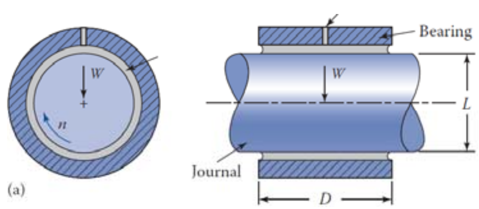
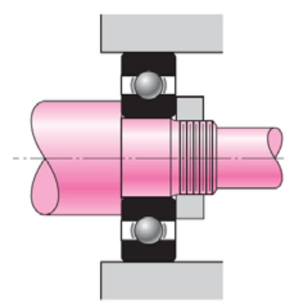
Bearings

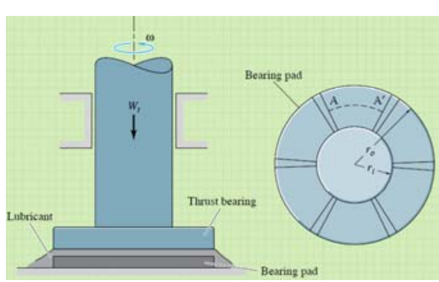
- Bearing: Transfer of load through contact
- Bearings are machine elements that
  - facilitate load transfer between two parts
  - also allows relative motion between them
- Issues
  - Contact stresses
  - Friction
  - Wear
  - Power loss due to frictional heating
- Simplest example
  - Door hinge
  - Hinges in a laptop display
- Bi-cycle: How many bearings are there?

