ME 1110 – Engineering Practice 1

Engineering Drawing and Design - Lecture 14

Mechanical Elements – Bearings

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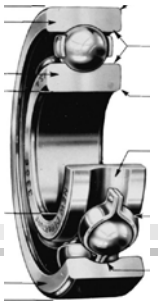
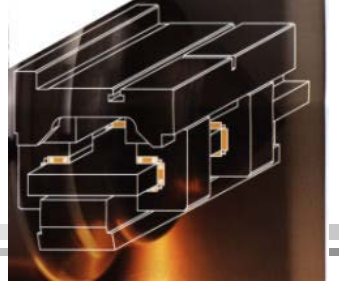
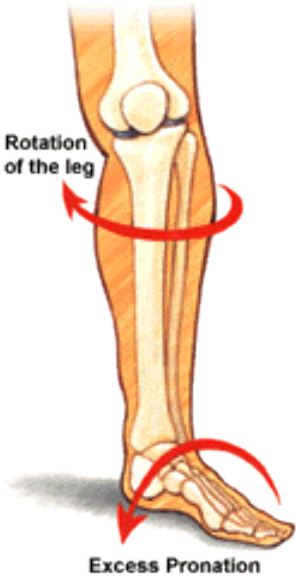
www.staff.city.ac.uk/~ra600/intro.htm

Introduction





Design web

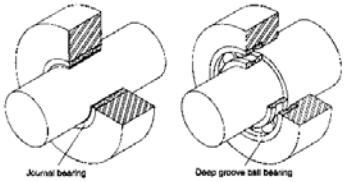


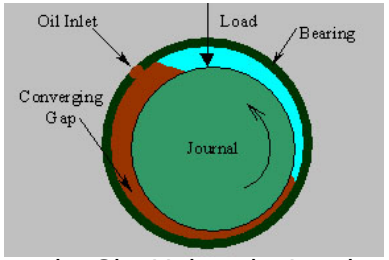
What is a bearing?

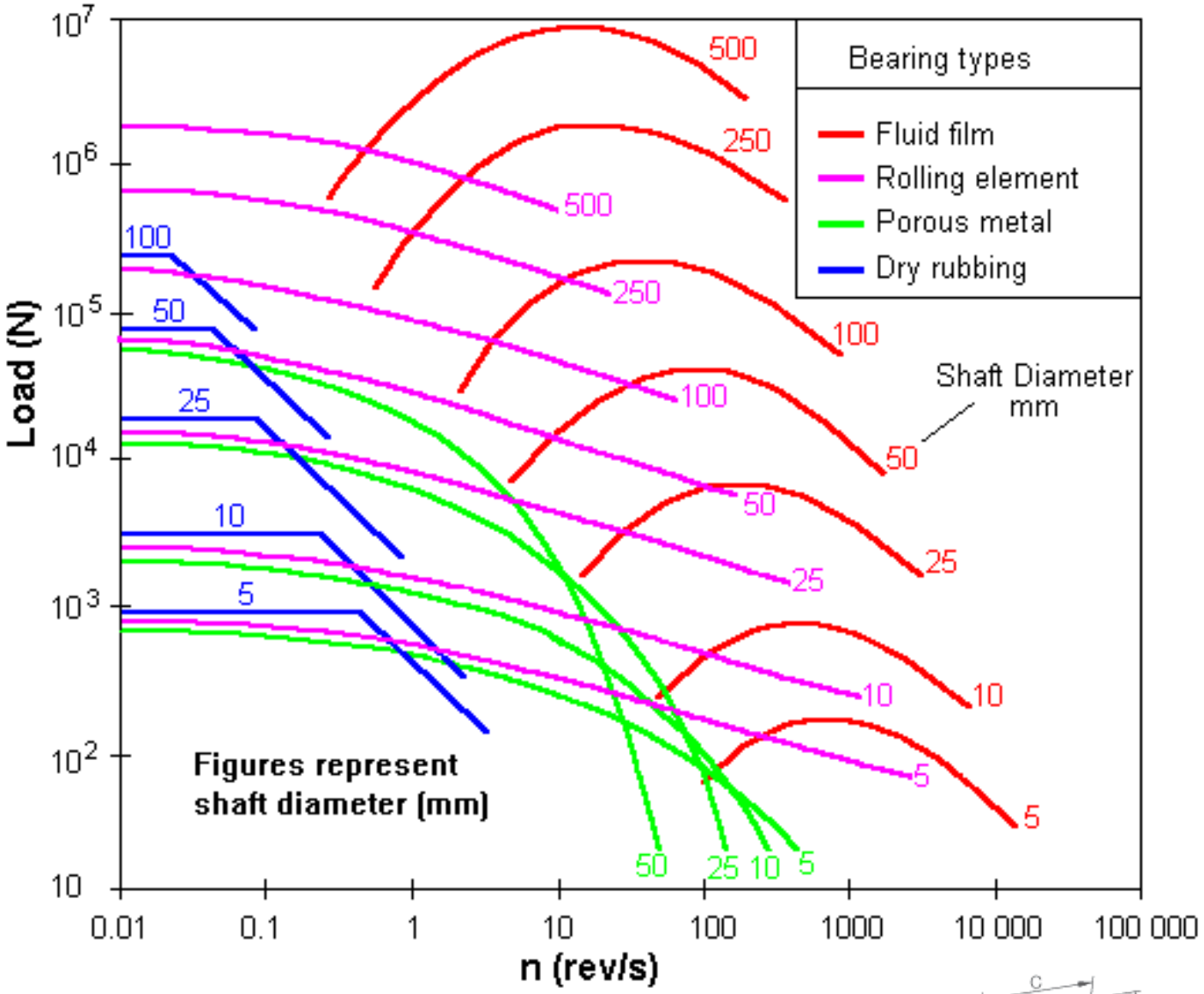
- In general - *a support or supporting element*
- In machine design - *a component that allows for relative motion between two bodies*

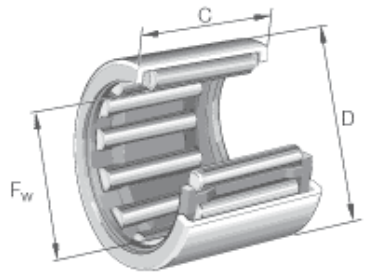
- Your skeleton is the central structure that supports your body and its modules
  Your ***joints are bearings*** that allow different body modules to move with respect to each other
- Bearings allow machines or their parts to move

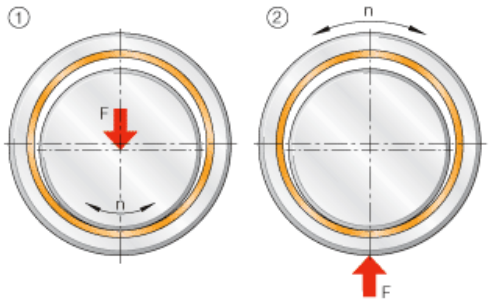
- Bearings can have many forms, but only two types of motions:
  Linear motion or **rotary** motion
- In all bearings, cleanliness and surface finish are most important
- There are many different types of bearings:
  - Sliding
  - Rolling
  - Flexing
  - Fluid Film (hydrodynamic)



