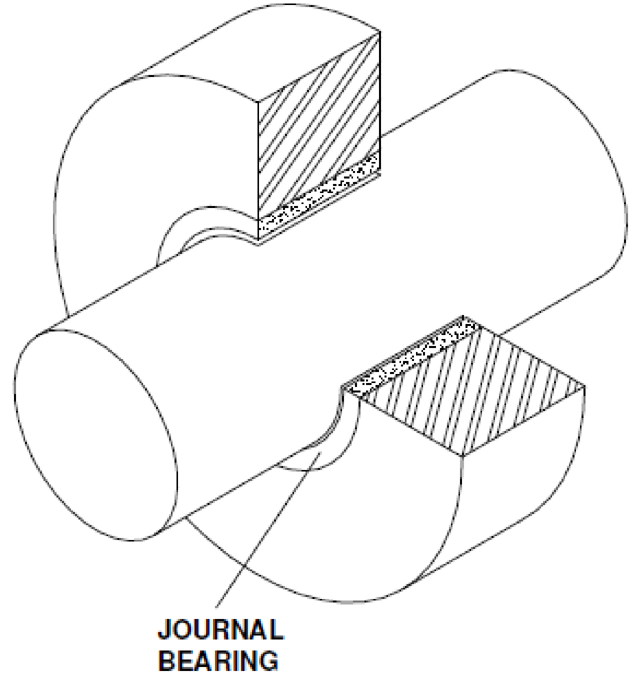
At the end of this section you should be able to:

- distinguish what sort of bearing to use for a given application,
- determine the life of a rolling element bearing using the life equation,
- select an appropriate rolling element bearing from a catalogue,
- specify the layout for rolling bearing sealing and lubrication.

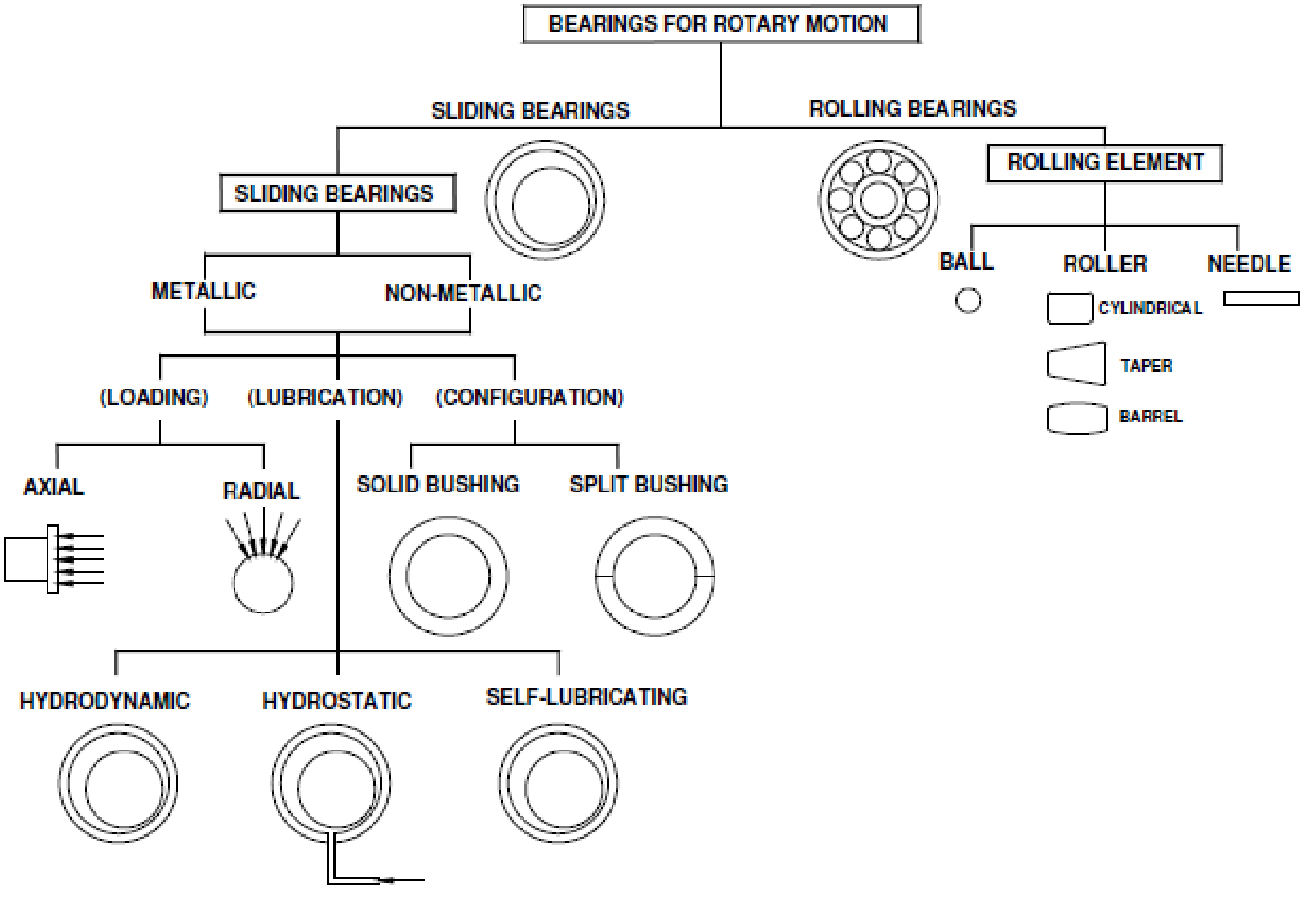
Rolling Contact Bearings



Sliding(Journal) bearings

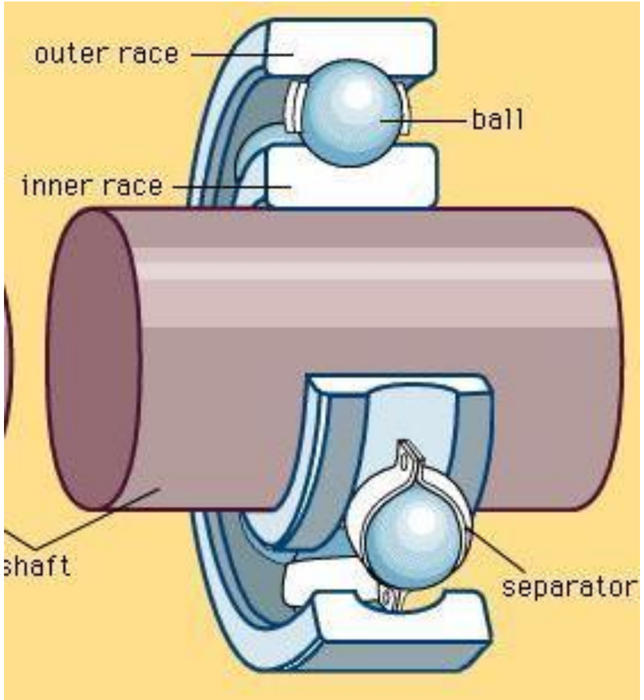


Types of bearing



Rolling Contact Bearings

- use spherical balls or some type of roller between the stationary and moving elements.
- 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.



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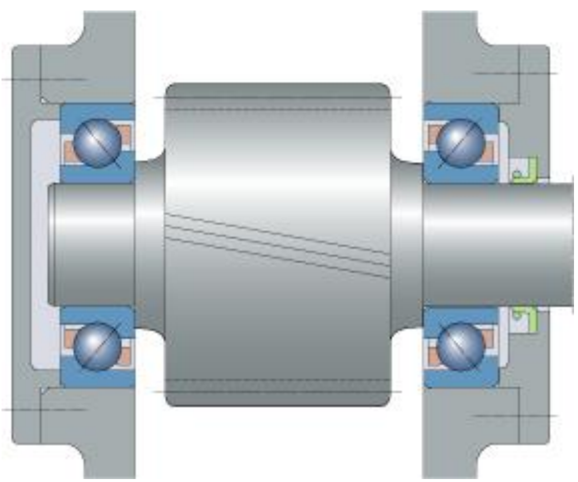
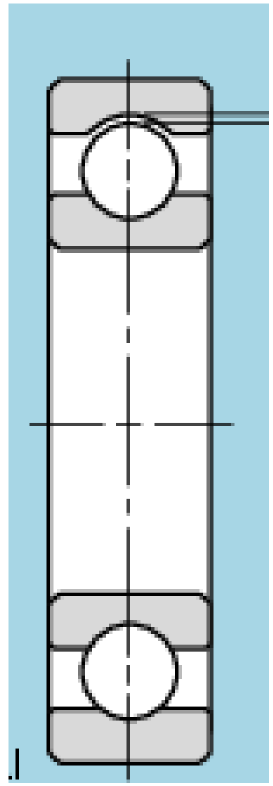
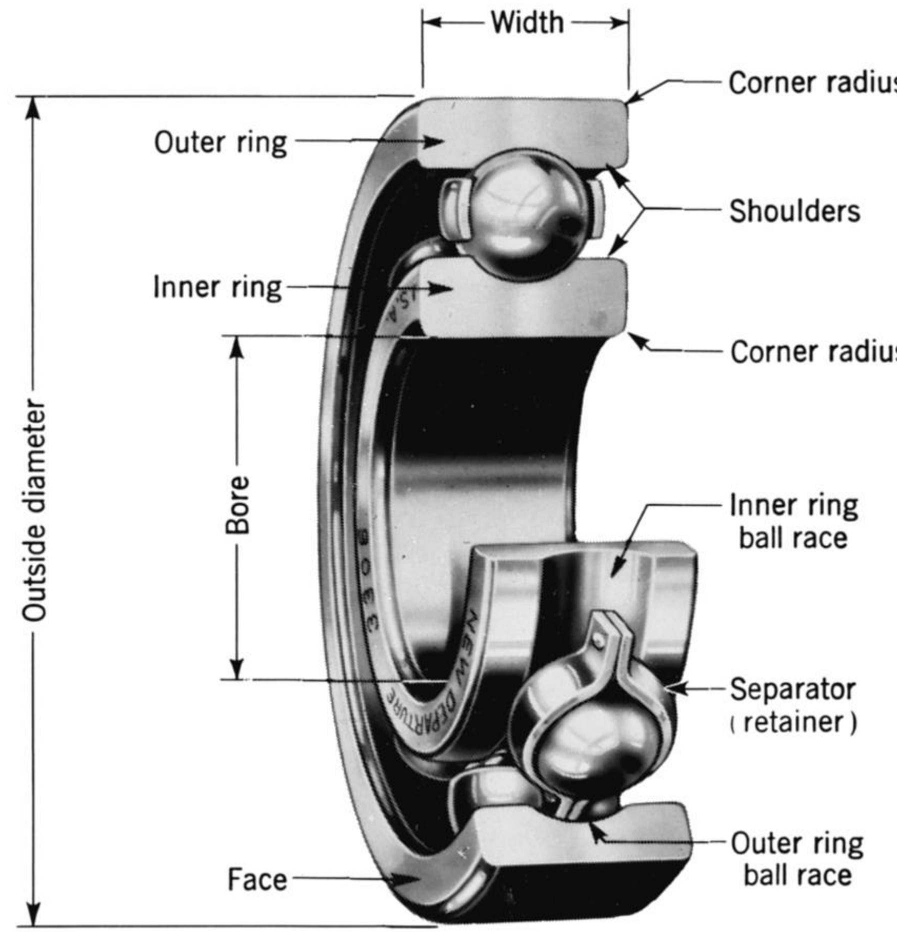


bearing components

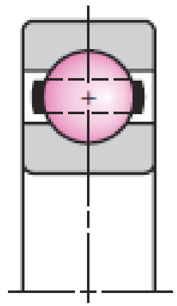
Inner ring
Outer ring
Ball or Roller
Cage





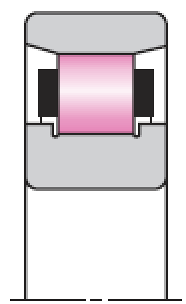
Types of roller bearings:

- Ball bearing



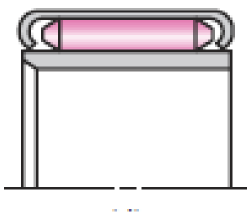
Roller bearings:

- *Straight (cylindrical) roller*:
  carry a greater radial load
  than



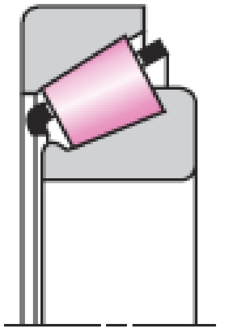
Types of roller bearings:

- *Needle roller*; are very useful where radial space is limited



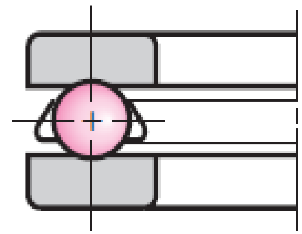
Types of roller bearings:

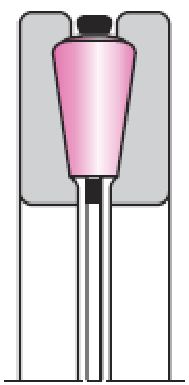
- *tapered roller*: combine the advantages of ball and straight roller bearings, can take radial and thrust loads and high load-carrying capacity

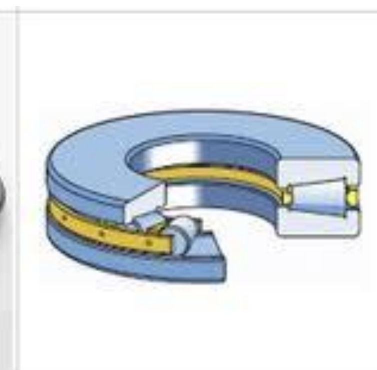


Types of roller bearings:

- *Thrust* tapered and ball roller;
For large thrust loads

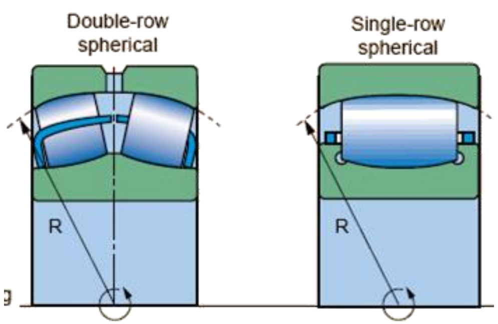




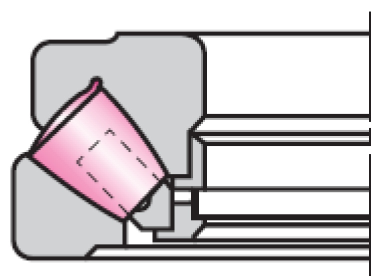


Types of roller bearings:

