University of Nottingham
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Bearings 2 – Rolling Element Bearings

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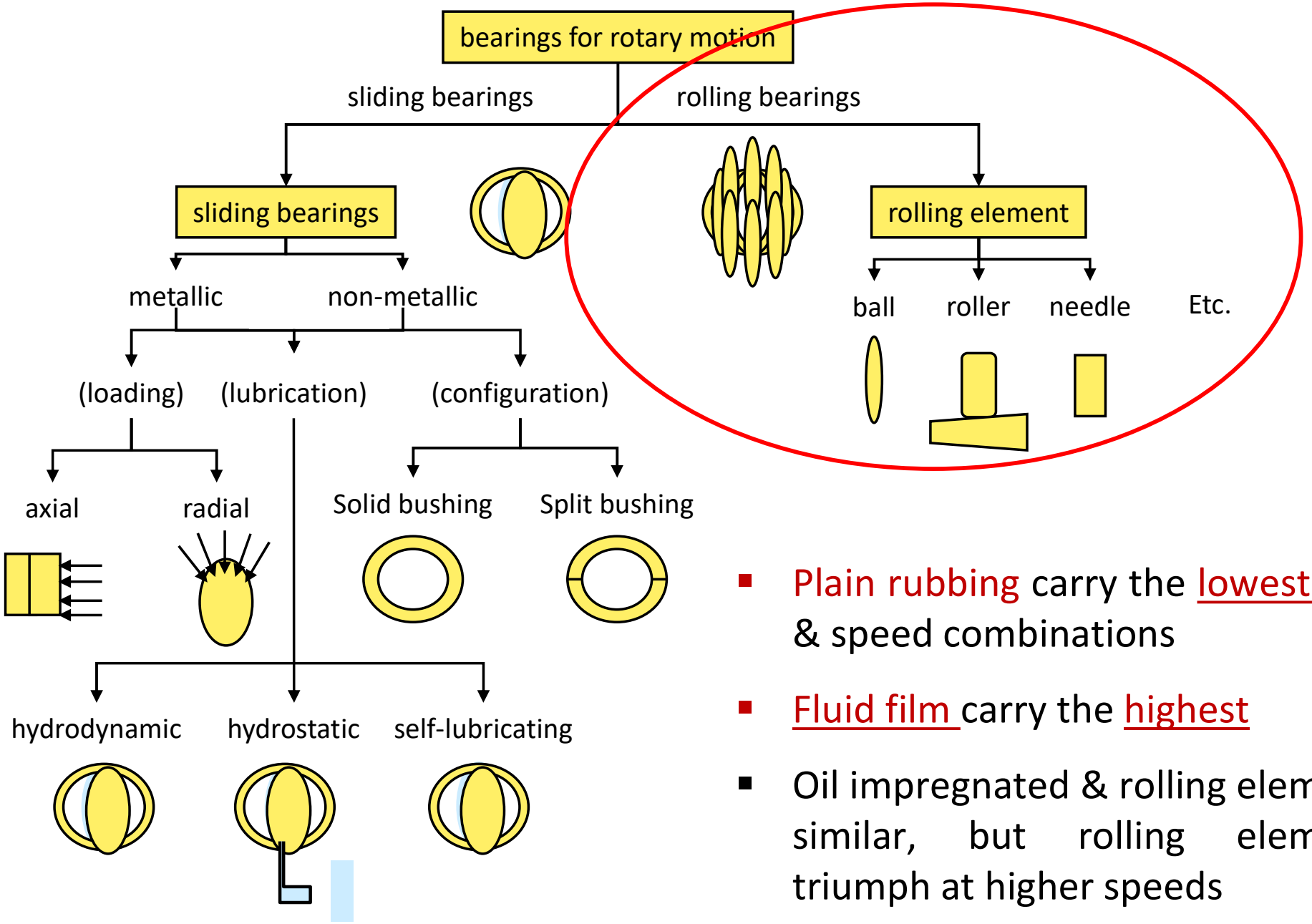
Mostly adapted from the work of Dr Simon Lawes