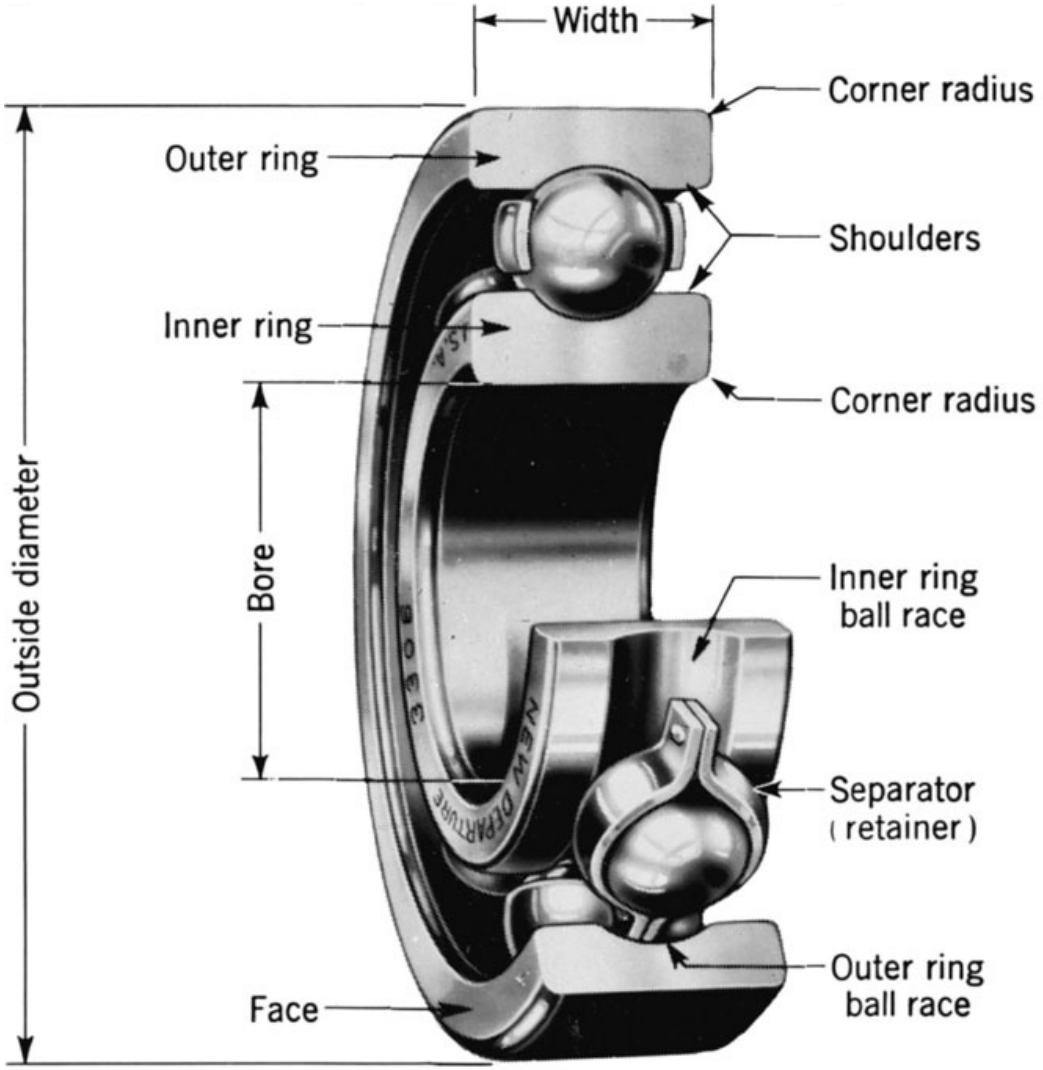



Load (N)
10^7
10^6
10^5
10^4
10^3
10^2
10
0.01
0.1
1
10
100
1000
10 000
100 000
n (rev/s)
Bearing types
Fluid film
Rolling element
Porous metal
Dry rubbing
Shaft Diameter
mm
Figures represent
shaft diameter (mm)
500
250
100
50
25
10
5


C
D
F_w


①
②
n
F
n
F

Rolling element bearings



Designed to take:

- Pure radial loads
- Pure thrust loads
- Combination of the two kinds of loads

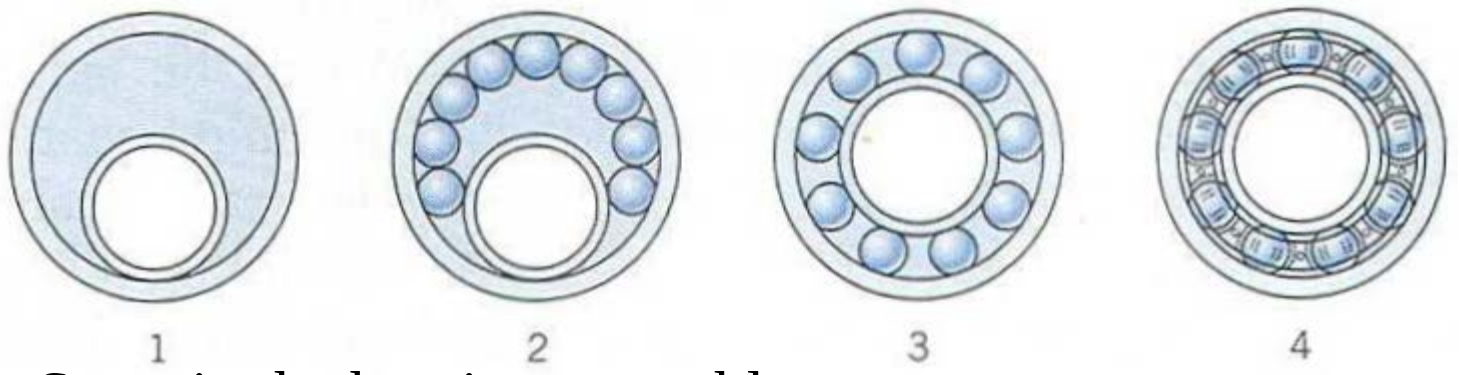
Main parts:

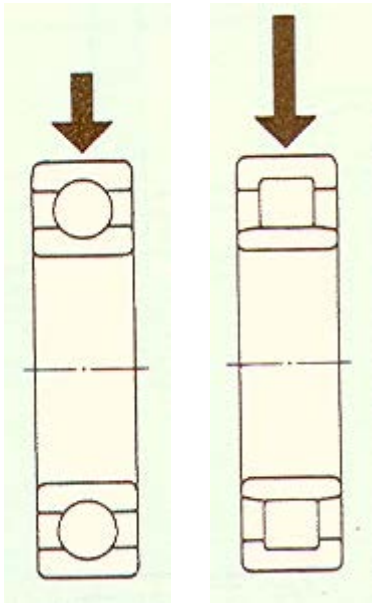
- Outer ring
- Inner ring
- Rolling elements (balls)
- Separator