Spherical Roller: permits angular misalignment



Spherical roller, thrust



Types of roller bearings:

CARB

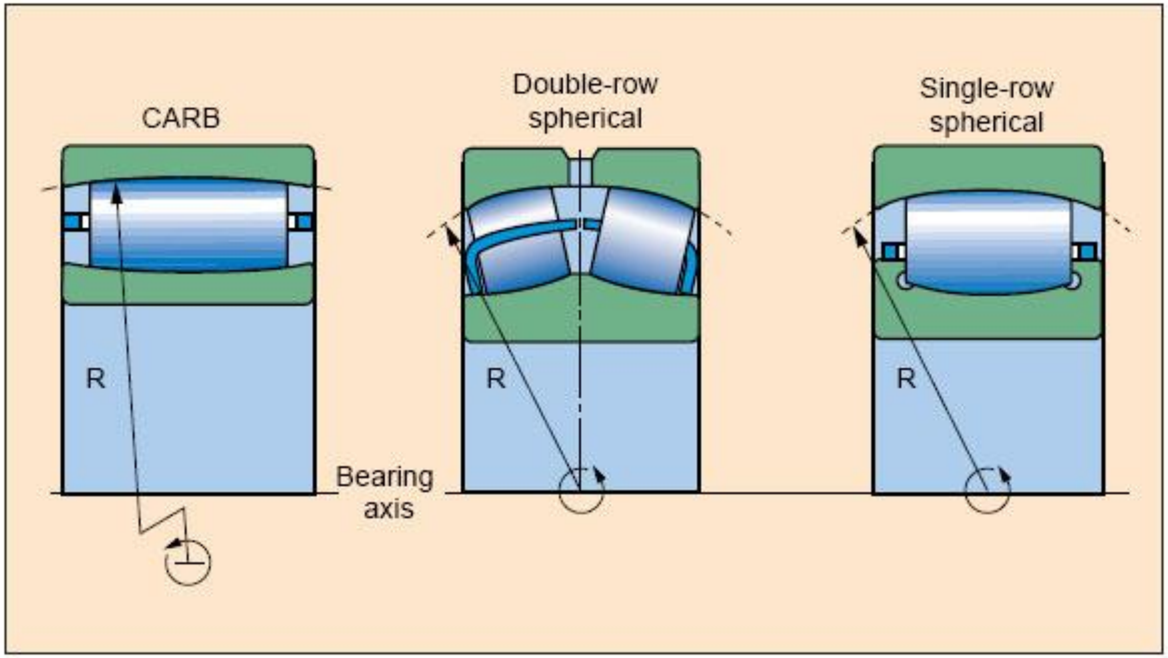
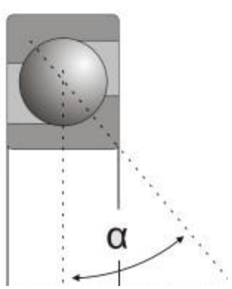
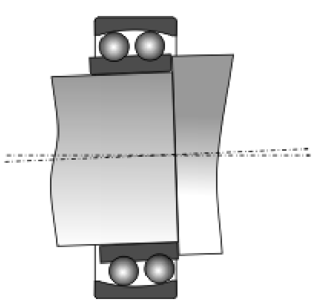


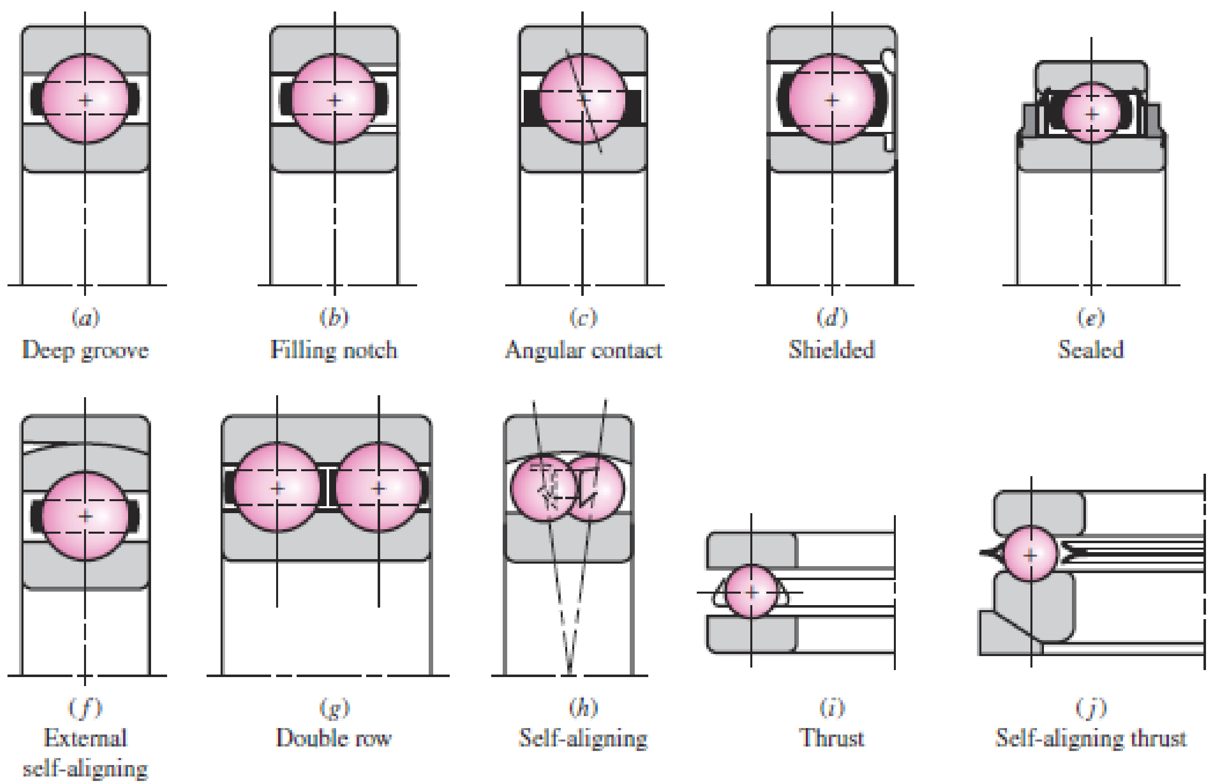
Figure 2 — CARB rollers are longer than those in spherical roller bearings, so they carry more load.

Various types of ball bearings

(a) single-row deep-groove , radial load as well as some thrust load
(b) filling notch , a greater number of balls to be inserted, increasing the load capacity
(c)angular-contact bearing, a greater thrust capacity
(d) Shielded(*e*) Sealed, measure of protection against dirt
(*f*)External self-aligning
(*g*) Double row to carry heavier radial and thrust loads
(h) Self-aligning withstand shaft misalignment of deflection
(i)   thrust bearings







Selection of Rolling Contact Bearings

-The bearings described here represent only a small portion of the many available Rolling element

-bearings are generally standard items and can be purchased from specialist manufacturers.

- The selection of a bearing from a manufacturer's catalogue involves consideration of the bearing load carrying capacity and the bearing geometry.

Manufacturers of rolling contact bearings :

SKF Inc., *www.skf.com*
FAG Bearings, *www.fag.com*
NSK Corporation, *www.tec.nsk.com*
Timken Corporation, *www.timken.com*

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

Bearing Life and Selection

- The load on a rolling contact bearing is exerted on a very small area. The resulting contact stresses are very high and of the order of 2000 MPa.

- Failure mode Despite strong steels bearings have a finite life and eventually fail due to fatigue.

- Fatigue failure consists of spalling of the load carrying surfaces

Common life measures are
• Number of revolutions of the inner ring (outer ring stationary) until the first tangible evidence of fatigue
• Number of hours of use at a standard angular speed until the first tangible evidence of fatigue

Bearing Life

- The American Bearing Manufacturers Association (ABMA) standard states that the failure criterion is the first evidence of fatigue.
- The fatigue criterion used by the Timken Company laboratories is the spalling or pitting of an area of 0.01 in^2.
- Timken also observes that the useful life of the bearing may extend considerably beyond this point.

The *rating life* is a term sanctioned by the ABMA and used by most manufacturers.

The rating life of a group of nominally identical ball or roller bearings is defined as the number of revolutions (or hours at a constant speed) that 90 percent of a group of bearings will achieve or exceed before the failure criterion develops.

The terms *minimum life, L_{10} life* are also used as synonyms for rating life.

The most commonly used rating life is $\mathbf{10^6}$ revolutions.

The Timken Company is a well-known exception, rating its bearings at 3 000 hours at 500 rev/min, which is 90(10^6) revolutions.

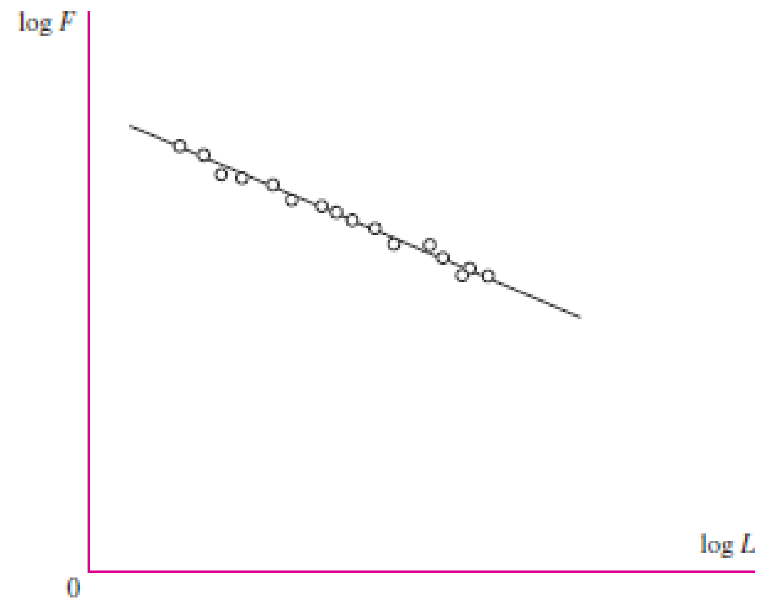
Bearing Life

Median life is the 50th percentile life of a group of bearings. The term *average life* has been used as a synonym for median life, contributing to confusion.

When many groups of bearings are tested, the median life is between 4 and 5 times the L_{10} life.

Bearing Load Life

When identical groups are tested to the life-failure criterion at different loads, the data are plotted on a graph as depicted in Fig. using a log-log transformation.



$$FL^{1/a} = \text{constant}$$

the result of many tests for various kinds of bearings result in

- a = 3 for ball bearings
- a = 10/3 for roller bearings (cylindrical and tapered roller)

A *catalog load*, $\boldsymbol{C_{10}}$*:* the **radial** load that causes 10 percent of a group of bearings to fail at the bearing manufacturer's rating life.

C_{10} is referred to as a *Basic Dynamic Load Rating,* or sometimes just Basic Load Rating, if the manufacturer's rating life is 10^6 revolutions.

Bearing Load Life

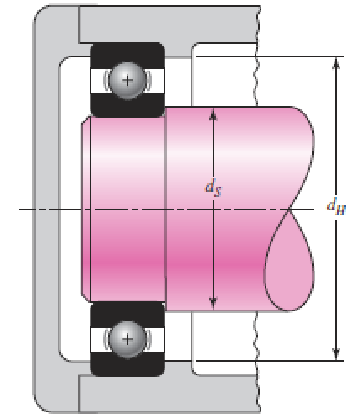
$\boldsymbol{C_0}$ is the basic static load rating. The ***basic static load rating*** is the load that will produce a total permanent deformation in the raceway and rolling element at any contact point of 0.0001 times the diameter of the rolling element. The basic static load rating is typically tabulated, along with the basic dynamic load rating C_{10}, in bearing manufacturers' publications.

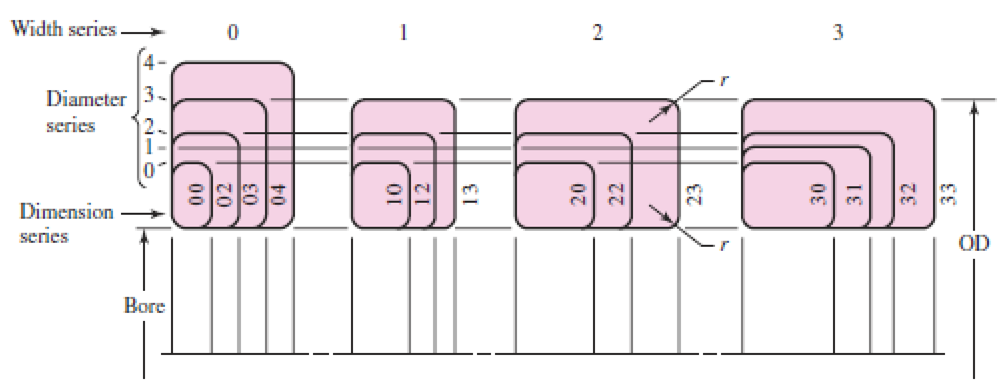
ABMA standard boundary dimensions for bearings.