Types of Bearings

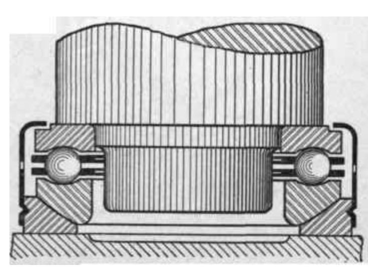


Radial Load

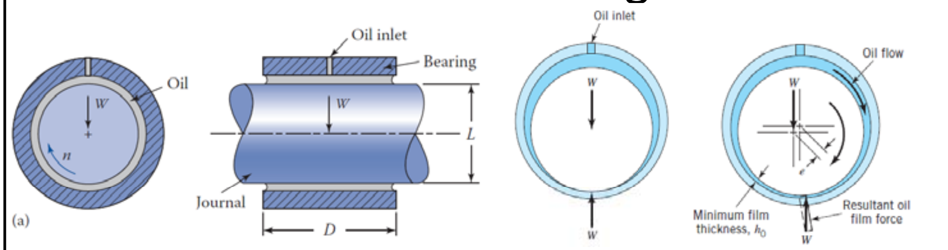




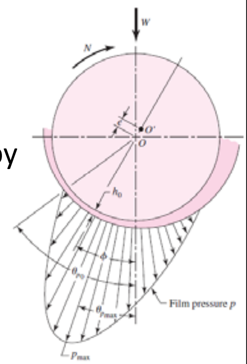
Thrust Load



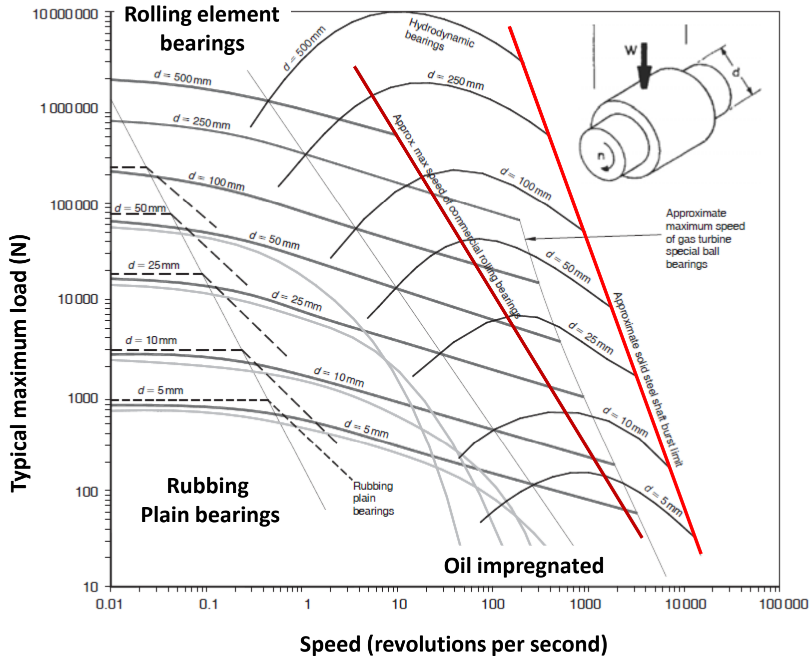
Journal bearing



- When the journal rotates, an oil film develops and thereafter, there is no metal to metal contact between bearing and journal
- Hydrodynamic bearings- Oil pressure is generated by journal rotation
  - High horse power high load applications: Crank shaft & connecting rod, steam turbines, compressors
- Hydrostatic bearing- Externally pressurized oil is introduced



Rolling element bearing	**Journal Bearing**
Low starting friction and starting torque	High starting friction and high starting torque
Nosier at high speeds	Quieter operation
Axial dimension small	Axial dimension is relatively large
Larger radial dimension	Radial dimension is smaller
Increase in noise is an indication impending failure	Failure is sudden with catastrophic effects
Can be designed to take both radial and thrust loads	Cannot take thrust loads
Relatively maintenance free	Needs constant monitoring of oil flow, pressure etc.
More accurate positioning of parts possible	Large bearings may need oil cooling systems.



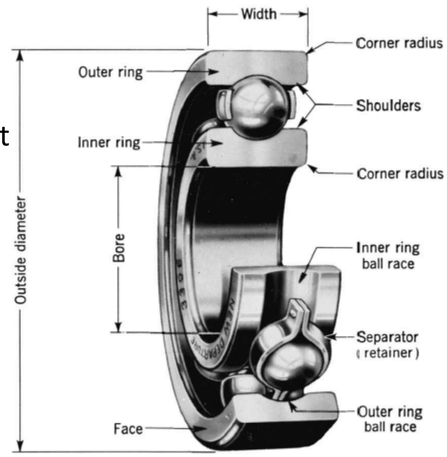
Rolling element bearings

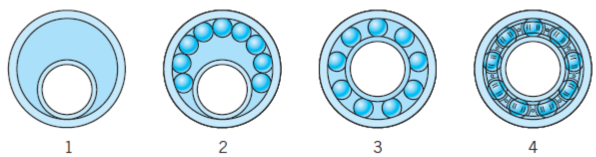
- The main load is transferred through elements in rolling contact
- The starting friction is twice that of rolling friction, but still it is negligible compared to sleeve bearings
- Typical coefficient of friction is about 0.001 to 0.005
- Presence of seals, lubricant, unusual large loads can increase friction further

Rolling element or anti-friction bearings

Outer ring is usually stationary

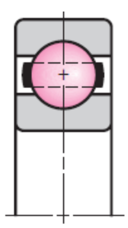
Inner ring is Press fitted to shaft





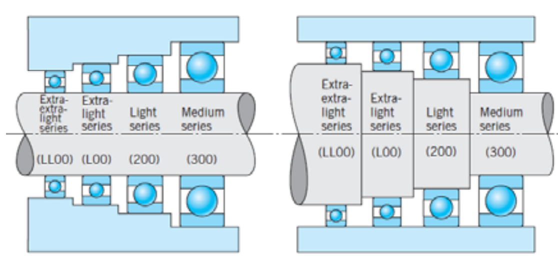
(b)

Deep groove or Conrad type ball bearing



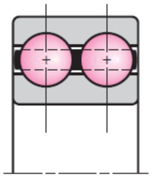
(a)

- Radius of the balls is slightly lower than that of groove to allow free rolling
- Designed primarily for radial loads, but also has good thrust load capacity
- In practice contact occurs over a small circular area due to elastic deformation
- Load capacity can be increased by using more number of balls or larger size balls



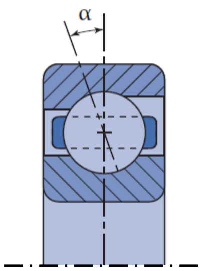
(a) Relative proportions of bearings with same bore dimension

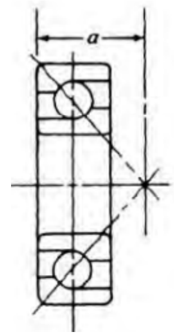
(b) Relative proportions of bearings with same outside diameter