Selection of bearings:

- Type and amount of load (axial - thrust, radial)
- Size, Speed
- Lubrication
- Life rating

Bearing assembly





Steps in the bearing assembly:

1. The inner ring inserted into the outer ring
2. Balls inserted in the remaining space
3. Balls distributed equidistantly, rings concentric
4. Retainer secures the balls

Number and size of balls determine the bearing load

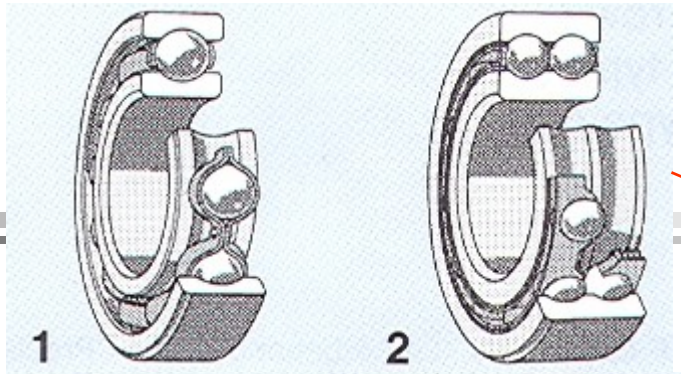
- More balls - smaller balls <> higher load-lower speed
- Less balls - bigger balls <> lower load-higher speeds

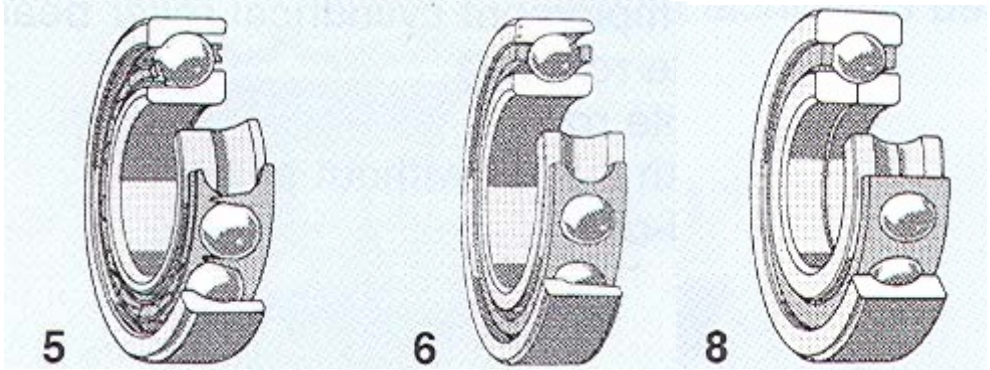
Rolling bearing types:

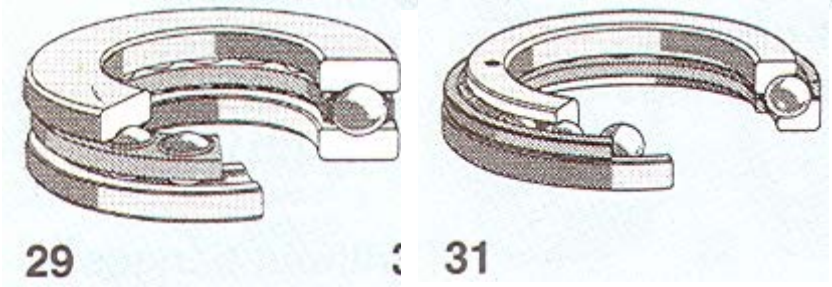
- Ball - roller
- Needle - taper roller & spherical roller

Roller bearings take more load then ball bearings

Ball Bearings





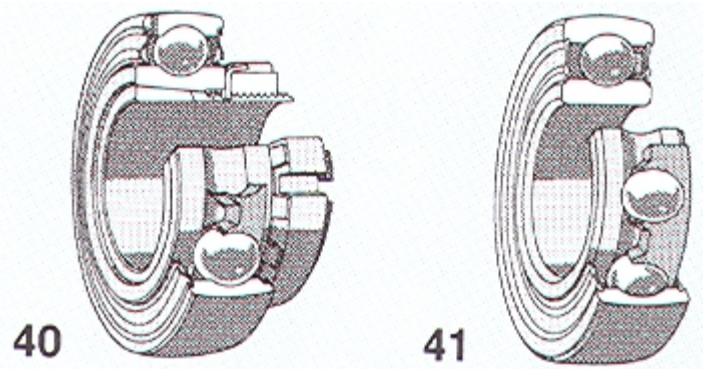


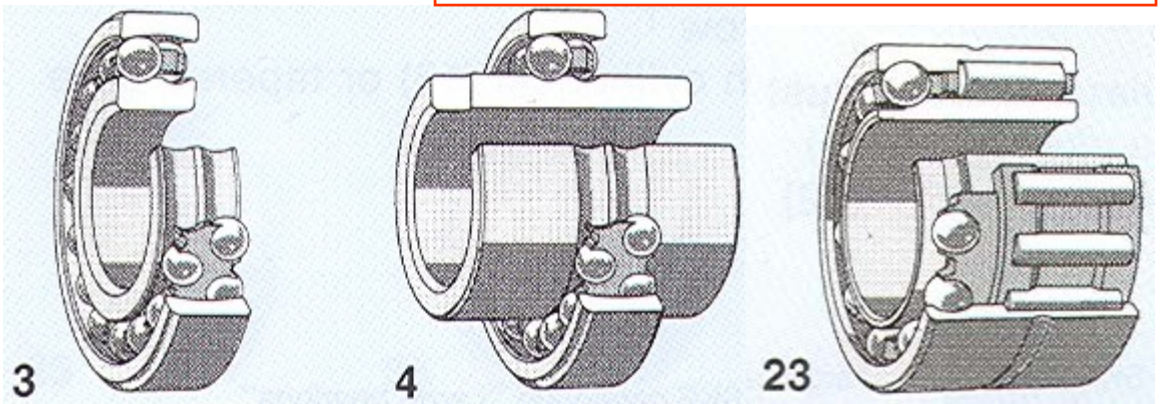
Deep groove ball bearings:
Take both radial and axial force

Angular contact – axial force:
2 point; 4 point

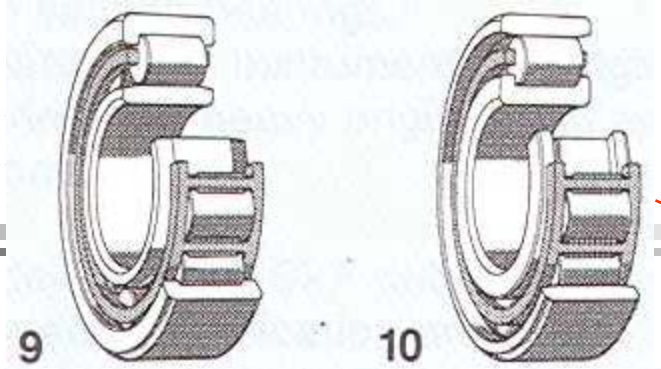
Thrust Ball bearings:
Deep grove, angular contact