Table 11–2

Dimensions and Load Ratings for Single-Row 02-Series Deep-Groove and Angular-Contact Ball Bearings

Bore, mm	OD, mm	Width, mm	Fillet Radius, mm	Shoulder Diameter, mm d_S	Shoulder Diameter, mm d_H	Load Ratings, kN Deep Groove C_{10}	Load Ratings, kN Deep Groove C_0	Load Ratings, kN Angular Contact C_{10}	Load Ratings, kN Angular Contact C_0
10	30	9	0.6	12.5	27	5.07	2.24	4.94	2.12
12	32	10	0.6	14.5	28	6.89	3.10	7.02	3.05
15	35	11	0.6	17.5	31	7.80	3.55	8.06	3.65
17	40	12	0.6	19.5	34	9.56	4.50	9.95	4.75
20	47	14	1.0	25	41	12.7	6.20	13.3	6.55
25	52	15	1.0	30	47	14.0	6.95	14.8	7.65
30	62	16	1.0	35	55	19.5	10.0	20.3	11.0
35	72	17	1.0	41	65	25.5	13.7	27.0	15.0
40	80	18	1.0	46	72	30.7	16.6	31.9	18.6
45	85	19	1.0	52	77	33.2	18.6	35.8	21.2
50	90	20	1.0	56	82	35.1	19.6	37.7	22.8
55	100	21	1.5	63	90	43.6	25.0	46.2	28.5
60	110	22	1.5	70	99	47.5	28.0	55.9	35.5
65	120	23	1.5	74	109	55.9	34.0	63.7	41.5
70	125	24	1.5	79	114	61.8	37.5	68.9	45.5
75	130	25	1.5	86	119	66.3	40.5	71.5	49.0
80	140	26	2.0	93	127	70.2	45.0	80.6	55.0
85	150	28	2.0	99	136	83.2	53.0	90.4	63.0
90	160	30	2.0	104	146	95.6	62.0	106	73.5
95	170	32	2.0	110	156	108	69.5	121	85.0



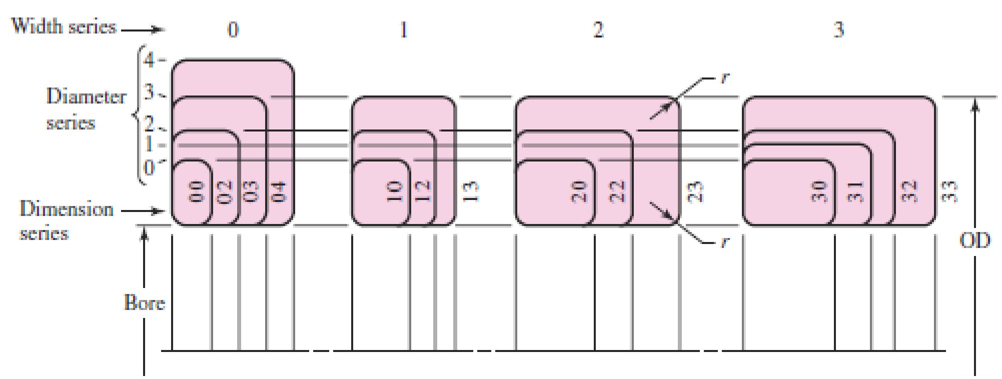


Bearing Selection

Dimensions and Basic Load Ratings for Cylindrical Roller Bearings

Table 11-3

	02-Series				03-Series			
Bore, mm	OD, mm	Width, mm	Load Rating, kN C_{10}	C_0	OD, mm	Width, mm	Load Rating, kN C_{10}	C_0
25	52	15	16.8	8.8	62	17	28.6	15.0
30	62	16	22.4	12.0	72	19	36.9	20.0
35	72	17	31.9	17.6	80	21	44.6	27.1
40	80	18	41.8	24.0	90	23	56.1	32.5
45	85	19	44.0	25.5	100	25	72.1	45.4
50	90	20	45.7	27.5	110	27	88.0	52.0
55	100	21	56.1	34.0	120	29	102	67.2
60	110	22	64.4	43.1	130	31	123	76.5
65	120	23	76.5	51.2	140	33	138	85.0
70	125	24	79.2	51.2	150	35	151	102
75	130	25	93.1	63.2	160	37	183	125
80	140	26	106	69.4	170	39	190	125
85	150	28	119	78.3	180	41	212	149
90	160	30	142	100	190	43	242	160
95	170	32	165	112	200	45	264	189
100	180	34	183	125	215	47	303	220
110	200	38	229	167	240	50	391	304
120	215	40	260	183	260	55	457	340
130	230	40	270	193	280	58	539	408
140	250	42	319	240	300	62	682	454
150	270	45	446	260	320	65	781	502



Bearing Selection

- for a given bore, there is an assortment of widths and outside diameters.
for a particular outside diameter, one can usually find a variety of bearings having different bores and widths.

- The housing and shaft shoulder diameters listed in the tables should be used whenever possible to secure adequate support for the bearing and to resist the maximum thrust loads

- manufacturers' handbooks contain data on bearing life for many classes of machinery, as well as information on load-application factors.

- The load-application factors in Table 11–5 serve the same purpose as factors of safety; use them to increase the equivalent load before selecting a bearing.

Type of Application	Life, kh
Instruments and apparatus for infrequent use	Up to 0.5
Aircraft engines	0.5–2
Machines for short or intermittent operation where service interruption is of minor importance	4–8
Machines for intermittent service where reliable operation is of great importance	8–14
Machines for 8-h service that are not always fully utilized	14–20
Machines for 8-h service that are fully utilized	20–30
Machines for continuous 24-h service	50–60
Machines for continuous 24-h service where reliability is of extreme importance	100–200

Type of Application	Load Factor
Precision gearing	1.0–1.1
Commercial gearing	1.1–1.3
Applications with poor bearing seals	1.2
Machinery with no impact	1.0–1.2
Machinery with light impact	1.2–1.5
Machinery with moderate impact	1.5–3.0

Bearing Selection

to relate the desired load and life requirements to the published catalog load rating corresponding to the catalog rating life.

$$F_R L_R^{1/a} = F_D L_D^{1/a}$$

where the units of L_R and L_D are revolutions, and the subscripts *R* and *D* stand for Rated and Desired.

to express the life in hours at a given speed. Accordingly, any life *L* in revolutions can be expressed as ***L* = 60H *n***

$$F_R(\mathcal{L}_R n_R 60)^{1/a} = F_D(\mathcal{L}_D n_D 60)^{1/a}$$

- F_R: catalog rating, lbf or kN
- $\mathcal{L}_R$: rating life in hours
- n_R: rating speed, rev/min
- F_D: desired radial load, lbf or kN
- $\mathcal{L}_D$: desired life, hours
- n_D: desired speed, rev/min

$$C_{10} = F_R = F_D\left(\frac{L_D}{L_R}\right)^{1/a} = F_D\left(\frac{\mathcal{L}_D n_D 60}{\mathcal{L}_R n_R 60}\right)^{1/a}$$

EXAMPLE 11–1 Consider SKF, which rates its bearings for 1 million revolutions. If you desire a life of 5000 h at 1725 rev/min with a load of 400 lbf with a reliability of 90 percent, for which catalog rating would you search in an SKF catalog?

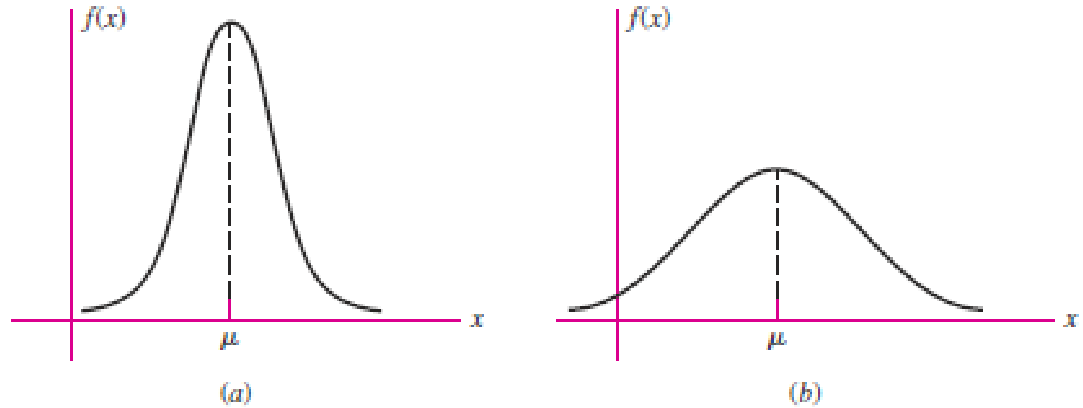
Solution The rating life is $L_{10} = L_R = \mathcal{L}_R n_R 60 = 10^6$ revolutions. From Eq. (11–3),

Answer
$$C_{10} = F_D \left(\frac{\mathcal{L}_D n_D 60}{\mathcal{L}_R n_R 60} \right)^{1/a} = 400 \left[\frac{5000(1725)60}{10^6} \right]^{1/3} = 3211 \text{ lbf} = 14.3 \text{ kN}$$

Probability Distributions

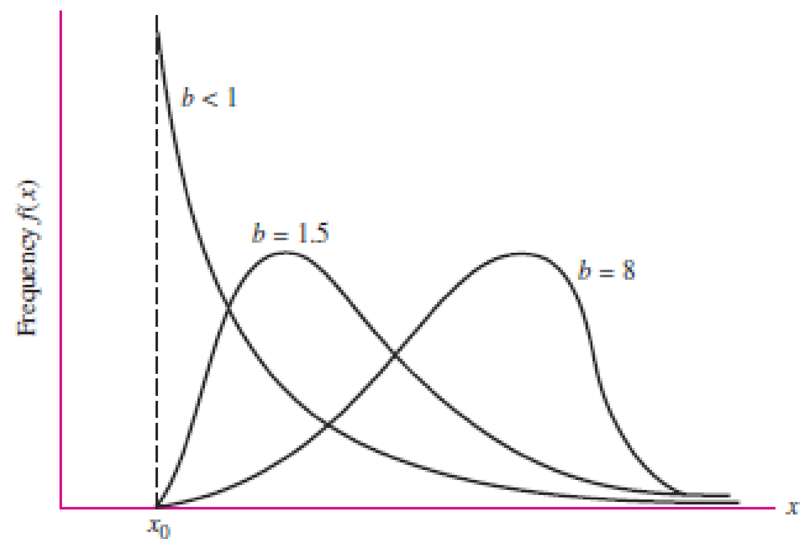
The shape of the normal distribution curve: (*a*) small ˆσ ; (*b*) large ˆσ .

$$f(x) = \frac{1}{\hat{\sigma}_x\sqrt{2\pi}} \exp\left[-\frac{1}{2}\left(\frac{x-\mu_x}{\hat{\sigma}_x}\right)^2\right]$$



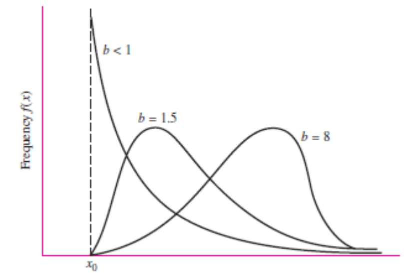
The density function of the Weibull distribution showing the effect of skewness of the shape parameter *b*.

$$R(x) = \exp\left[-\left(\frac{x-x_0}{\theta-x_0}\right)^b\right]$$



Relating Load, Life, and Reliability

At constant load, the life measure distribution is right skewed



reliability can be expressed as

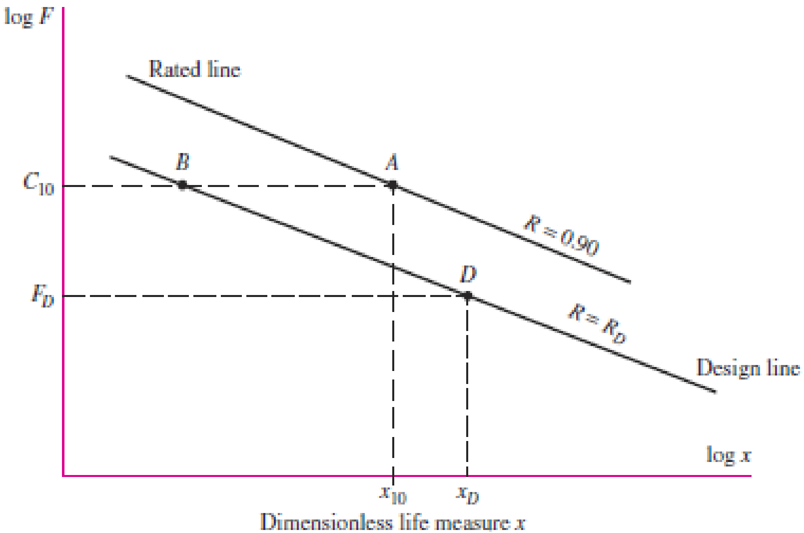
$$R = \exp\left[-\left(\frac{x - x_0}{\theta - x_0}\right)^b\right]$$

where R = reliability
x = life measure dimensionless variate, $L/L10$
x_0 = guaranteed, or "minimum,'' value of the variate
θ = characteristic parameter corresponding to the 63.2121 percentile value of the variate
b = shape parameter that controls the skewness

The Weibull parameters are usually provided in the manufacturer's catalog.

three distributional parameters
x_0=0.02 θ=4.459 b=1.483

catalog load rating is defined as the radial load that causes 10 percent of a group of bearings to fail at the bearing manufacturer's rating life



(11–7)

$$C_{10} \doteq a_f F_D \left[\frac{x_D}{x_0 + (\theta - x_0)(1 - R_D)^{1/b}} \right]^{1/a} \qquad R \geq 0.90$$

The application factor serves as a factor of safety to increase the design load to take into account overload, dynamic loading, and uncertainty

If the bearing reliability of the shaft with its pair of bearings is to be R, then R is related to the individual bearing reliabilities R_A and R_B by

$$R = R_A R_B$$

EXAMPLE 11–3 The design load on a ball bearing is 413 lbf and an application factor of 1.2 is appropriate. The speed of the shaft is to be 300 rev/min, the life to be 30 kh with a reliability of 0.99. What is the C_{10} catalog entry to be sought (or exceeded) when searching for a deep-groove bearing in a manufacturer's catalog on the basis of 10^6 revolutions for rating life? The Weibull parameters are $x_0 = 0.02$, $(\theta - x_0) = 4.439$, and $b = 1.483$.

Solution

$$x_D = \frac{L_D}{L_R} = \frac{60\mathcal{L}_D n_D}{L_{10}} = \frac{60(30\,000)300}{10^6} = 540$$

Thus, the design life is 540 times the L_{10} life. For a ball bearing, $a = 3$. Then, from Eq. (11–7),

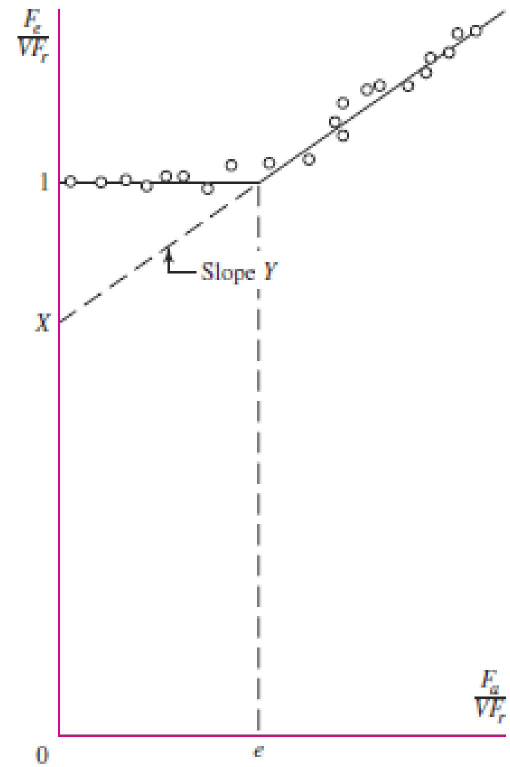
Answer

$$C_{10} = (1.2)(413)\left[\frac{540}{0.02 + 4.439(1 - 0.99)^{1/1.483}}\right]^{1/3} = 6696 \text{ lbf}$$

Type of Application	Load Factor
Precision gearing	1.0–1.1
Commercial gearing	1.1–1.3
Applications with poor bearing seals	1.2
Machinery with no impact	1.0–1.2
Machinery with light impact	1.2–1.5
Machinery with moderate impact	1.5–3.0

Combined Radial and Thrust Loading

F_a and F_r to be the axial thrust and radial loads, F_e to be the *equivalent radial load* that does the same damage as the combined radial and thrust loads together.



$$F_e = X_i V F_r + Y_i F_a$$

$F_a/V F_r \leq e \Rightarrow i = 1$

$F_a/V F_r > e \Rightarrow i = 2$.