- Increases load capacity
- Increases bearing width
- Less misalignment tolerance

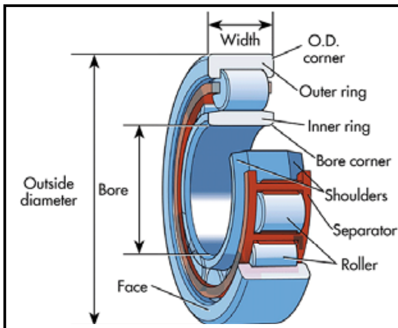
Double row deep groove





Angular contact

- Can accommodate higher thrust loads in one direction along with radial load
- Preferred angle 15˚ ≤ 45˚



Cylindrical roller bearing

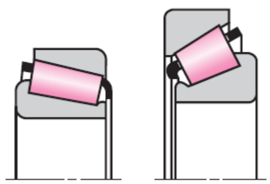
- Cylindrical rollers are used
- Contact is a patch
- Higher radial load capacity
- **Poor thrust load capacity**
- **Should not be subjected to thrust loads at all**

Spherical roller bearing

- Allows outer ring to swivell with respect to inner ring
- Can accommodate misalignment
- Called self aligning bearing
- **Poor thrust load capacity**
- **Should not be subjected to thrust loads at all**

- Roller bearing with small diameter elongated rollers
- Used when radial space is limited
- Cannot withstand thrust loads

Needle bearings



Tapered roller bearing

- Can carry substantial thrust loads along with high radial loads
- Used extensively in automotive wheels

Thrust bearings

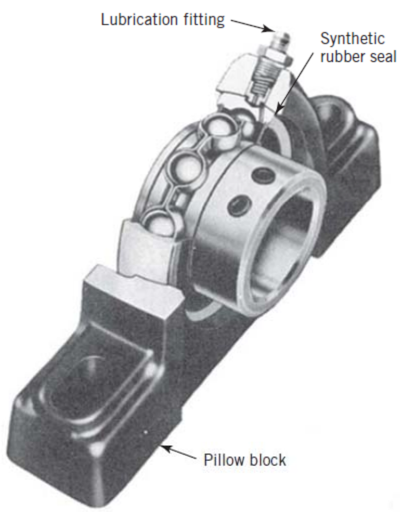
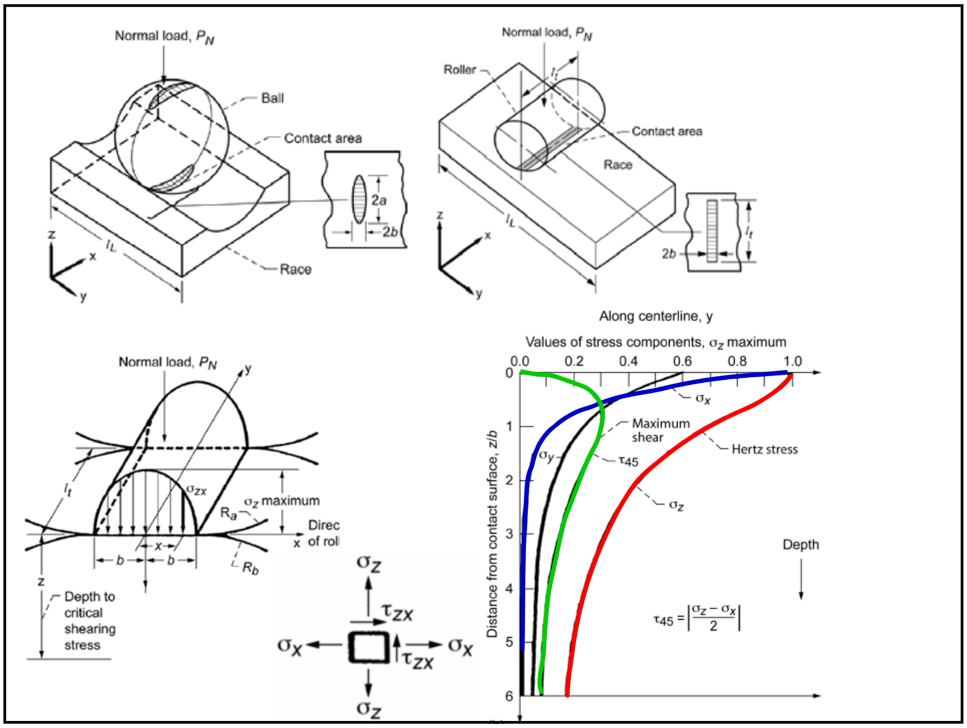