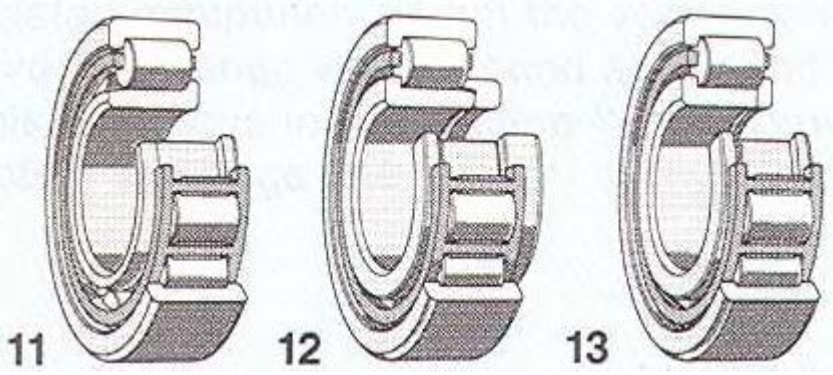
Special, self aligning and combined
Ball bearings

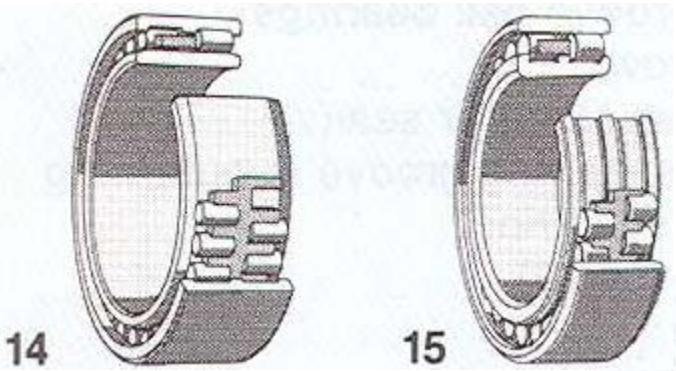


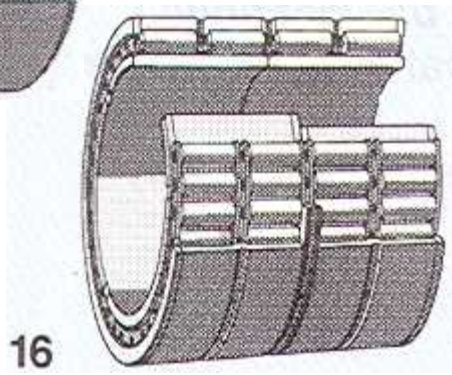


Straight Roller Bearings







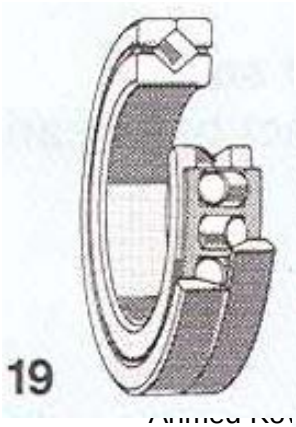


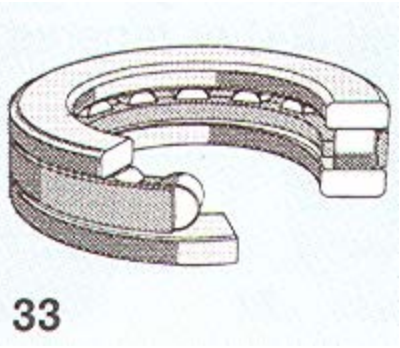
NU and N Types
radial force

NJ, NI Types
Better location, some thrust

Multi-row straight
Roller bearings

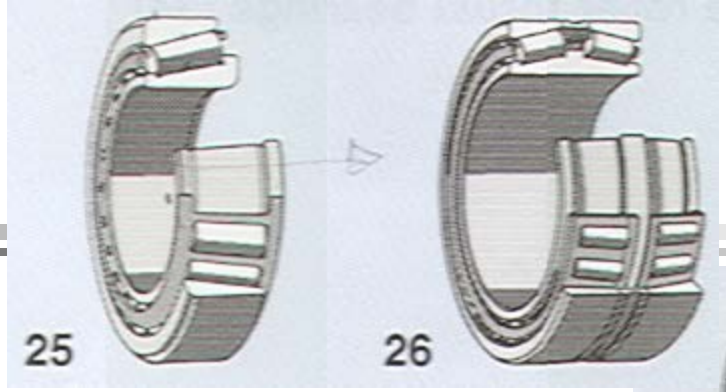
Thrust straight rollers
Combined radial and thrust



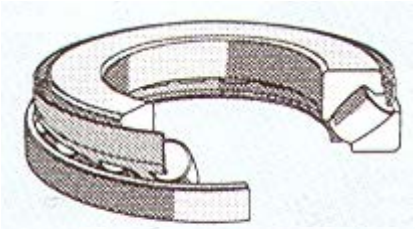


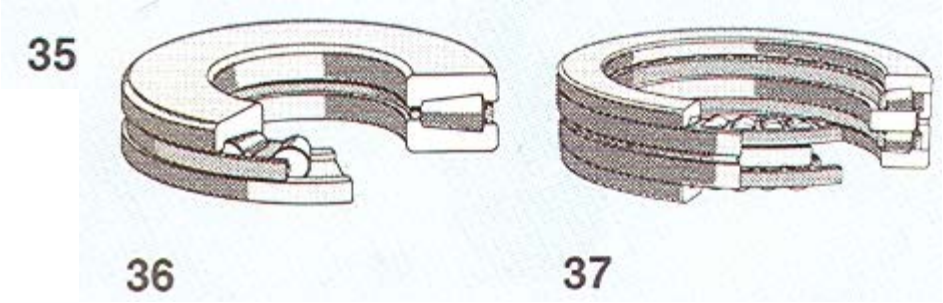
Taper Roller and Needle Bearings

Design web



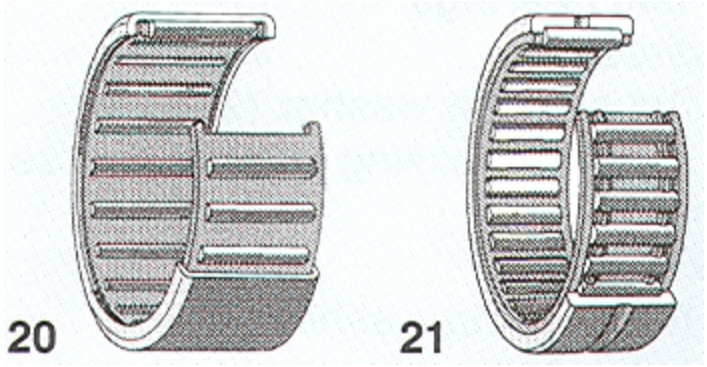
Taper roller bearing
radial and axial load