X and *Y* factors depend upon the geometry and construction of the specific bearing. Table

The rotation factor
outer-ring rotation $V = 1.2$
inner-ring rotation $V = 1$
Self-aligning bearings V = 1 for rotation of either ring.

Table 11–1

Equivalent Radial Load Factors for Ball Bearings

F_a/C_0	e	$F_a/(VF_r) \le e$ X_1	Y_1	$F_a/(VF_r) > e$ X_2	Y_2
0.014*	0.19	1.00	0	0.56	2.30
0.021	0.21	1.00	0	0.56	2.15
0.028	0.22	1.00	0	0.56	1.99
0.042	0.24	1.00	0	0.56	1.85
0.056	0.26	1.00	0	0.56	1.71
0.070	0.27	1.00	0	0.56	1.63
0.084	0.28	1.00	0	0.56	1.55
0.110	0.30	1.00	0	0.56	1.45
0.17	0.34	1.00	0	0.56	1.31
0.28	0.38	1.00	0	0.56	1.15
0.42	0.42	1.00	0	0.56	1.04
0.56	0.44	1.00	0	0.56	1.00

*Use 0.014 if $F_a/C_0 < 0.014$.

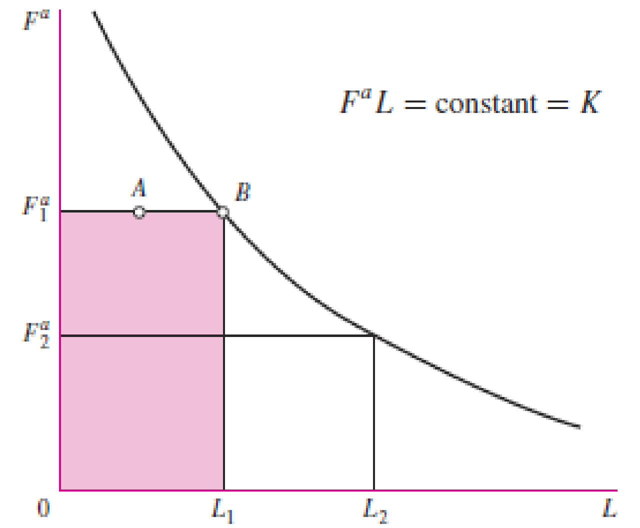
C_0 is the basic static load rating

Since straight or cylindrical roller bearings will take no axial load, or very little, the *Y* factor is always zero.

EXAMPLE 11–4 An SKF 6210 angular-contact ball bearing has an axial load F_a of 400 lbf and a radial load F_r of 500 lbf applied with the outer ring stationary. The basic static load rating C_0 is 4450 lbf and the basic load rating C_{10} is 7900 lbf. Estimate the $\mathcal{L}_{10}$ life at a speed of 720 rev/min.

Variable Loading

The linear damage hypothesis:
For load F_1, the area under the curve from $L = 0$ to $L = L_A$ is a measure of the damage D.



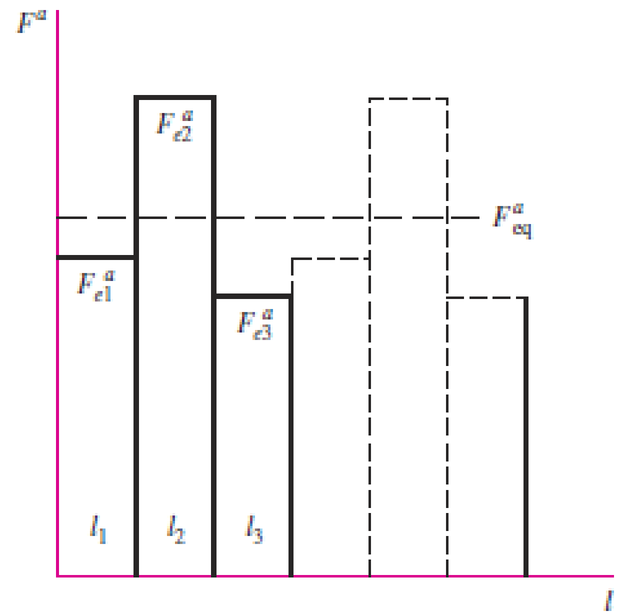
$$D = F_{e1}^a l_1 + F_{e2}^a l_2 + F_{e3}^a l_3$$

$$D = F_{eq}^a (l_1 + l_2 + l_3)$$

$$F_{eq} = \left[\frac{F_{e1}^a l_1 + F_{e2}^a l_2 + F_{e3}^a l_3}{l_1 + l_2 + l_3}\right]^{1/a} = \left[\sum f_i F_{ei}^a\right]^{1/a}$$

$$F_{eq} = \left[\frac{\sum n_i t_i F_{ei}^a}{\sum n_i t_i}\right]^{1/a}$$

$$F_{eq} = \left[\sum f_i (a_{fi} F_{ei})^a\right]^{1/a} \qquad L_{eq} = \frac{K}{F_{eq}^a}$$



How much life is left if the next level of stress is held until failure

$$\sum \frac{l_i}{L_i} = 1$$

Selection of Ball and Cylindrical Roller Bearings

EXAMPLE 11–5 A ball bearing is run at four piecewise continuous steady loads as shown in the following table. Columns (1), (2), and (5) to (8) are given.

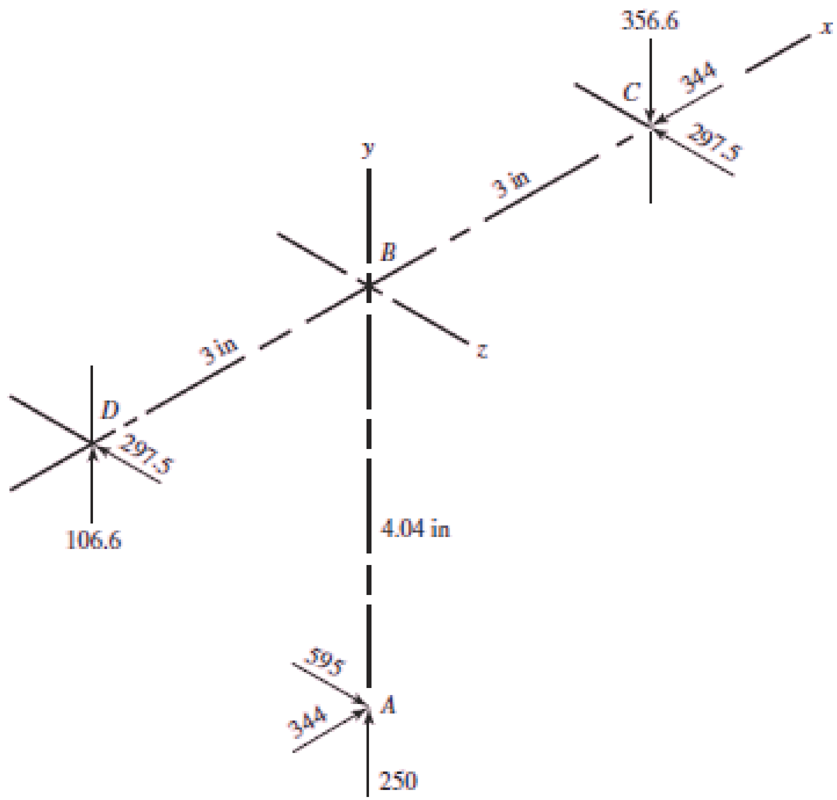
(1) Time Fraction	(2) Speed, rev/min	(3) Product, Column (1) × (2)	(4) Turns Fraction, (3)/∑(3)	(5) F_{ri}, lbf	(6) F_{ai}, lbf	(7) F_{ei}, lbf	(8) a_{fi}	(9) $a_{fi} F_{ei}$, lbf
0.1	2000	200	0.077	600	300	794	1.10	873
0.1	3000	300	0.115	300	300	626	1.25	795
0.3	3000	900	0.346	750	300	878	1.10	966
0.5	2400	1200	0.462	375	300	668	1.25	835
		2600	1.000					

Columns 1 and 2 are multiplied to obtain column 3. The column 3 entry is divided by the sum of column 3, 2600, to give column 4. Columns 5, 6, and 7 are the radial, axial, and equivalent loads respectively. Column 8 is the appropriate application factor. Column 9 is the product of columns 7 and 8.

Solution From Eq. (11–10), with $a = 3$, the equivalent radial load F_e is

Answer
$$F_e = \left[0.077(873)^3 + 0.115(795)^3 + 0.346(966)^3 + 0.462(835)^3\right]^{1/3} = 884 \text{ lbf}$$

EXAMPLE 11–7 The second shaft on a parallel-shaft 25-hp foundry crane speed reducer contains a helical gear with a pitch diameter of 8.08 in. Helical gears transmit components of force in the tangential, radial, and axial directions (see Chap. 13). The components of the gear force transmitted to the second shaft are shown in Fig. 11–12, at point *A*. The bearing reactions at *C* and *D*, assuming simple-supports, are also shown. A ball bearing is to be selected for location *C* to accept the thrust, and a cylindrical roller bearing is to be utilized at location *D*. The life goal of the speed reducer is 10 kh, with a reliability factor for the ensemble of all four bearings (both shafts) to equal or exceed 0.96 for the Weibull parameters of Ex. 11–3. The application factor is to be 1.2.

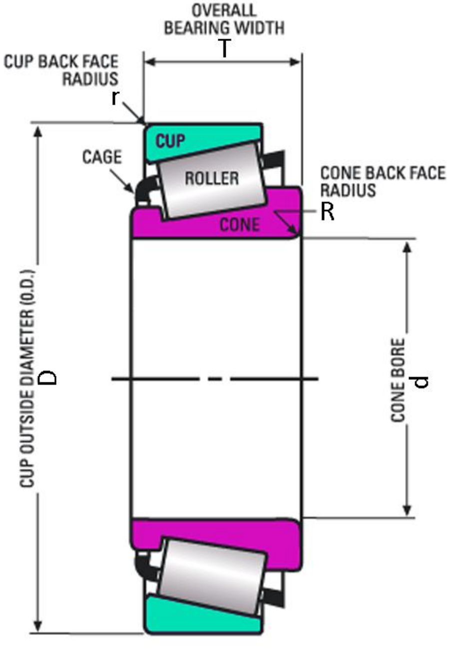


Selection of Tapered Roller Bearings

number of features that make them complicated

It is strongly recommended that the designer become familiar with the specifics of the supplier

Many of the suppliers will provide online software tools to aid in bearing selection.



Tapered Roller Bearings

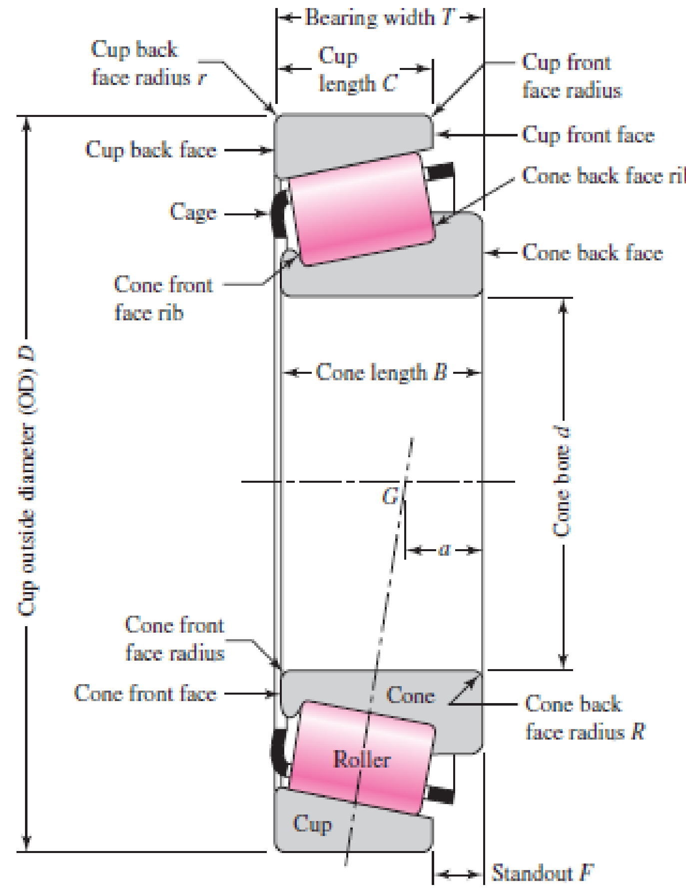
components of a tapered roller bearing

- Cone (inner ring)
- Cup (outer ring)
- Tapered rollers
- Cage (spacer-retainer)

The assembled bearing consists of two separable parts:
(1) the cone assembly: the cone, the rollers, and the cage; and
(2) the cup.