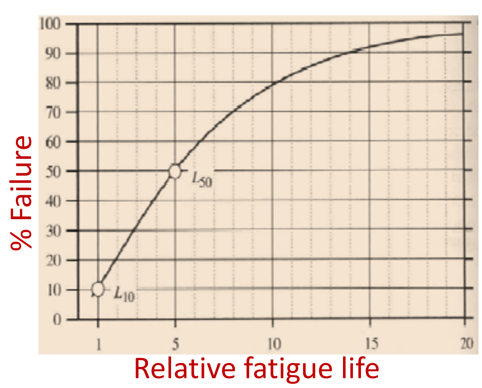
Table 4.5 Merits of different rolling contact bearings

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

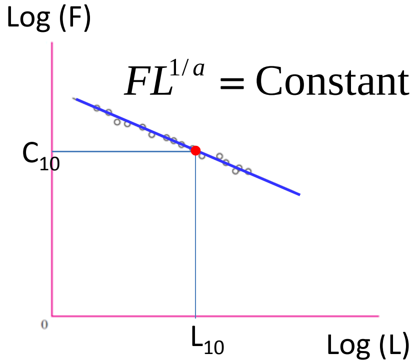


Rolling element bearing life

- L_{10} life: The number of revolutions or hours at a constant speed that 90% of a nominally identical group of bearings will achieve or exceed before failure
- L_{50} is 4 to 5 times L_{10}
- C_{10} load rating for a bearing: the radial load (dynamic) for which L_{10} life is assured with 90% reliability- Given in bearing catalogues



Bearing selection



$$F_D L_D^{1/a} = C_{10} L_{10}^{1/a}$$

$$C_{10} = F_D \left(\frac{L_D}{L_{10}}\right)^{1/a}$$

$$a = \begin{cases} 3 \text{ for ball bearings} \\ 10/3 \text{ for roller bearings} \end{cases}$$

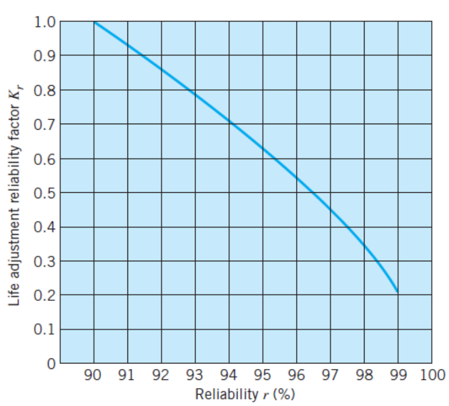
$L_{10} = 10^6$ revolutions for SKF

$L_{10} = 90 \times 10^6$ revolutions for Timken

The reliability in this case is 90% or 0.9 as L_{10} life is used

Factoring reliability

- **If there are n bearings in a machine, each designed with reliability of 0.9, then the combined reliability is 0.9^n**
- **If a combined reliability of 0.9 for the machine is desired then each bearing should be designed for a reliability greater than 0.9**
- **Bearing life follows Weibull distribution**



$$C_{10} = F_D \left(\frac{L_D}{K_r L_{10}}\right)^{1/a}$$

$$K_r = 4.48\{\ln(100/R)\}^{2/3}$$

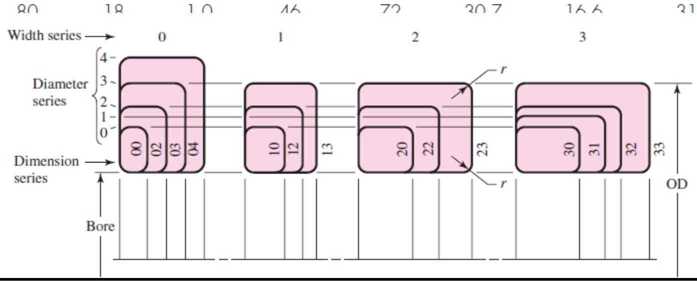
R is reliability in %

Table 11–2

SKF bearings: $L_{10} = 10^6$ revolutions

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	31.0	18.6
45									21.2
50									22.8