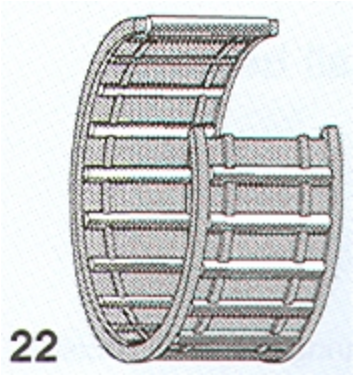


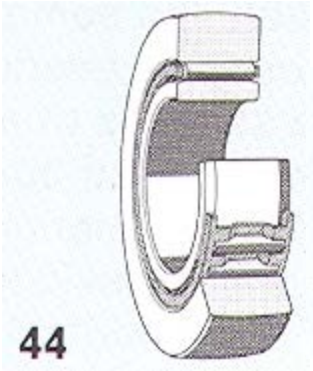


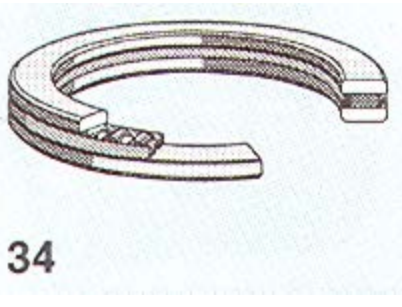
Thrust taper roller bearing
Mainly axial load