Outlines

- Overview of Rolling Element Bearings
- Properties
- Static and Dynamic Load Capacity
- Location and Installation Guides

Bearing Selection



- Plain rubbing carry the lowest load & speed combinations
- Fluid film carry the highest
- Oil impregnated & rolling elements similar, but rolling elements triumph at higher speeds

Bearings

deep groove ball bearing

self-aligning roller bearing

cylindrical roller bearing

self-aligning ball bearing

bearing block

tapered roller bearing

thrust bearing

angular contact ball bearing

needle roller bearing

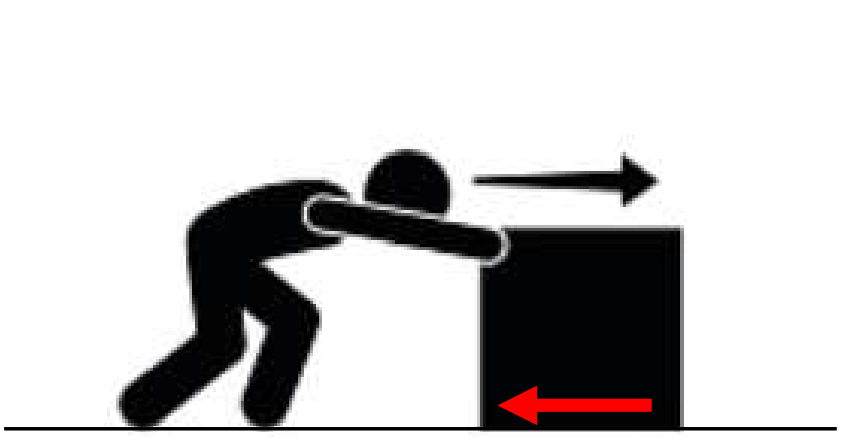
SKF

Bearings

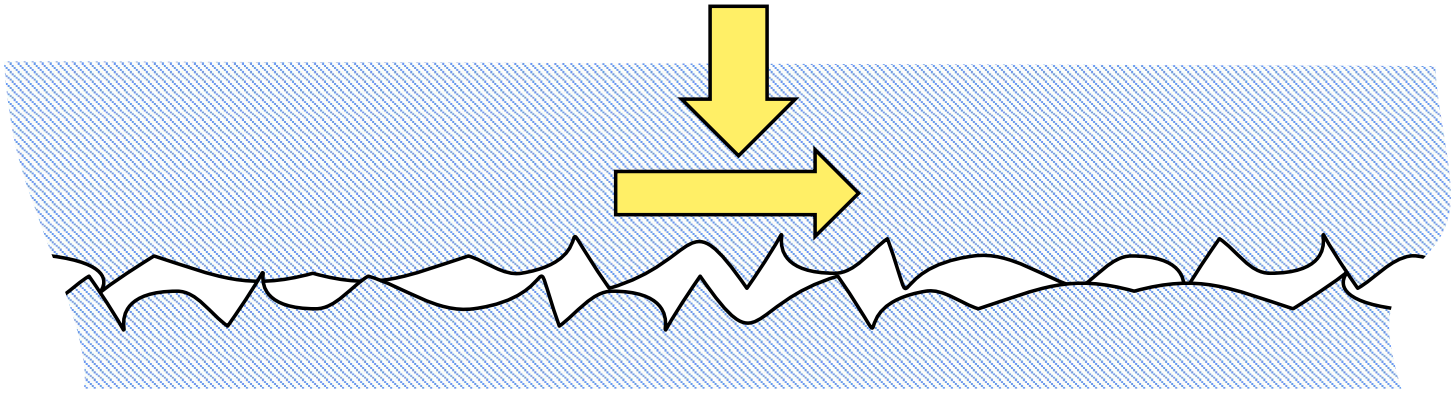
Definition - *Machinery.*

The support and guide of a rotating, oscillating, or sliding motion between components in a mechanical system.

Function: Provide load support and low friction between surfaces in relative motion, with long life and minimal maintenance.