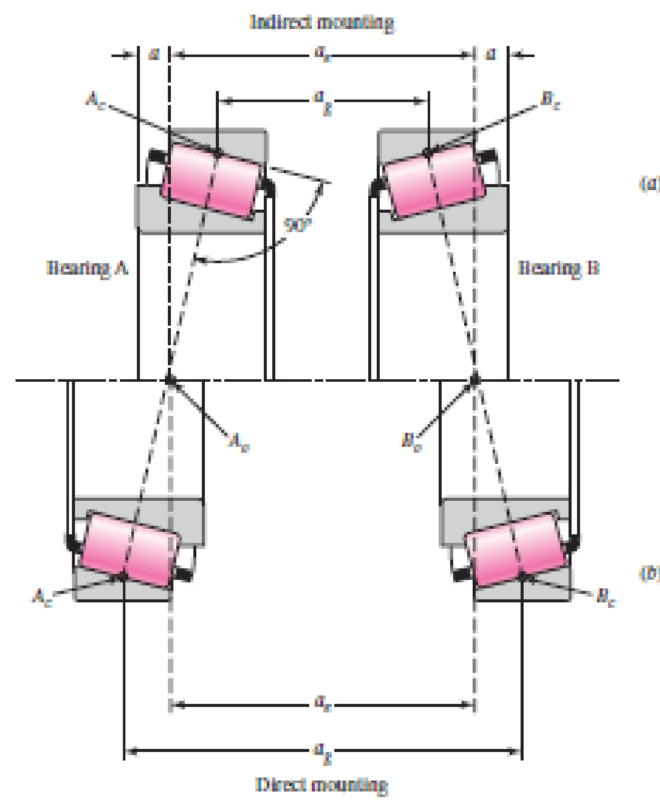
Point *G is the* location of the effective load center; use this point to estimate the radial bearing load

A tapered roller bearing can carry both radial and thrust (axial) loads, or any combination of the two

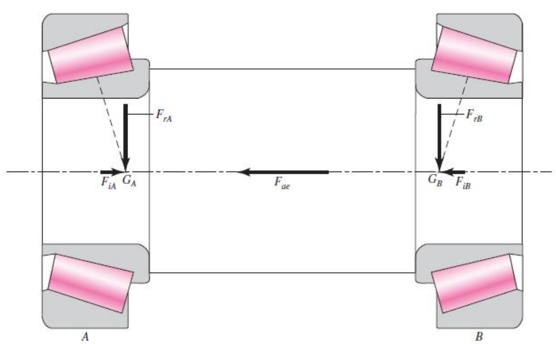


Tapered Roller Bearings

even when an external thrust load is not present, the radial load will induce a thrust reaction within the bearing because of the taper.
To avoid the separation of the races and the rollers, this thrust must be resisted by an equal and opposite force.
One way of generating this force is to always use at least two tapered roller bearings on a shaft



Thus direct and indirect mounting involve space and compactness needed or desired, but with the same system stability.



Tapered Roller Bearings

Fi , induced thrust load from a radial load with a 180◦ load zone, Timken provides the equation

$$F_i = \frac{0.47 F_r}{K}$$

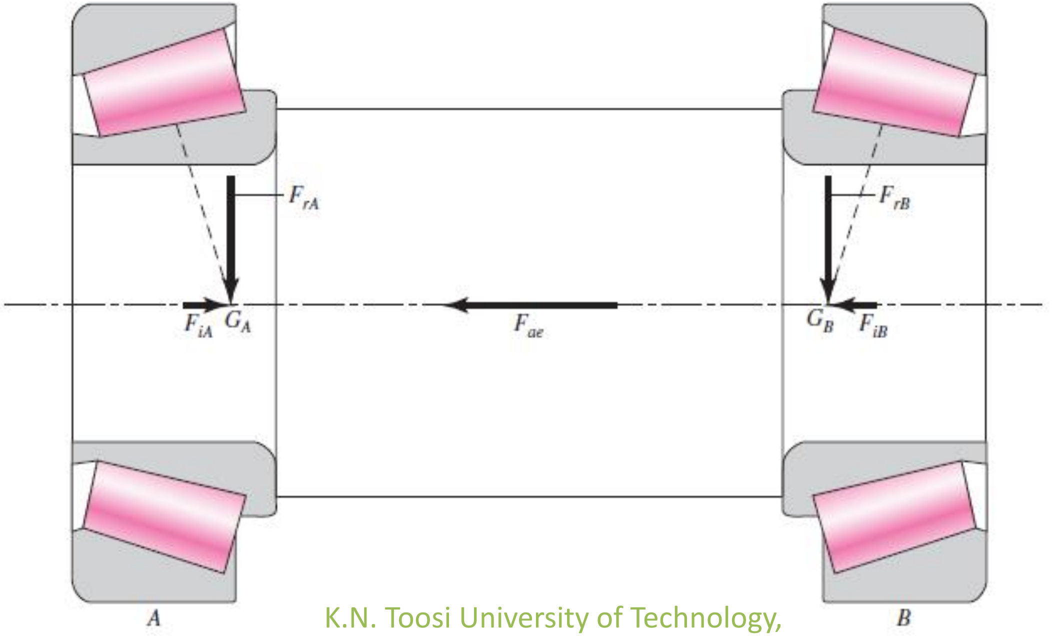
K factor is geometry-specific, can be first approximated with 1.5 for a radial bearing and 0.75 for a steep angle bearing in the preliminary selection

exact value of *K for each bearing can be found* in the bearing catalog

F_{rA} *and* F_{rB} *are the* radial loads carried by the bearings applied at the effective force centers G_A *and* G_B

F_{iA} *and* F_{iB} The induced loads *due to the effect of the radial loads*

F_{ae} externally applied thrust load *on the shaft*



equivalent radial loads. $Fe = XV\,Fr + Y\,Fa$,

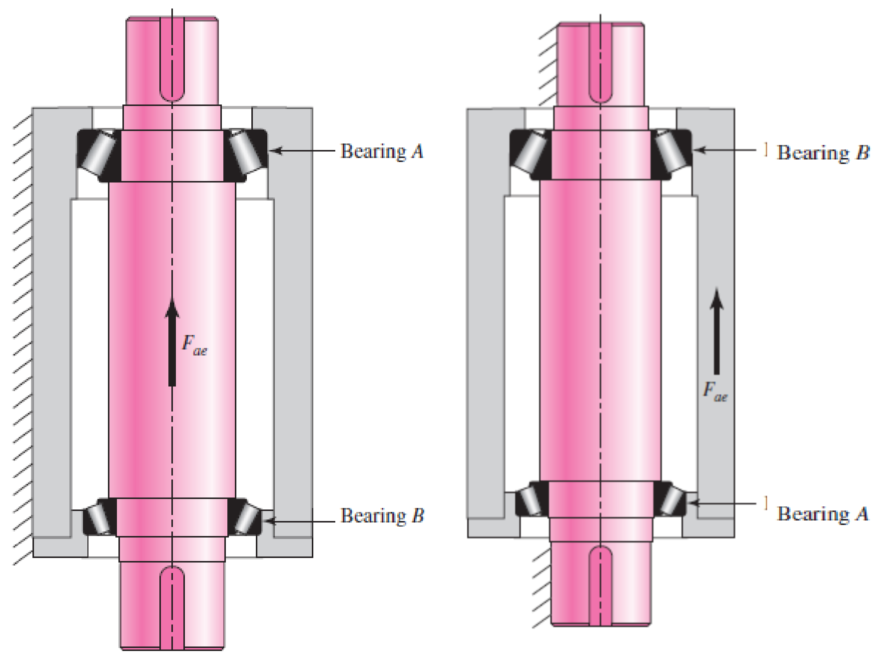
Timken & SKF recommend using *X = 0.4 and V = 1 for all cases* $Fe = 0.4Fr + KFa$

F_a *is the net axial* combination of the induced axial load from the other bearing and the external axial load

only one of the bearings will carry the net axial load.
it is depends on the direction the bearings are mounted, the relative magnitudes of the induced loads, the direction of the external load, and whether the shaft or the housing is the moving part.

First, determine visually which bearing is being "squeezed" by the external thrust load, and label it as bearing *A*

Label the other bearing as bearing *B*



Second, determine which bearing actually carries the net axial load.

if the induced thrust *Fi A from bearing A happens to be larger than the combination* of the external thrust and the thrust induced by bearing *B, then bearing B will carry* the net thrust load.

$$\text{If} \qquad F_{iA} \le (F_{iB} + F_{ae}) \qquad \begin{cases} F_{eA} = 0.4F_{rA} + K_A(F_{iB} + F_{ae}) & (11\text{–}16a) \\ F_{eB} = F_{rB} & (11\text{–}16b) \end{cases}$$

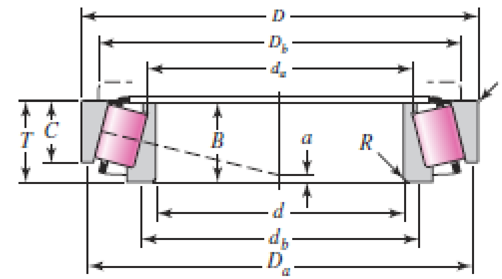
$$\text{If} \qquad F_{iA} > (F_{iB} + F_{ae}) \qquad \begin{cases} F_{eB} = 0.4F_{rB} + K_B(F_{iA} - F_{ae}) & (11\text{–}17a) \\ F_{eA} = F_{rA} & (11\text{–}17b) \end{cases}$$

In any case, if the equivalent radial load is ever less than the original radial load, then the original radial load should be used.

Once the equivalent radial loads are determined, they should be used to find the catalog rating load using any of Eqs. (11–3), (11–6), or (11–7) as before.
Since KA and KB are dependent on the specific bearing chosen, it may be necessary to iterate
the process.

bore	outside diameter	width	rating at 500 rpm for 3000 hours L_{10} one-row radial	rating at 500 rpm for 3000 hours L_{10} thrust	fac-tor	eff. load center	part numbers cone	part numbers cup	cone: max shaft fillet radius	cone: width	cone: backing shoulder diameters	cone: backing shoulder diameters	cup: max hous-ing fillet radius	cup: width	cup: backing shoulder diameters	cup: backing shoulder diameters
d	D	T	N lbf	N lbf	K	a②			R①	B	d_b	d_a	r①	C	D_b	D_a
25.000 0.9843	52.000 2.0472	16.250 0.6398	8190 1840	5260 1180	1.56	−3.6 −0.14	◆30205	◆30205	1.0 0.04	15.000 0.5906	30.5 1.20	29.0 1.14	1.0 0.04	13.000 0.5118	46.0 1.81	48.5 1.91
25.000 0.9843	52.000 2.0472	19.250 0.7579	9520 2140	9510 2140	1.00	−3.0 −0.12	◆32205-B	◆32205-B	1.0 0.04	18.000 0.7087	34.0 1.34	31.0 1.22	1.0 0.04	15.000 0.5906	43.5 1.71	49.5 1.95
25.000 0.9843	52.000 2.0472	22.000 0.8661	13200 2980	7960 1790	1.66	−7.6 −0.30	◆33205	◆33205	1.0 0.04	22.000 0.8661	34.0 1.34	30.5 1.20	1.0 0.04	18.000 0.7087	44.5 1.75	49.0 1.93
25.000 0.9843	62.000 2.4409	18.250 0.7185	13000 2930	6680 1500	1.95	−5.1 −0.20	◆30305	◆30305	1.5 0.06	17.000 0.6693	32.5 1.28	30.0 1.18	1.5 0.06	15.000 0.5906	55.0 2.17	57.0 2.24
25.000 0.9843	62.000 2.4409	25.250 0.9941	17400 3910	8930 2010	1.95	−9.7 −0.38	◆32305	◆32305	1.5 0.06	24.000 0.9449	35.0 1.38	31.5 1.24	1.5 0.06	20.000 0.7874	54.0 2.13	57.0 2.24
25.159 0.9905	50.005 1.9687	13.495 0.5313	6990 1570	4810 1080	1.45	−2.8 −0.11	07096	07196	1.5 0.06	14.260 0.5614	31.5 1.24	29.5 1.16	1.0 0.04	9.525 0.3750	44.5 1.75	47.0 1.85
25.400 1.0000	50.005 1.9687	13.495 0.5313	6990 1570	4810 1080	1.45	−2.8 −0.11	07100	07196	1.0 0.04	14.260 0.5614	30.5 1.20	29.5 1.16	1.0 0.04	9.525 0.3750	44.5 1.75	47.0 1.85
25.400 1.0000	50.005 1.9687	13.495 0.5313	6990 1570	4810 1080	1.45	−2.8 −0.11	07100-S	07196	1.5 0.06	14.260 0.5614	31.5 1.24	29.5 1.16	1.0 0.04	9.525 0.3750	44.5 1.75	47.0 1.85
25.400 1.0000	50.292 1.9800	14.224 0.5600	7210 1620	4620 1040	1.56	−3.3 −0.13	L44642	L44610	3.5 0.14	14.732 0.5800	36.0 1.42	29.5 1.16	1.3 0.05	10.668 0.4200	44.5 1.75	47.0 1.85
25.400 1.0000	50.292 1.9800	14.224 0.5600	7210 1620	4620 1040	1.56	−3.3 −0.13	L44643	L44610	1.3 0.05	14.732 0.5800	31.5 1.24	29.5 1.16	1.3 0.05	10.668 0.4200	44.5 1.75	47.0 1.85
25.400 1.0000	51.994 2.0470	15.011 0.5910	6990 1570	4810 1080	1.45	−2.8 −0.11	07100	07204	1.0 0.04	14.260 0.5614	30.5 1.20	29.5 1.16	1.3 0.05	12.700 0.5000	45.0 1.77	48.0 1.89
25.400 1.0000	56.896 2.2400	19.368 0.7625	10900 2450	5740 1290	1.90	−6.9 −0.27	1780	1729	0.8 0.03	19.837 0.7810	30.5 1.20	30.0 1.18	1.3 0.05	15.875 0.6250	49.0 1.93	51.0 2.01
25.400 1.0000	57.150 2.2500	19.431 0.7650	11700 2620	10900 2450	1.07	−3.0 −0.12	M84548	M84510	1.5 0.06	19.431 0.7650	36.0 1.42	33.0 1.30	1.5 0.06	14.732 0.5800	48.5 1.91	54.0 2.13
25.400 1.0000	58.738 2.3125	19.050 0.7500	11600 2610	6560 1470	1.77	−5.8 −0.23	1986	1932	1.3 0.05	19.355 0.7620	32.5 1.28	30.5 1.20	1.3 0.05	15.080 0.5937	52.0 2.05	54.0 2.13
25.400 1.0000	59.530 2.3437	23.368 0.9200	13900 3140	13000 2930	1.07	−5.1 −0.20	M84249	M84210	0.8 0.03	23.114 0.9100	36.0 1.42	32.5 1.27	1.5 0.06	18.288 0.7200	49.5 1.95	56.0 2.20
25.400 1.0000	60.325 2.3750	19.842 0.7812	11000 2480	6550 1470	1.69	−5.1 −0.20	15578	15523	1.3 0.05	17.462 0.6875	32.5 1.28	30.5 1.20	1.5 0.06	15.875 0.6250	51.0 2.01	54.0 2.13
25.400 1.0000	61.912 2.4375	19.050 0.7500	12100 2730	7280 1640	1.67	−5.8 −0.23	15101	15243	0.8 0.03	20.638 0.8125	32.5 1.28	31.5 1.24	2.0 0.08	14.288 0.5625	54.0 2.13	58.0 2.28
25.400 1.0000	62.000 2.4409	19.050 0.7500	12100 2730	7280 1640	1.67	−5.8 −0.23	15100	15245	3.5 0.14	20.638 0.8125	38.0 1.50	31.5 1.24	1.3 0.05	14.288 0.5625	55.0 2.17	58.0 2.28
25.400 1.0000	62.000 2.4409	19.050 0.7500	12100 2730	7280 1640	1.67	−5.8 −0.23	15101	15245	0.8 0.03	20.638 0.8125	32.5 1.28	31.5 1.24	1.3 0.05	14.288 0.5625	55.0 2.17	58.0 2.28

SINGLE-ROW STRAIGHT BORE



Minus value indicates center is inside cone back face.