Bearings with thrust and radial load

- When there is a radial load F_r and a thrust load F_a; then the bearing is chosen using an equivalent radial load F_e

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

$$\frac{F_a}{VF_r} \le e; \; X_i = 1 \text{ and } Y_i = 0$$

Axial load does not affect radial load capacity

$$\frac{F_a}{VF_r} > e; \text{ refer table for } X_i \text{ and } Y_i$$

$$V = \begin{cases} 1 \text{ if inner race is rotating} \\ 1.2 \text{ if outer race is rotating} \end{cases}$$

$$V = \; 1 \text{ in both case for self aligning bearing}$$

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: The static load which the bearing can withstand without permanent deformation of any component
- Permanent deformation is called Brinnelling- noisy bearing
- A load of $8C_0$ or more is required to fracture a bearing.
- C_0 can be exceed if the speed is not very high

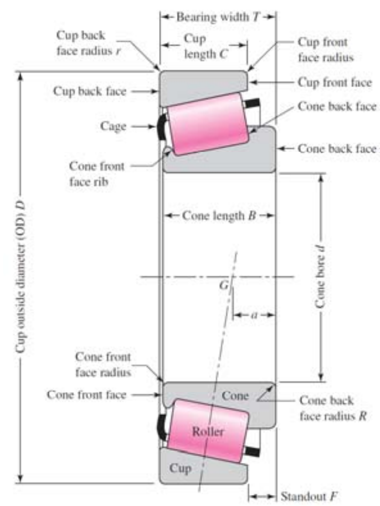
Dimensions and Basic Load Ratings for Cylindrical Roller Bearings

	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

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

Selection of tapered roller bearings

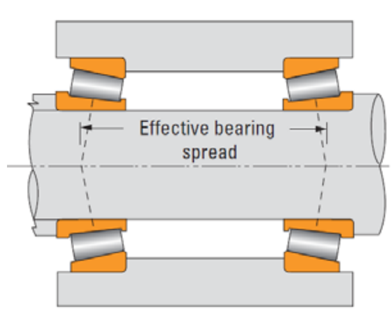


G is the point on the shaft where the resultant reaction is assumed to act

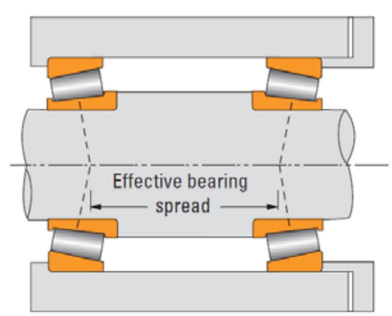
- A radial load generates a thrust load which will separate the cup and cone

$$F_{ai} = \frac{0.47F_r}{K} \text{ for Timken bearings}$$

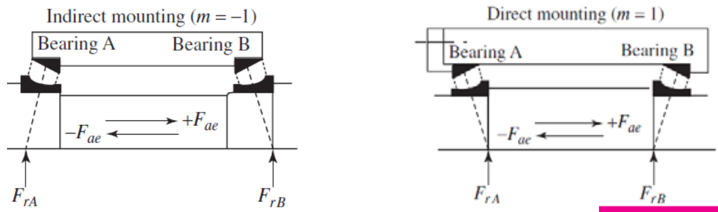
- *K* depends on bearing size. The above equation assumes a load zone of 180 degrees.



INDIRECT MOUNTING – Tapered Roller Bearing (Back-to-Back – Angular Contact Ball Bearings)

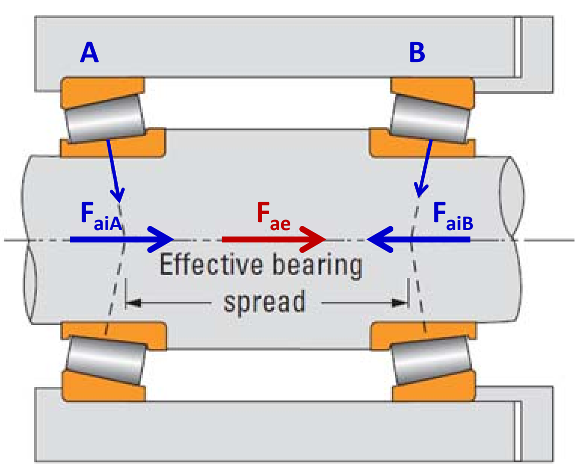


DIRECT MOUNTING – Tapered Roller Bearing (Face-to-Face – Angular Contact Ball Bearings)