Needle roller bearings
with or without inner ring,
thrust

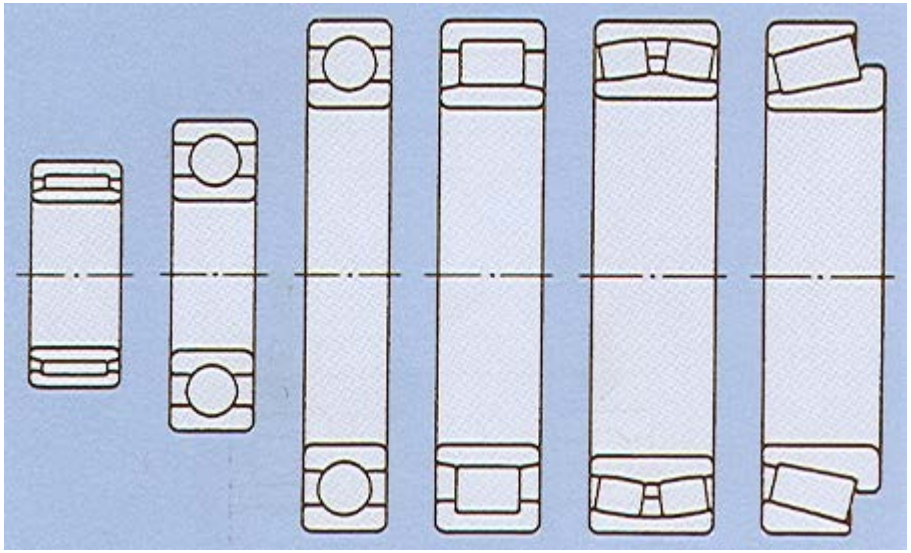


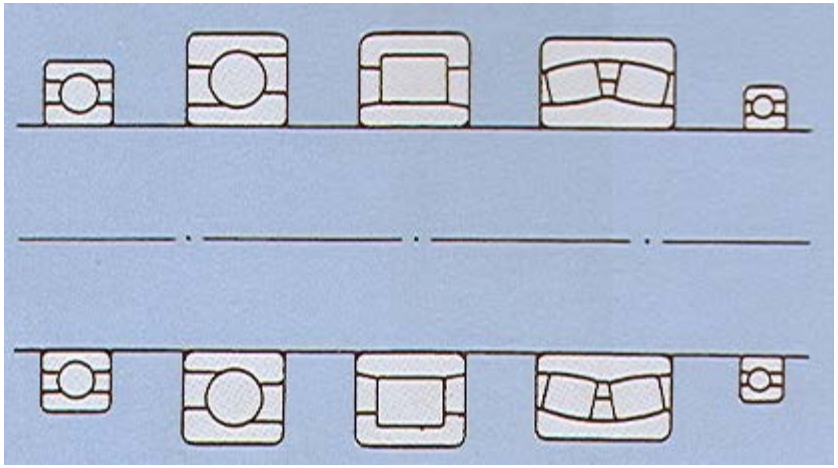


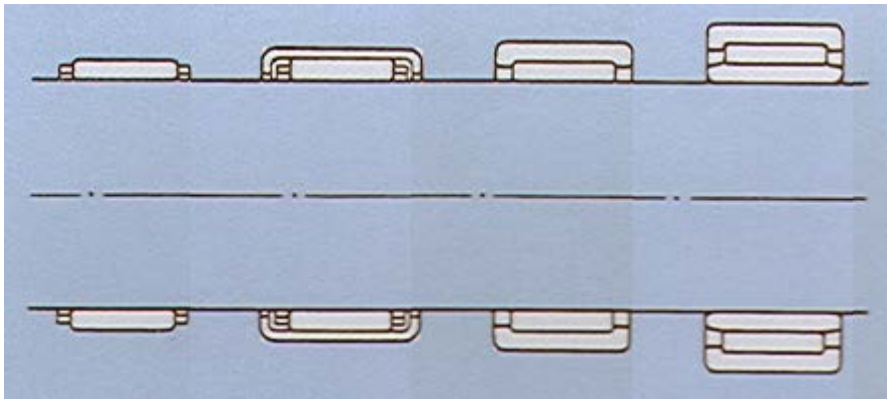


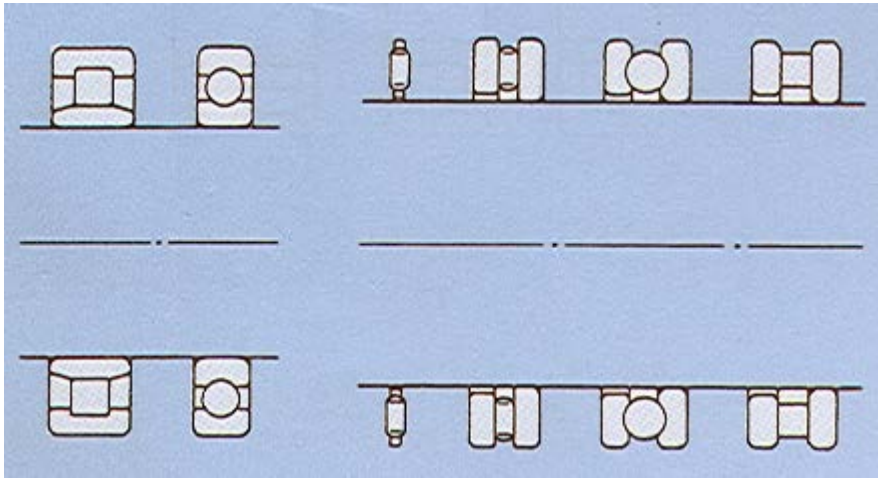


Comparison of bearing types

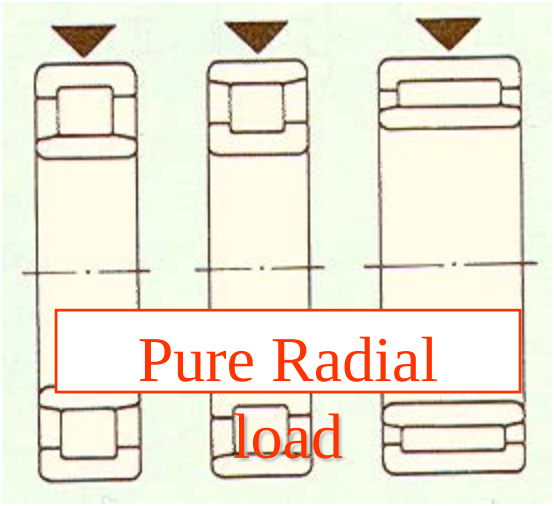


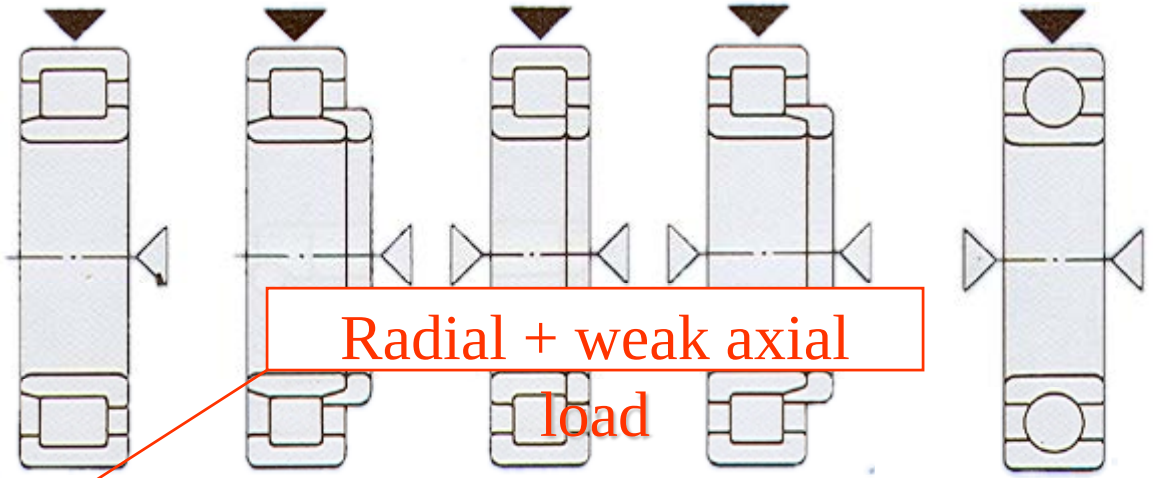


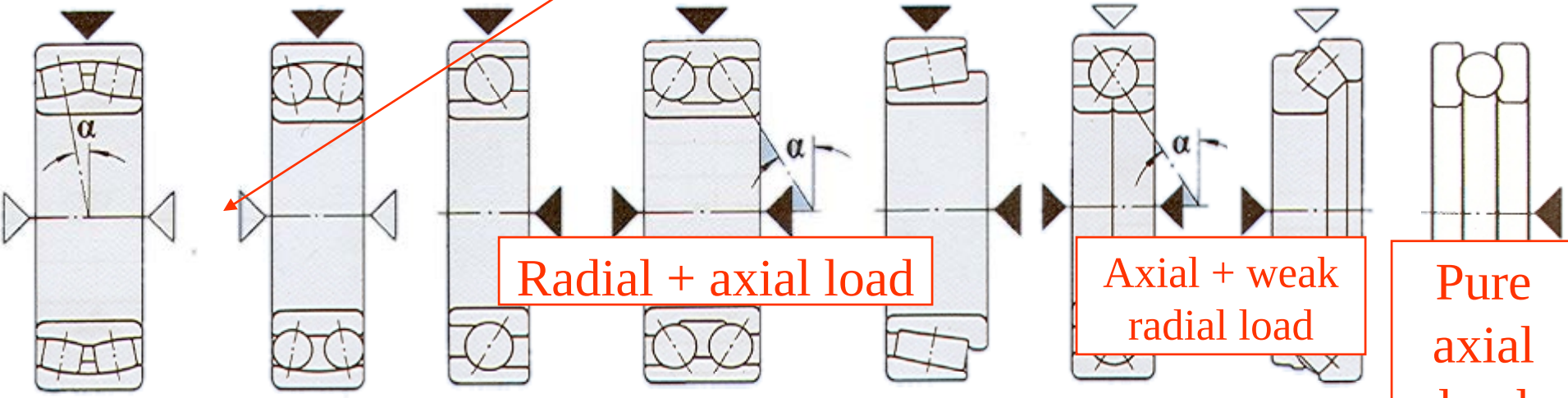




Forces that bearings can sustain

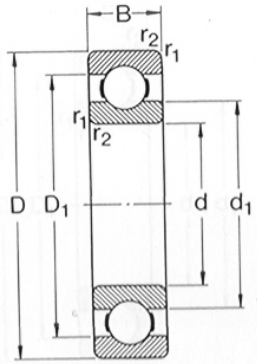




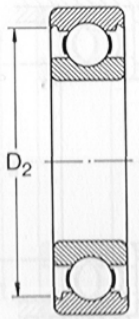


How to select the bearing from the catalogue

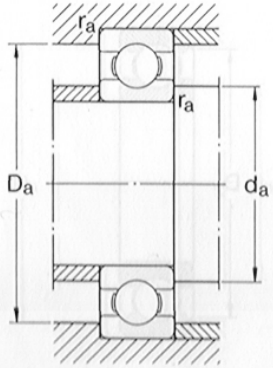
Deep groove ball bearings
single row
d **35–55** mm