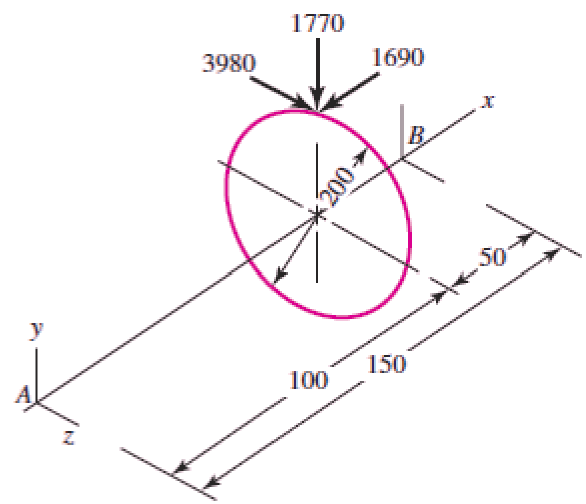
Timken two-parameter Weibell model :

x0 = 0, θ = 4.48, and b = 3/2.

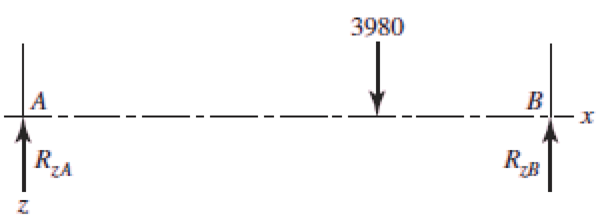
Figure 11–15 *(Continued on next page)*

Catalog entry of single-row straight-bore Timken roller bearings, in part. *(Courtesy of The Timken Company.)*

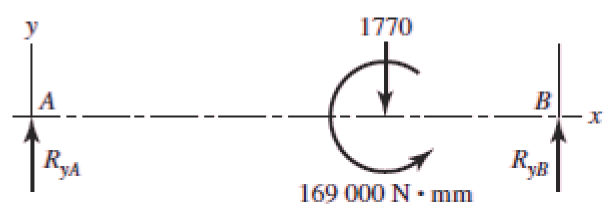
EXAMPLE 11–8 The shaft depicted in Fig. 11–18*a* carries a helical gear with a tangential force of 3980 N, a radial force of 1770 N, and a thrust force of 1690 N at the pitch cylinder with directions shown. The pitch diameter of the gear is 200 mm. The shaft runs at a speed of 800 rev/min, and the span (effective spread) between the direct-mount bearings is 150 mm. The design life is to be 5000 h and an application factor of 1 is appropriate. If the reliability of the bearing set is to be 0.99, select suitable single-row tapered-roller Timken bearings.



(*a*)



(*b*)



(*c*)

Design Assessment for Selected Rolling-Contact Bearings

"If you pull on something in the environment, you find that it is attached to everything else."

All this points out the necessary iterative nature of designing

An outline of a design assessment for a rolling contact bearing includes, at a minimum,

- Bearing reliability for the load imposed and life expected
- Shouldering on shaft and housing satisfactory
- Journal finish, diameter and tolerance compatible
- Housing finish, diameter and tolerance compatible
- Lubricant type according to manufacturer's recommendations; lubricant paths and volume supplied to keep operating temperature satisfactory
- Preloads, if required, are supplied

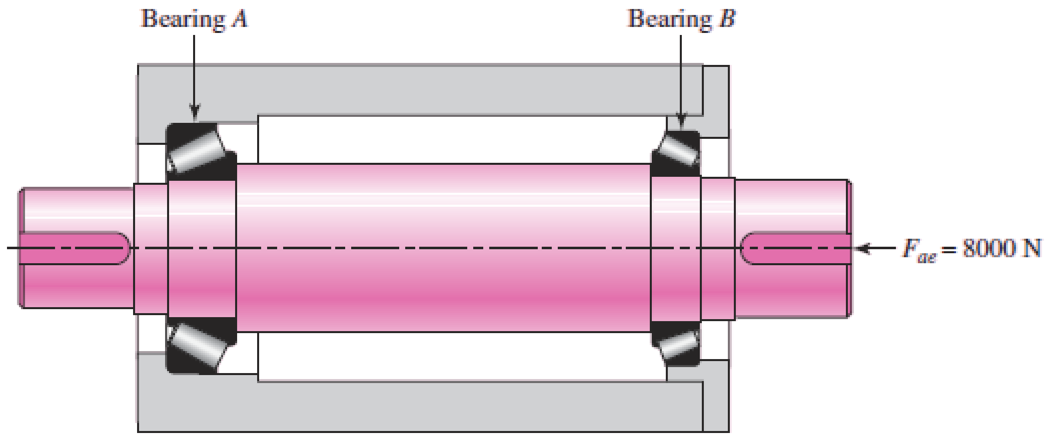
EXAMPLE 11–11

Consider a constrained housing as depicted in Fig. 11–19 with two direct-mount tapered roller bearings resisting an external thrust F_{ae} of 8000 N. The shaft speed is 950 rev/min, the desired life is 10 000 h, the expected shaft diameter is approximately 1 in. The reliability goal is 0.95. The application factor is appropriately $a_f = 1$.

(*a*) Choose a suitable tapered roller bearing for *A*.

(*b*) Choose a suitable tapered roller bearing for *B*.

(*c*) Find the reliabilities R_A, R_B, and R.



Solution (*a*) By inspection, note that the left bearing carries the axial load and is properly labeled as bearing A. The bearing reactions at A are

$$F_{rA} = F_{rB} = 0$$

$$F_{aA} = F_{ae} = 8000 \text{ N}$$

Since bearing B is unloaded, we will start with $R = R_A = 0.95$.

With no radial loads, there are no induced thrust loads. Eq. (11–16) is applicable.

$$F_{eA} = 0.4F_{rA} + K_A(F_{iB} + F_{ae}) = K_A F_{ae}$$

If we set $K_A = 1$, we can find C_{10} in the thrust column and avoid iteration:

$$F_{eA} = (1)8000 = 8000 \text{ N}$$

$$F_{eB} = F_{rB} = 0$$

The multiple of rating life is

$$x_D = \frac{L_D}{L_R} = \frac{\mathcal{L}_D n_D 60}{L_R} = \frac{(10\,000)(950)(60)}{90(10^6)} = 6.333$$

Then, from Eq. (11–7), for bearing A

$$C_{10} = a_f F_{eA}\left[\frac{x_D}{4.48(1 - R_D)^{2/3}}\right]^{3/10}$$

$$= (1)8000\left[\frac{6.33}{4.48(1 - 0.95)^{2/3}}\right]^{3/10} = 16\,159 \text{ N}$$

Answer Figure 11–15 presents one possibility in the 1-in bore (25.4-mm) size: cone, HM88630, cup HM88610 with a thrust rating $(C_{10})_a = 17\,200$ N.

Answer (*b*) Bearing *B* experiences no load, and the cheapest bearing of this bore size will do, including a ball or roller bearing.

(*c*) The actual reliability of bearing *A*, from Eq. (11–21), is

Answer

$$R_A \doteq 1 - \left\{\frac{x_D}{4.48[C_{10}/(a_f F_D)]^{10/3}}\right\}^{3/2}$$

$$\doteq 1 - \left\{\frac{6.333}{4.48\,[17\,200/(1 \times 8000)]^{10/3}}\right\}^{3/2} = 0.963$$

which is greater than 0.95, as one would expect. For bearing *B*,

Answer

$$F_D = F_{eB} = 0$$

$$R_B \doteq 1 - \left[\frac{6.333}{0.85(17\,200/0)^{10/3}}\right]^{3/2} = 1 - 0 = 1$$

as one would expect. The combined reliability of bearings *A* and *B* as a pair is

Answer

$$R = R_A R_B = 0.963(1) = 0.963$$

which is greater than the reliability goal of 0.95, as one would expect.

Lubrication

The purposes of an antifriction-bearing lubricant may be summarized as follows:

1 To provide a film of lubricant between the sliding and rolling surfaces
2 To help distribute and dissipate heat
3 To prevent corrosion of the bearing surfaces
4 To protect the parts from the entrance of foreign matter

Either oil or grease may be employed as a lubricant.

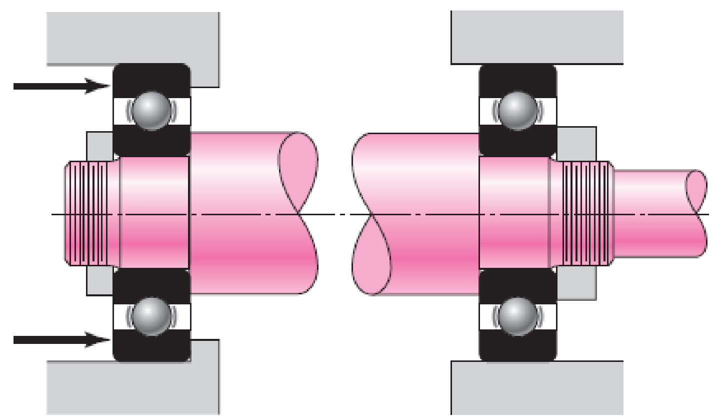
Use Grease When	Use Oil When
1. The temperature is not over 200°F.	1. Speeds are high.
2. The speed is low.	2. Temperatures are high.
3. Unusual protection is required from the entrance of foreign matter.	3. Oiltight seals are readily employed.
4. Simple bearing enclosures are desired.	4. Bearing type is not suitable for grease lubrication.
5. Operation for long periods without attention is desired.	5. The bearing is lubricated from a central supply which is also used for other machine parts.

Mounting and Enclosure

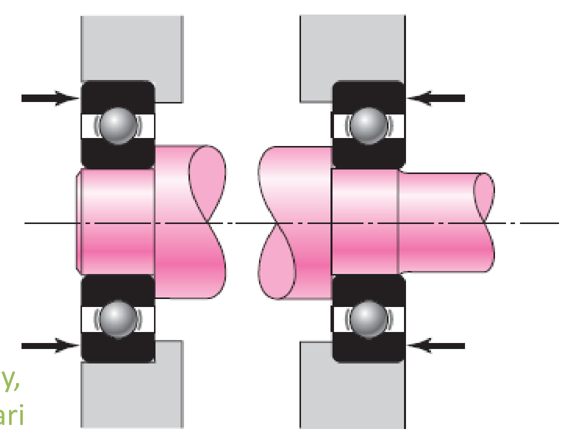
There are so many methods of mounting antifriction bearings that each new design is a real challenge to the ingenuity of the designer

The most frequently encountered mounting problem is that which requires one bearing at each end of a shaft.

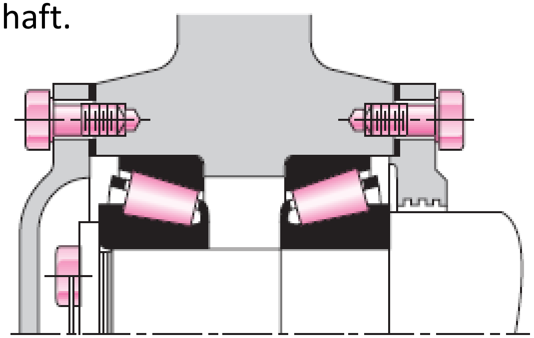
One of the bearings usually has the added function of positioning or axially locating the shaft

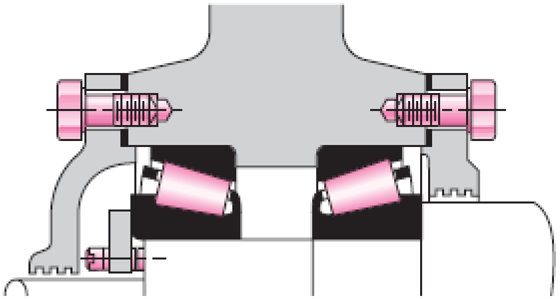


For example, the function of the shaft shoulder may be performed by retaining rings, by the hub of a gear or pulley, or by spacing tubes or rings. The round nuts may be replaced by retaining rings or by washers locked in position by screws, cotters, or taper pins. The housing shoulder may be replaced by a retaining ring; the outer ring of the bearing may be grooved for a retaining ring, or a flanged outer ring may be used.

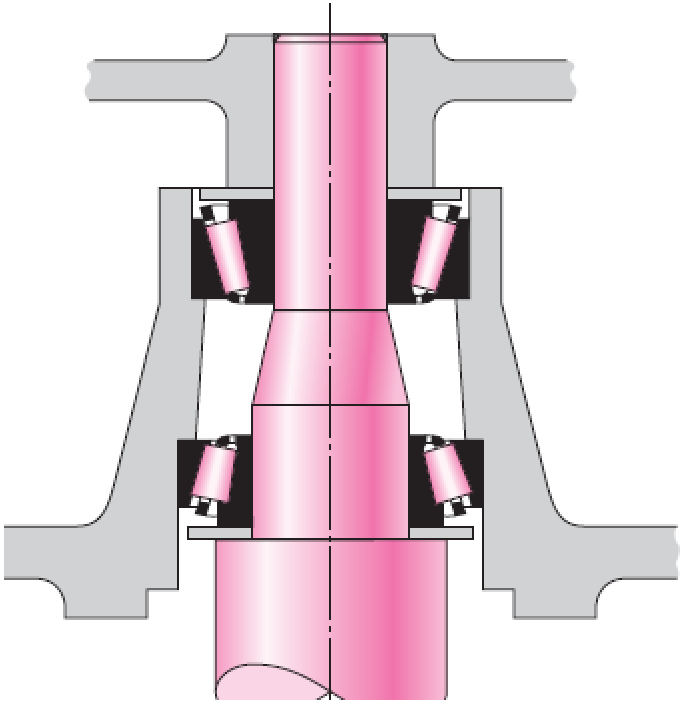


two bearings could be used to obtain additional rigidity or increased load capacity or to cantilever a shaft.