Thrust Condition	Thrust Load	Dynamic Equivalent Radial Load
$\frac{0.47F_{rA}}{K_A} \le \frac{0.47F_{rB}}{K_B} - mF_{ae}$	$F_{aA} = \frac{0.47F_{rB}}{K_B} - mF_{ae}$	$P_A = 0.4F_{rA} + K_A F_{aA}$
	$F_{aB} = \frac{0.47F_{rB}}{K_B}$	$P_B = F_{rB}$
$\frac{0.47F_{rA}}{K_A} > \frac{0.47F_{rB}}{K_B} - mF_{ae}$	$F_{aA} = \frac{0.47F_{rA}}{K_A}$	$P_A = F_{rA}$
	$F_{aB} = \frac{0.47F_{rAB}}{K_A} + mF_{ae}$	$P_B = 0.4F_{rB} + K_B F_{aB}$

Note: If $P_A < F_{rA}$, use $P_A = F_{rA}$ or if $P_B < F_{rB}$, use $P_B = F_{rB}$.



DIRECT MOUNTING – Tapered Roller Bearing
(Face-to-Face – Angular Contact Ball Bearings)

$$F_{aiA} = \frac{0.47F_{rA}}{K_A}$$

$$F_{aiB} = \frac{0.47F_{rB}}{K_B}$$

$$F_{aiA} \le F_{aiB} - F_{ae}$$
$$F_{aA} = F_{aiB} - F_{ae}$$
$$P_A = 0.4F_{rA} + K_A F_{aA}$$
$$P_B = F_{rB}$$

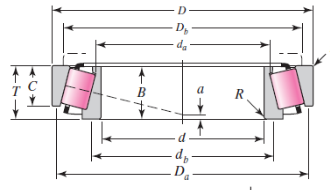
$$F_{aiA} > F_{aiB} - F_{ae}$$
$$F_{aB} = F_{aiA} + F_{ae}$$
$$P_A = F_{rA}$$
$$P_B = 0.4F_{rB} + K_B F_{aB}$$

- K_A and K_B are known only after selecting a bearing
- Assume K_A and K_B as 1.5 at start and then iterate

Timken

- L_{10} is 90 x 10^6 revolutions
- Negative 'a' means center is inside cone's back face
- The thrust load rating given is for pure thrust load, i.e. zero radial load

SINGLE-ROW STRAIGHT BORE



									cone				cup			
bore	outside diameter	width	rating at 500 rpm for 3000 hours L_{10}		factor	eff. load center	part numbers		max shaft fillet radius	width	backing shoulder diameters		max housing fillet radius	width	backing shoulder diameters	
			one-row radial	thrust			cone	cup								
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

Preloading

- Removes internal clearances
- Increases fatigue life
- Reduces shaft slope
- **Follow manufacture's recommendation**

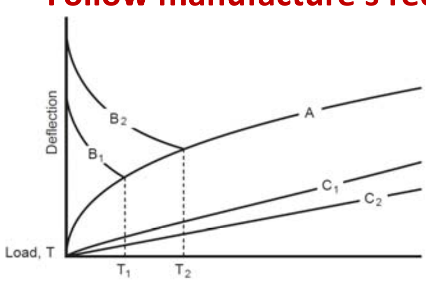
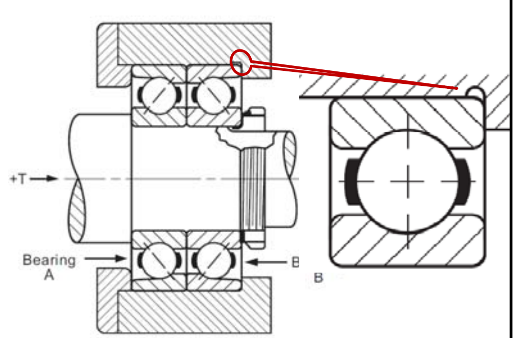
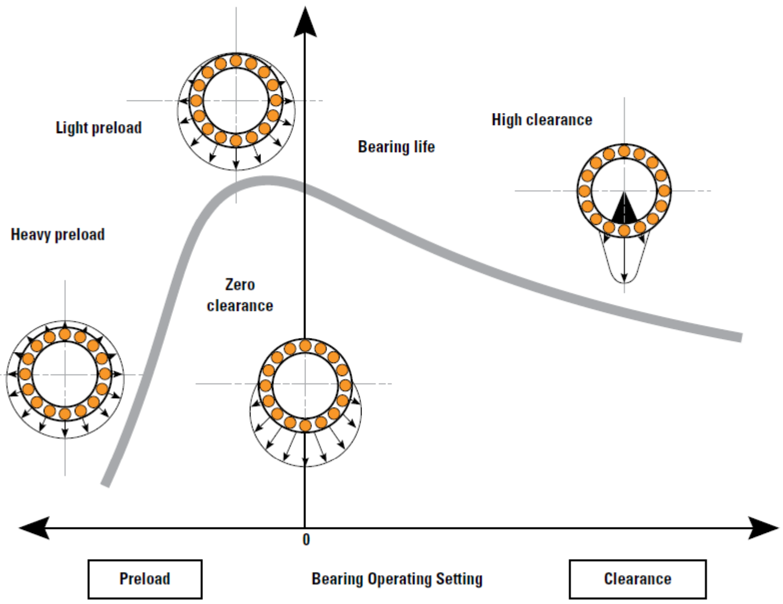