With full outer ring shoulders



With recessed outer ring shoulders



Principal dimensions			Basic load ratings dynamic	static	Fatigue load limit	Speed ratings Lubrication grease	oil	Mass	Designation
d	D	B	C	C_0	P_u				
mm			N		N	r/min		kg	–
35	47	7	4 750	3 200	166	13 000	16 000	0,030	**61807**
	55	10	9 560	6 200	290	11 000	14 000	0,080	**61907**
	62	9	12 400	8 150	375	10 000	13 000	0,11	**16007**
	62	14	15 900	10 200	440	10 000	13 000	0,16	**6007**
	72	17	25 500	15 300	655	9 000	11 000	0,29	**6207**
	80	21	33 200	19 000	815	8 500	10 000	0,46	**6307**
	100	25	55 300	31 000	1 290	7 000	8 500	0,95	**6407**
40	52	7	4 940	3 450	186	11 000	14 000	0,034	**61808**
	62	12	13 800	9 300	425	10 000	13 000	0,12	**61908**
	68	9	13 300	9 150	440	9 500	12 000	0,13	**16008**
	68	15	16 800	11 600	490	9 500	12 000	0,19	**6008**
	80	18	30 700	19 000	800	8 500	10 000	0,37	**6208**
	90	23	41 000	24 000	1 020	7 500	9 000	0,63	**6308**
	110	27	63 700	36 500	1 530	6 700	8 000	1,25	**6408**
45	58	7	6 050	4 300	228	9 500	12 000	0,040	**61809**
	68	12	14 000	9 800	465	9 000	11 000	0,14	**61909**
	75	10	15 600	10 800	520	9 000	11 000	0,17	**16009**
	75	16	20 800	14 600	640	9 000	11 000	0,25	**6009**
	85	19	33 200	21 600	915	7 500	9 000	0,41	**6209**
	100	25	52 700	31 500	1 340	6 700	8 000	0,83	**6309**
	120	29	76 100	45 000	1 900	6 000	7 000	1,55	**6409**

Dimensions						Abutment and fillet dimensions		
d	d_1 ≈	D_1 ≈	D_2 ≈	$r_{1,2}$ min		d_a min	D_a max	r_a max
mm						mm		
35	38,7	43,5	–	0,3		37	45	0,3
	41,6	48,6	–	0,6		39	51	0,6
	44	53,3	–	0,3		37	60	0,3
	43,7	53,6	55,7	1		40	57	1
	46,9	60,6	62,7	1,1		41,5	65,5	1
	49,5	66,1	69,2	1,5		43	72	1,5
	57,4	80,6	–	1,5		43	92	1,5
40	43,7	48,5	–	0,3		42	50	0,3
	47	55,2	–	0,6		44	58	0,6
	49,4	57	–	0,3		42	66	0,3
	49,2	59,1	61,1	1		45	63	1
	52,6	67,9	69,8	1,1		46,5	73,5	1
	56,1	74,7	77,7	1,5		48	82	1,5
	62,8	88	–	2		49	101	2
45	48,7	54,5	–	0,3		47	56	0,3
	52,3	60,8	–	0,6		49	64	0,6
	55	65,4	–	0,6		49	71	0,6
	54,7	65,6	67,8	1		50	70	1
	57,6	72,9	75,2	1,1		51,5	78,5	1
	62,1	83,7	86,7	1,5		53	92	1,5
	68,9	96,9	–	2		54	111	2

Bearing Life - Definitions

- Contact stresses occur on the inner ring, the rolling element and on the outer ring during a bearing operation.
- If the bearing is clean and properly lubricated is sealed against dirt and operates at normal temperatures then metal fatigue is the only cause of failure.
- Endurance of a bearing is then limiting factor – *bearing life* ***L***:
  - » Number of revolutions of the inner ring until the first evidence of fatigue.
  - » Number of hours of use at standard angular speed until the first evidence of fatigue
- *Rating life (minimum life)* of a bearing, $\boldsymbol{L_{10}}$
  - » *number of revolution or hours of operation that 90% of a group of identical bearings will achieve or exceed before the failure criterion develops.*
- Both previous life estimations are based on the *reliability factor*.
- The 'new' theory includes *fatigue load limit* $\boldsymbol{P_u}$ in the estimation of *the bearing life*

Bearing Life - Calculation

- *The **size** of a bearing* is initially selected on the relation of its ***load carrying capacity*** and ***the*** carried ***load*** with the ***life and reliability r***equirement.
- *Load carrying capacity* is specified for each bearing in a catalogue with:
  - » C – basic dynamic load rating – *for variable loads and high speeds*
  - » Co – basic static load rating - for static loads and low speeds
- *The load* calculated from free body diagrams or by other means.
- *Rating life* can be calculated from the life equation. The form of the life equation depends on the accuracy required. ***Basic rating life is***:

$$L_{10} = \left(\frac{C}{P}\right)^{a} \qquad [10^6\ rev]$$

$$L_{10h} = \frac{10^6}{60n} L_{10} \qquad [hours]$$

$$L_{10s} = \frac{\pi D}{1000} L_{10} \qquad [10^6\ km]$$

a = 3 - for ball bearings
a = 3.33- for roller bearings
P [N] – equivalent dynamic load rating
n [rpm] – rotational speed
D [m] - wheel diameter

Adjusted Bearing Life

- If a bearing is not operating in the ideal conditions then the basic rating life should be adjusted:

$$L_{adj} = a_T \, a_R \, a_{OC} \, L_{10} \qquad [10^6 \, rev]$$

Temperature [^{o}C]	150	200	250	300
a_T	1.00	0.90	0.75	0.60

Reliability [%]	90	95	96	97	98	99
a_R	1.00	0.62	0.53	0.44	0.33	0.21

- Coefficient a_{OC} represents means of lubrication and dust prevention. It varies from 0.20 – 2.20. Values depend on relative viscosity of lubricant. Values higher the one are possible for special lubricants and cooling.

Equivalent dynamic bearing load

$$P = x F_r + y F_a$$

P [N] - equivalent dynamic bearing load
F_r [N] – actual radial bearing load
F_a [N] – actual axial bearing load
x – radial load factor
y – axial load factor

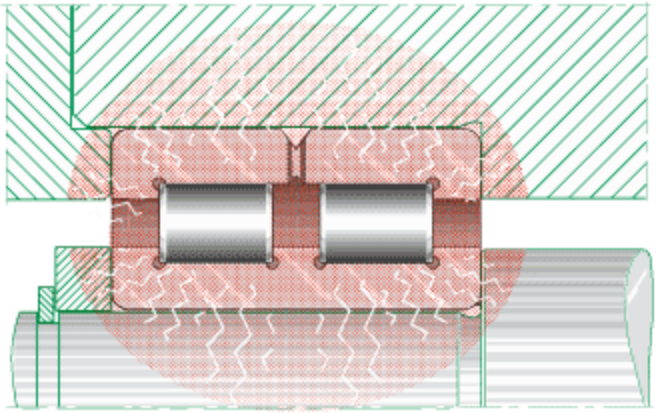
Bearing type	Condition	x	y
Deep groove ball bearing	$F_a/F_r<=0.5$	1	0
	$F_a/F_r>0.5$	0.56	1-2
Self aligning ball bearings	$F_a/F_r<=e^*$	1	Y^*
	$F_a/F_r>e^*$	0.65	y^*
Angular contact ball bearings	$F_a/F_r<=1.14$	1	0
	$F_a/F_r>1.14$	0.35	0.57
Double row angular contact ball bearings	$F_a/F_r<=0.86$	1	0.73
	$F_a/F_r>0.86$	0.62	1.17
Four-point contact ball bearings	$F_a/F_r<=0.95$	1	0.66
	$F_a/F_r>0.95$	0.6	1.07
Cylindrical roller bearing (with flanges)	$F_a/F_r<=0.2$	1	0
	$F_a/F_r>0.2$	0.92	0.6
Needle roller bearings	-	1	0
Trust roller bearings	-	0	1
Taper roller bearings	$F_a/F_r<=e^*$	1	0
	$F_a/F_r>e^*$	0.4	Y^*
Taper roller bearings	1.00	0.75	0.60