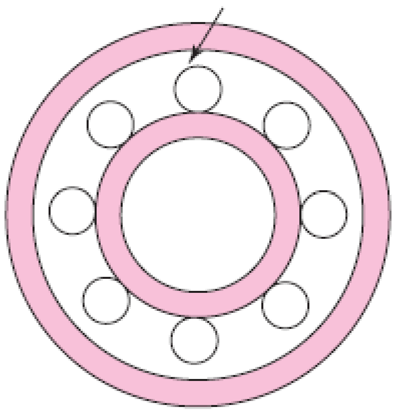


In either case it should be noted that the effect of the mounting is to preload the bearings in an axial direction.



Preloading

The object of preloading is to remove the internal clearance usually found in bearings, to increase the fatigue life, and to decrease the shaft slope at the bearing.



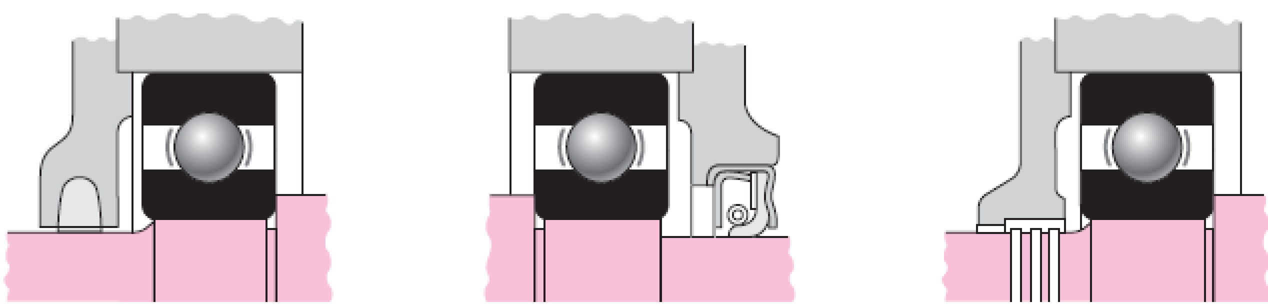
Enclosures

To exclude dirt and foreign matter and to retain the lubricant, the bearing mountings must include a seal

Felt seals may be used with grease lubrication when the speeds are low

The *commercial seal is an assembly consisting of the rubbing element and, generally,* a spring backing, which are retained in a sheet-metal jacket they should not be used for high speeds

The *labyrinth seal is especially effective for high-speed installations and may be used* with either oil or grease.



(*a*) Felt seal (*b*) Commercial seal (*c*) Labyrinth seal

SKF Bearing type selection

The matrix can only provide a rough guide so that in each individual case it is necessary to make a more qualified selection referring to the information given in the catalogue

Symbols
+++ excellent
++ good
+ fair
- poor
-- unsuitable
← single direction
←→ double direction

Design

1 Tapered bore
2 Shields or seals
3 Self-aligning
4 Non-separable
5 Separable

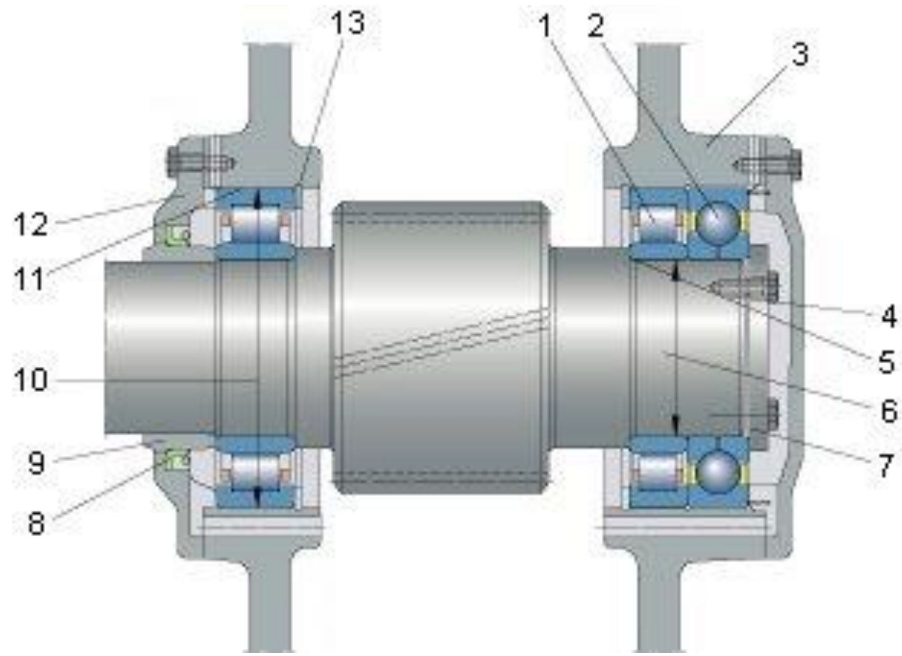
Characteristics
Suitability of bearings for

6 Purely radial load
7 Purely axial load
8 Combined load
9 Moment load
10 High speed
11 High running accuracy
12 High stiffness
13 Quiet running
14 Low friction
15 Compensation for misalignment in operation
16 Compensation for errors of alignment (initial)
17 Locating bearing arrangements
18 Non-locating bearing arrangement
19 Axial displacement possible in bearing

Bearing type	Variant	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
Deep groove ball bearings	a, b		a				+	+ ←→	+ ←→	– b+	+++ b+	+++ b+	+	+++	+++	–	–	++ ←→	+	––
Angular contact ball bearings							+	+ ←	++ ←	–	++	+++	+	++	++	–	–	++ ←	––	––
	a, b, c		b		a, b	c	++	+ ←→	++ ←→	+	+	++	++	+	+	––	––	++ ←→	+	––
							–	++ ←→	+ ←→	+	++	+	+	+	+	––	––	++ ←→	–	––
Self-aligning ball bearings							+	–	–	––	+++	++	–	++	+++	+++	+++	+ ←→	+	––
Cylindrical roller bearings							++	––	––	––	++	++	++	++	++	–	–	––	+++	+++
	a, a, b, b						++	+ a← b←→	+ a← b←→	––	++	++	++	+	++	–	–	++ a← b←→	+ a←	+ a←
full complement	a, b				a	b	+++	–	+ ←	––	–	+	+++	–	–	–	–	+ ←	+	+
	a, a, b, c		a				+++	–	+ a←→ b←	+	–	+	+++	–	–	––	––	+ a←→ b←	+ c	+ b← c←→
Needle roller bearings	a, b, c		a	c			++	––	––	––	+	+ a++	a++ b++	+	–	––	–– c++	––	+++	+++
	a, b, c		b,c				++	––	––	––	+	+	++	+	–	––	––	––	+++	+++
	a, b, c		b,c				+	+ c++ ←	+ ←	–	+	+	++	+	–	––	––	+ ←	––	––
Tapered roller bearings							++	++ ←	+++ ←	–	+	+	++	+	+	–	–	+++ ←	––	––
	a, b						+++	++ ←→	+++ ←→	+	+	+	+++	+	+	–	––	+++ ←→	–	––
Spherical roller bearings							+++	+ ←→	+++ ←→	––	+	+	++	+	+	+++	+++	++ ←→	+	––
CARB bearings							+++	––	––	––	+	+	++	+	+	+++	+++	––	+++	+++
full complement							+++	––	––	––	–	+	+++	+	+	+++	+++	––	+++	+++
Thrust ball bearings	a, b						––	+ a← b←→	––	––	–	++ a	+	–	+	–	––	++ a← b←→	––	––
	a, b						––	+ a← b←→	––	––	–	+	+	–	+	–	++	++ a← b←→	––	––
Needle (a) / Cylindrical (b) roller thrust bearings	a, b						––	++ ←	––	––	–	a+ b++	++	–	–	––	––	++ ←	––	––
Spherical roller thrust bearings							––	+++ ←	+ ←	––	–	+	++	–	+	+++	+++	+++ ←	––	––

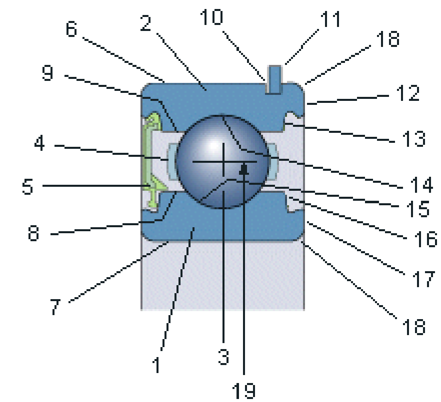
SKF Bearing designation: terminology

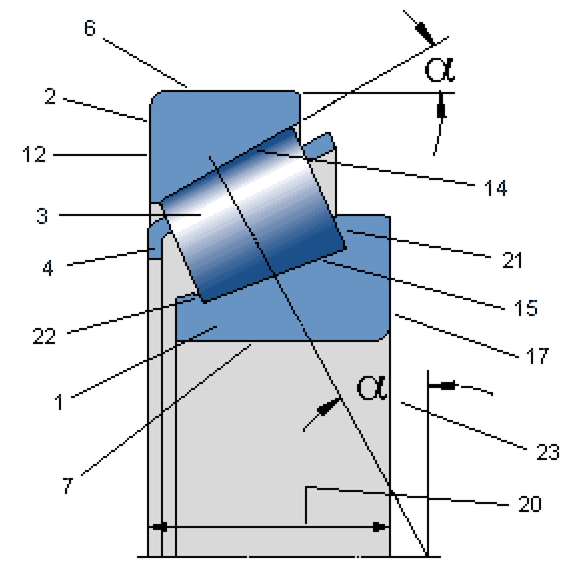
1. **Cylindrical roller bearing**
2. **Four-point contact ball bearing**
3. **Housing**
4. **Shaft**
5. **Shaft abutment shoulder**
6. **Shaft diameter**
7. **Locking plate**
8. **Radial shaft seal**
9. **Distance ring**
10. **Housing bore diameter**
11. **Housing bore**
12. **Housing cover**
13. **Snap ring**



SKF Bearing designation: terminology

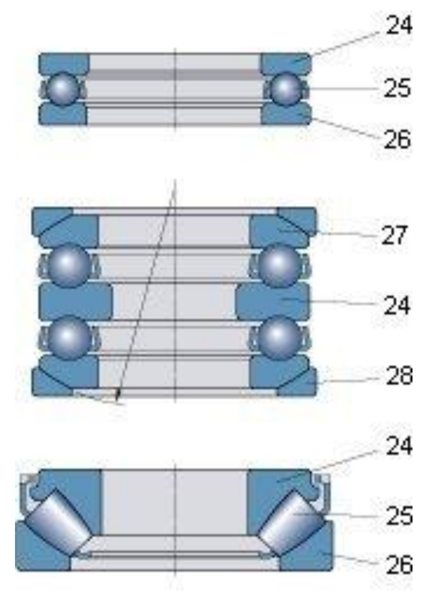
1. Inner ring
2. Outer ring
3. Rolling element: ball, cylindrical roller, needle roller, tapered roller, spherical roller
4. Cage
5. Capping device
   Seal – made of elastomer, contact or non-contact
   Shield – made of sheet steel, non-contact
6. Outer ring outside diameter
7. Inner ring bore
8. Inner ring shoulder diameter
9. Outer ring shoulder diameter
10. Snap ring groove
11. Snap ring
12. Outer ring side face
13. Seal anchorage groove
14. Outer ring raceway
15. Inner ring raceway
16. Sealing groove
17. Inner ring side face
18. Chamfer
19. Mean bearing diameter
20. Total bearing width
21. Guiding flange
22. Retaining flange
23. Contact angle





SKF Bearing designation: terminology

24. **Shaft washer**
25. **Rolling element and cage assembly**
26. **Housing washer**
27. **Housing washer with sphered seat surface**
28. **Sphered seat washer**