Fig. A-29
Axial load-deflection curve of back-to-back mounted angular-contact bearings. Curve A is for Bearing A, B is for bearing B, and C_1 and C_2 are preload curves.



- **Bearing radial stiffness: 80-150 kN/mm**



Bearing life versus bearing operating conditions

(Timken bearing damage analysis with lubrication reference guide)

Misalignment

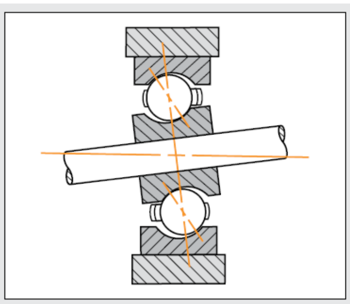


Fig. 35A. Shaft misalignment.

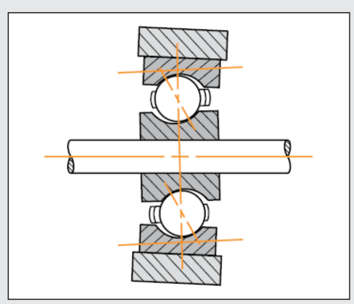


Fig. 35B. Housing misalignment.

(Timken bearing damage analysis with lubrication reference guide)

- Misalignment tolerance
  - Tapered roller bearing: < 0.001 radians
  - Spherical roller bearings: < 0.0087 radians
  - Deep groove ball bearings: 0.0035 to 0.0047 radians
- **If there is misalignment, a load factor of 2 is desirable**

Lubrication

- Roller bearings are lubricated for
  - Distributing and dissipating heat
  - Preventing corrosion
  - Protection from contamination
- Grease
  - < 90^{o} C, low speed and unattended operation
- Oil
  - High speed and high temperature, requires a seal

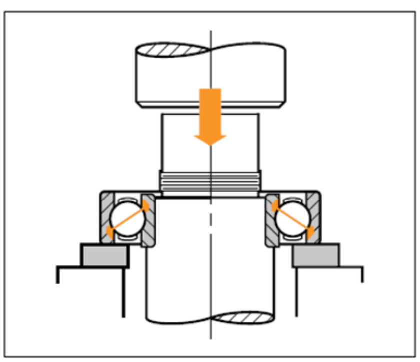


Fig. 55A. *Incorrect.*

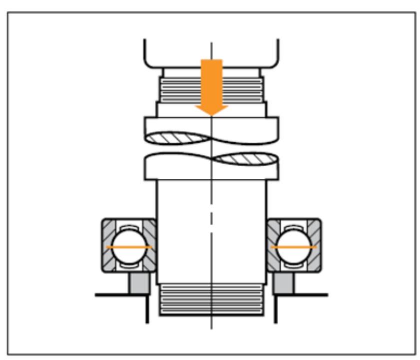


Fig. 55B. *Correct.*

(Timken bearing damage analysis with lubrication reference guide)

Bearing life

- The following can reduce the installed life of a bearing
  - Faulty mounting
  - Improper adjustment
  - Insufficient lubrication
  - Contamination
  - Abuse (over load)
  - Poor housing support
  - High static misalignment or shaft/housing deflection
  - Inconsistent or improper maintenance practices