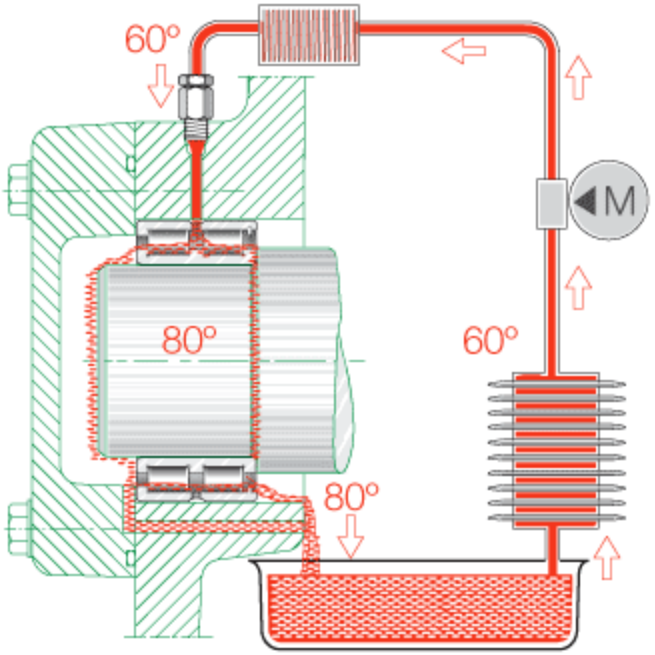
Rearing Type	Direction of Load			Ratio of Load/Bulk			Misalignment Capacity		
	radial	axial	both	high	med	low	high	med	low
Thrust Ball		y			y				y
Deep Groove Ball	y		y		y			y	
Cylindrical Roller	y		certain types		y				y
Needle Roller	y			y					y
Tapered Roller	y	y	y		y				y
Self-aligning Ball	y		y			y	y		
Self-aligning Spherical Roller	y		y		y		y		
Angular Contact Ball		y	y			y			y

Machine Usage Type	Life Required of Bearings (Hours)
household appliances — intermittent use	300 - 3000
hand tools, construction equipment — short period use	3000 - 8000
lifts, cranes — high reliability for short periods	8000 - 12000
8h/day gears, motors — full day partial use	10000 - 25000
8h/day machine tools, fans — full day full use	20000 - 30000
continuous use	40000 - 50000

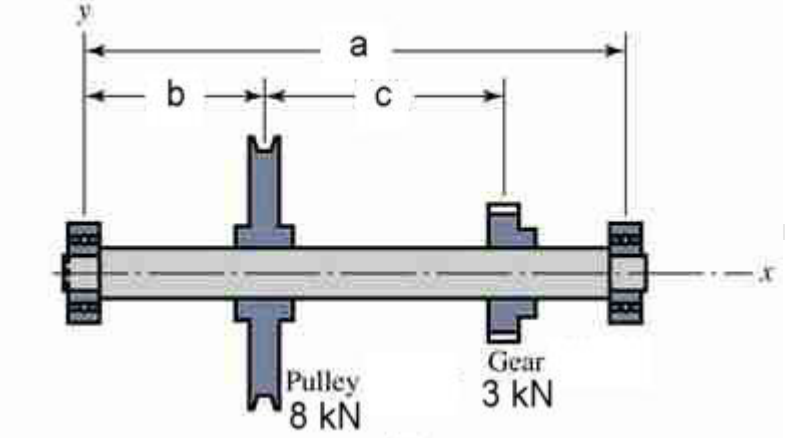
Bearing speeds

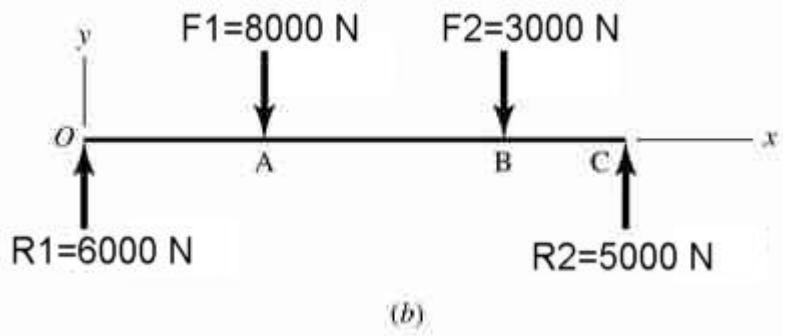
- There is a limit to the speed at which rolling bearings can operate.
- The *top speed* is limited by the operating *temperature* of the bearing.
  The *heat is* generated by the *friction* between rolling elements.
  The heat is removed by: the conduction through the shaft and housing
  lubricant





Example





Select the bearings and determine their rating life for the driving mechanism shown in the Figure. The shaft is 450 mm long and supported by deep-groove bearing in point *O* and plane roller bearing in point *C*. Assume minimum shaft diameter to be 20 mm. Mounted upon the shaft are a V-belt pulley, which contributes a radial load of F_1=8kN to the shaft, and a gear which contributes a radial load of F_2=3kN. The two loads are in the same plane and have the same direction. Minimum required bearing life is 2000 h with 90% reliability. Shaft rotates constantly at n=1000 rpm.

F1=8 kN a=450 mm c=200 mm
F2=3 kN b=150 mm d=20 mm
$L_{10h}=(L_{10h})_O=(L_{10h})_C$=2000 h n=1000 rpm

SOLUTION:

$$L_{10h}=\frac{10^6}{60n}\left(\frac{C}{P}\right)^a \Rightarrow C=P*\sqrt[a]{\frac{60n}{10^6}L_{10h}}$$

$$P_O=R_1=6000N \qquad P_C=R_2=5000N$$

$$C_0=6000*\sqrt[3]{\frac{60*1000}{10^6}2000}=29,595N$$

$$C_0=5000*\sqrt[3.33]{\frac{60*1000}{10^6}2000}=21,025N$$

Selected from the catalogue for deep-groove ball bearings:
6404 20x72x19 mm C=30,700 N

Selected from the catalogue for cylindrical roller bearings:
NU 204 20x47x14 mm C=25,100 N