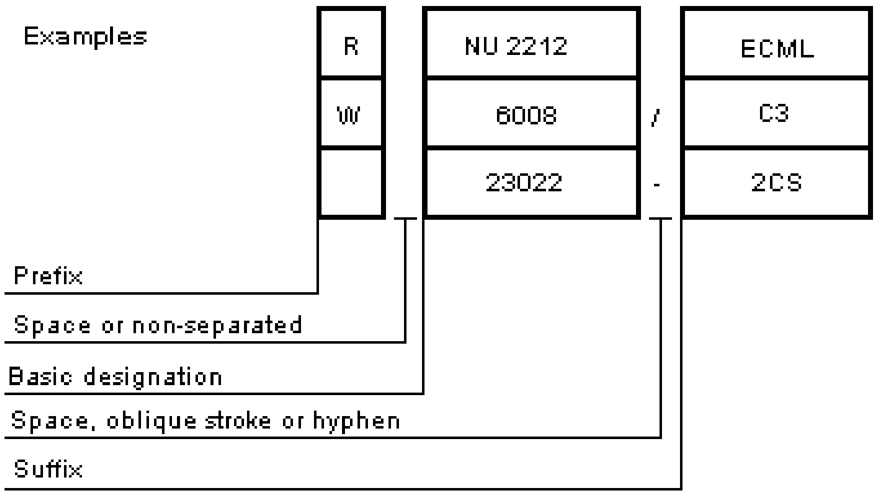


SKF Bearing designation system

Prefix

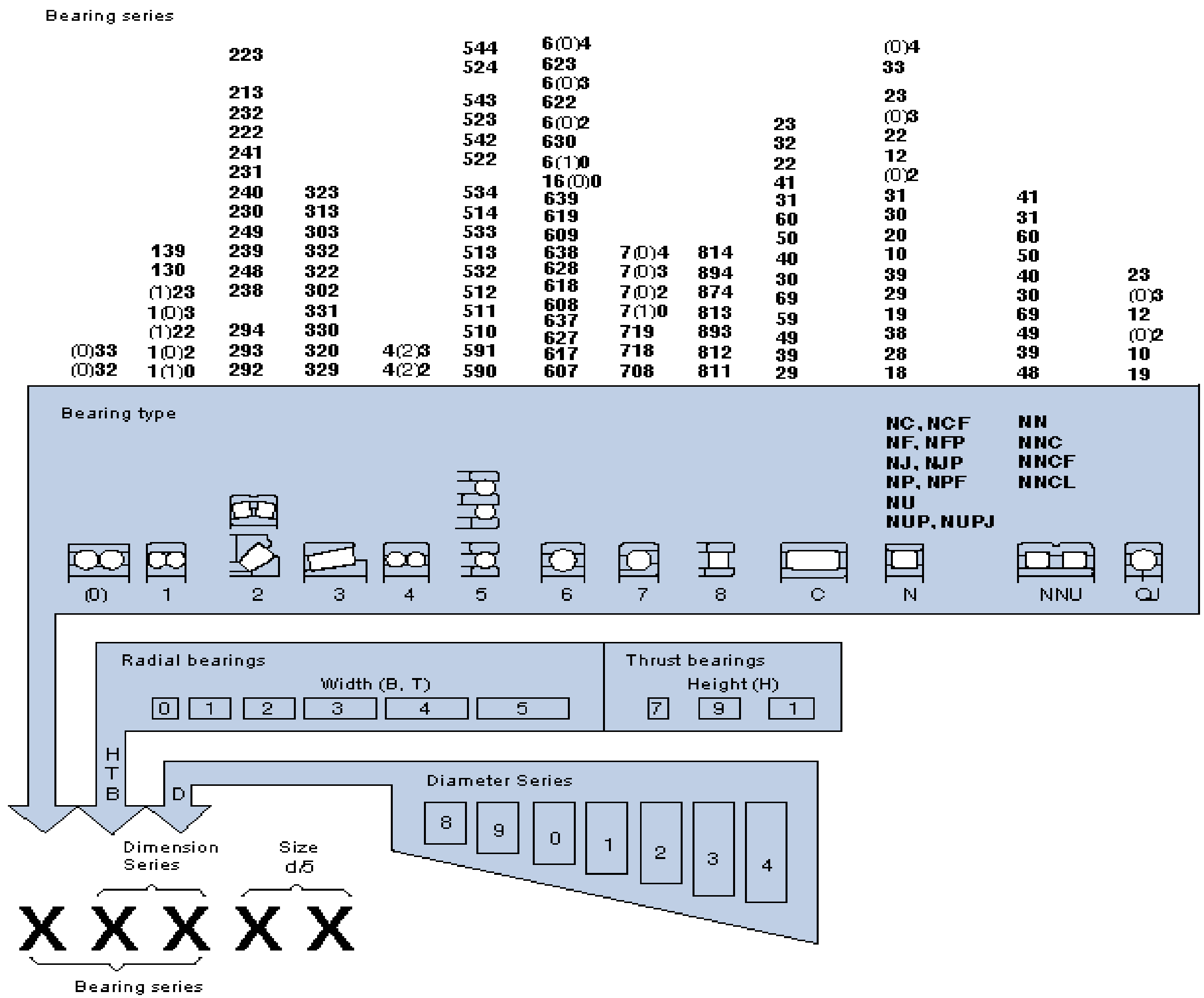
Basic

Suffix



SKF Bearing designation system

- **Bearing type**
- **Width or height**
- **Outer diameter**
- **Bore diameter**



SKF Bearing designation system

Bearing type

0	Double row angular contact ball bearings
1	Self-aligning ball bearings
2	Spherical roller bearings, spherical roller thrust bearings
3	Tapered roller bearings
4	Double row deep groove ball bearings
5	Thrust ball bearings
6	Single row deep groove ball bearings
7	Single row angular contact ball bearings
8	Cylindrical roller thrust bearings

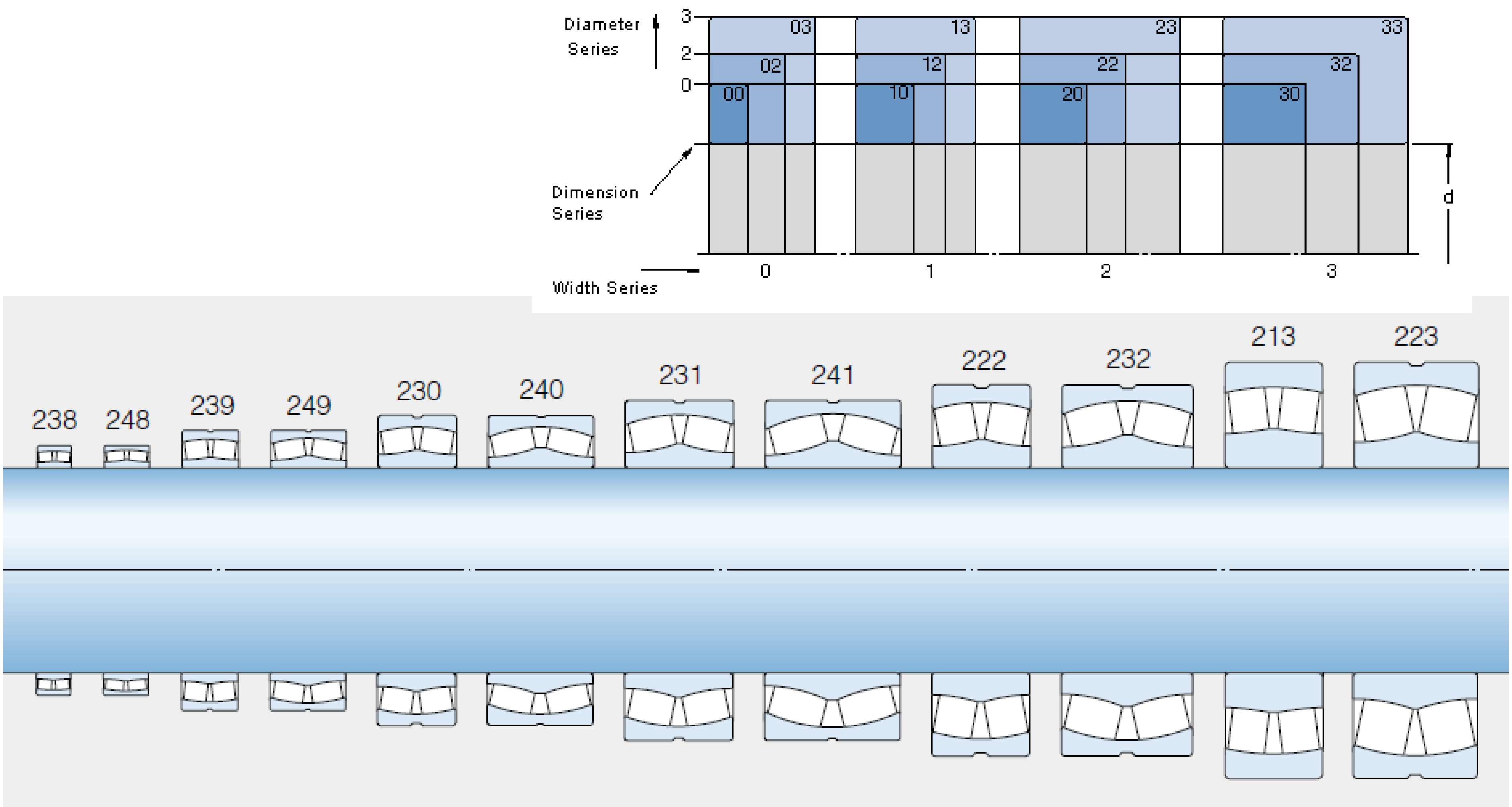
SKF Bearing designation system

Bearing type

BK	Drawn cup needle roller bearings with closed end
C	CARB Toroidal roller bearings
HK	Drawn cup needle roller bearings with open ends
K	Needle roller and cage thrust assemblies
N	Cylindrical roller bearings A second and sometimes a third letter are used to identify the configuration of the flanges, e.g. NJ, NU, NUP; double or multi-row cylindrical roller bearing designations always start with NN.
NA	Needle roller bearings with boundary dimensions to ISO 15
NK	Needle roller bearings
QJ	Four-point contact ball bearings
T	Tapered roller bearings, a few metric sizes to ISO 355-1977 Inch tapered roller bearings with dimensions to an ABMA series are designated according to a different system to ANSI-ABMA Standard 19 (see also under prefix K-)

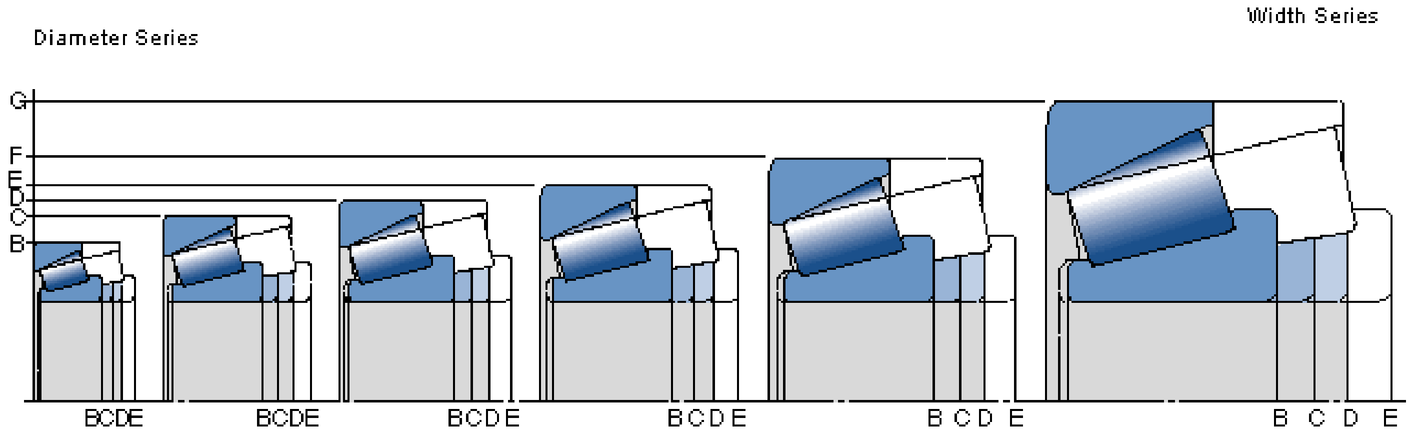
SKF Bearing designation system

Dimension



SKF Bearing designation system

Dimension (Tapered roller bearing)



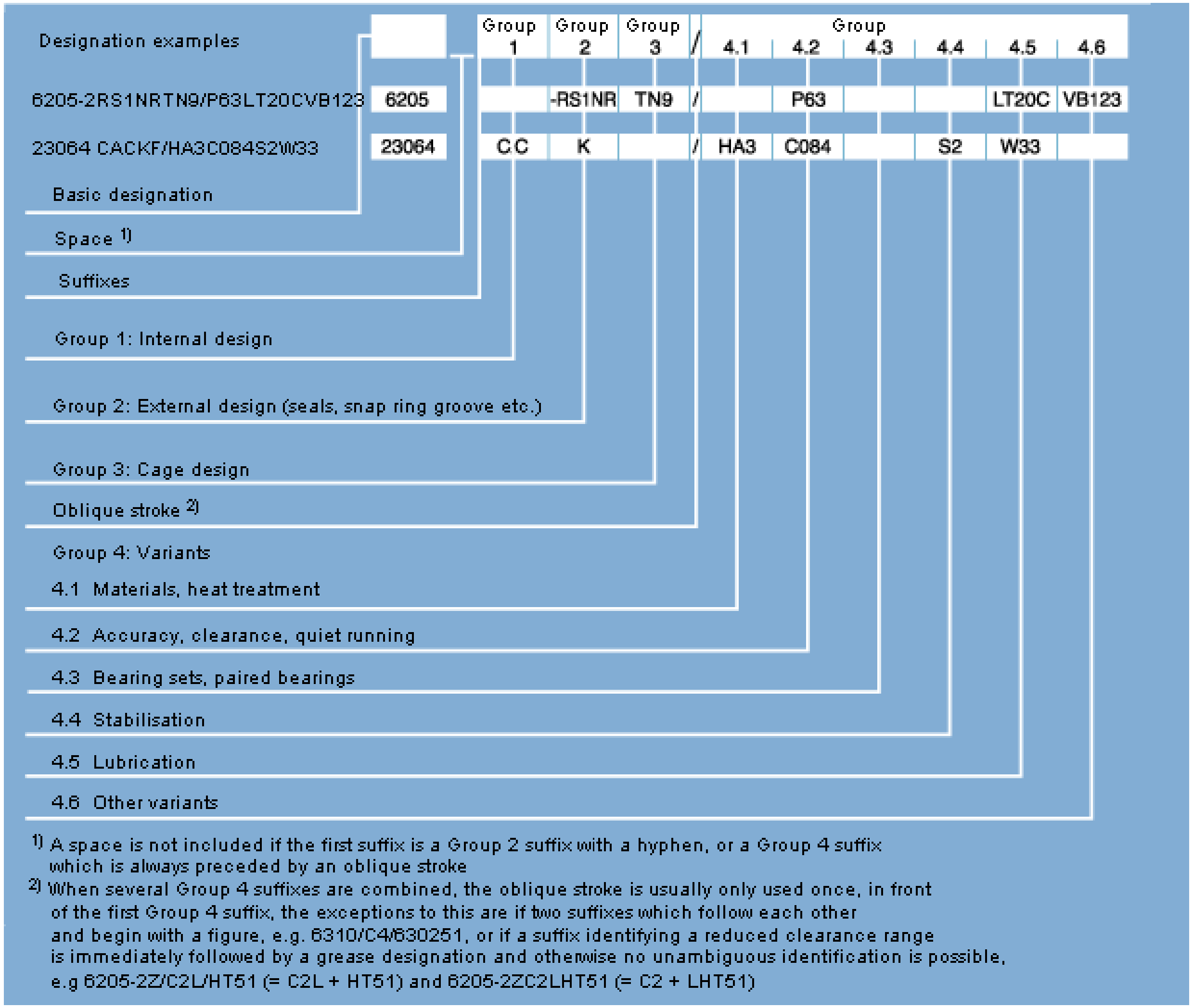
SKF Bearing designation system

Prefix

AR-	Ball or roller and cage assembly
E2.	SKF Energy Efficient bearings
GS	Housing washer of a cylindrical roller thrust bearing
IR-	Inner ring of radial bearing
K	Cylindrical roller and cage thrust assembly
K-	Inner ring with roller and cage assembly (cone) or outer ring (cup) of inch tapered roller bearing belonging to an ABMA standard series
L	Separate inner or outer ring of a separable bearing
OR-	Outer ring of radial bearing
R	Inner or outer ring with roller (and cage) assembly of a separable bearing
W	Stainless steel deep groove ball bearing
WF	Deep groove ball bearing of stainless steel with external flange on outer ring
WS	Shaft washer of a cylindrical roller thrust bearing
ZE	Bearing with SensorMount® feature

SKF Bearing designation system

Suffix



"You cannot depend on your eyes when your imagination is out of focus."

Mark Twain

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