(Timken bearing damage analysis with lubrication reference guide)

Fig. 25. Heavy spalling and fracturing from high loads on this spherical

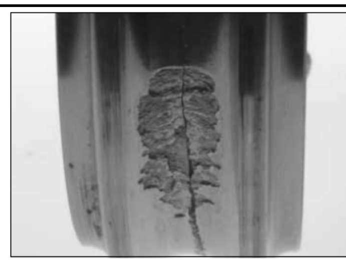
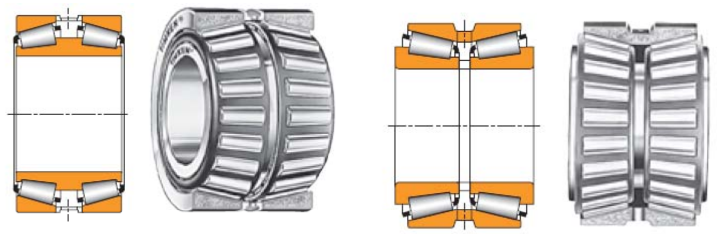


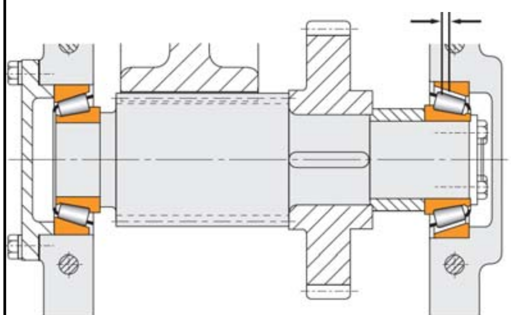
Fig. 27. This ball bearing inner ring depicts fatigue spalling from high loads. The fracture is a secondary damage mode.

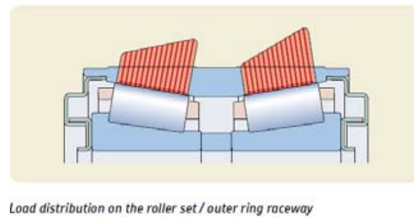
Fig. 22. Level 4 – This is an example of total bearing lockup.

Fig. 38. The housing bore was machined with an improper taper, causing the uneven load distribution and GSC spalling in this cylindrical roller bearing outer ring.

(Timken bearing damage analysis with lubrication reference guide)







Axial clearance for end play

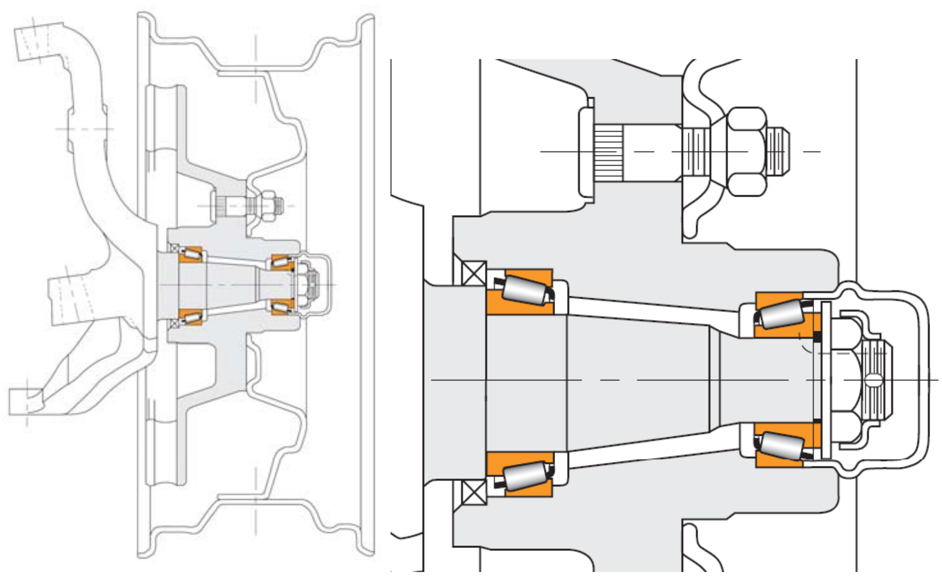


Fig. A-26
Truck nondriven wheel.