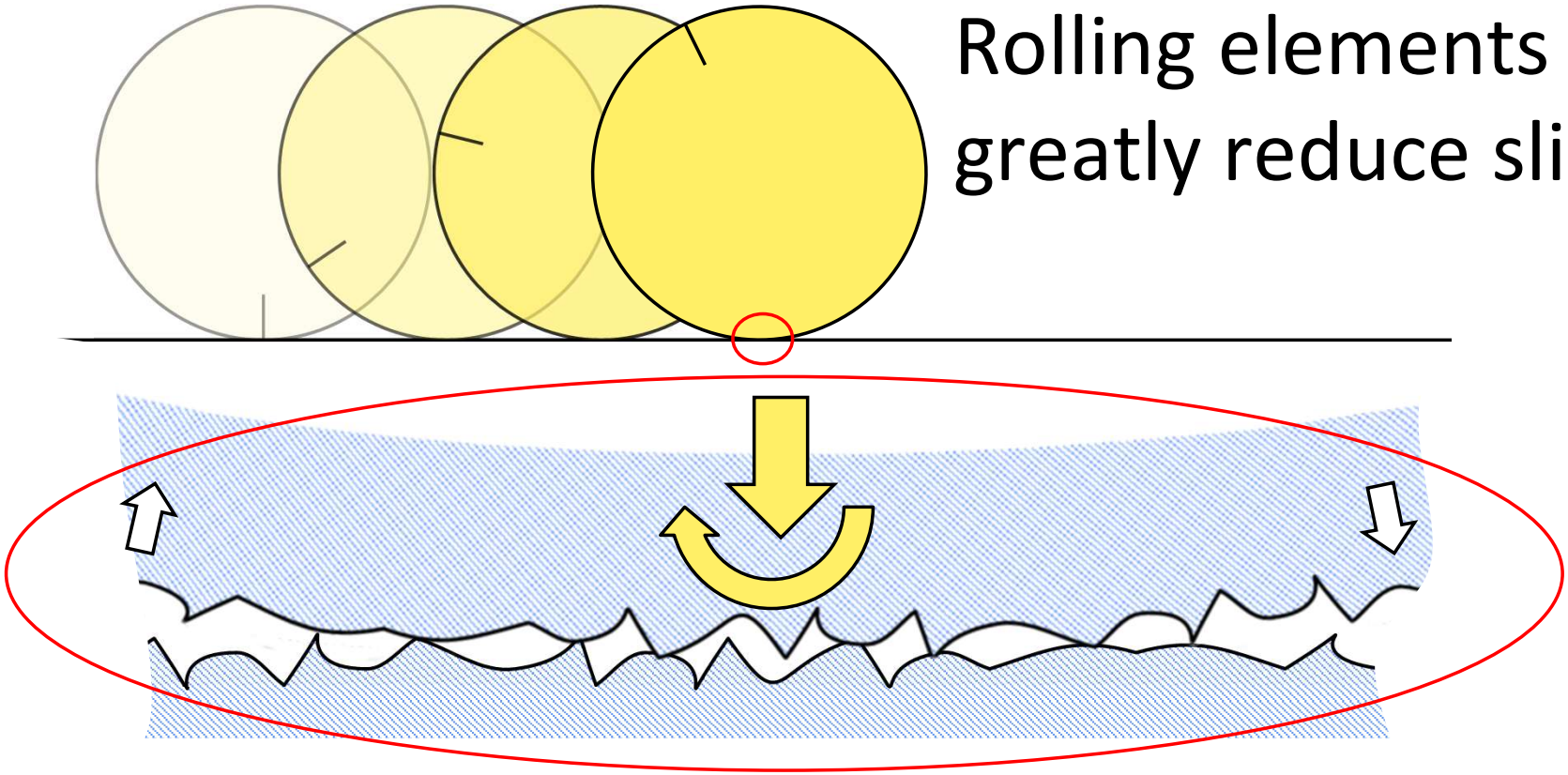


What causes friction between components in relative motion?



Real surfaces are never truly flat. They have asperities which stick out and make contact with the opposing face. When surfaces slide these asperities catch and must be deformed or broken. The force required to deform these asperities is experienced as friction

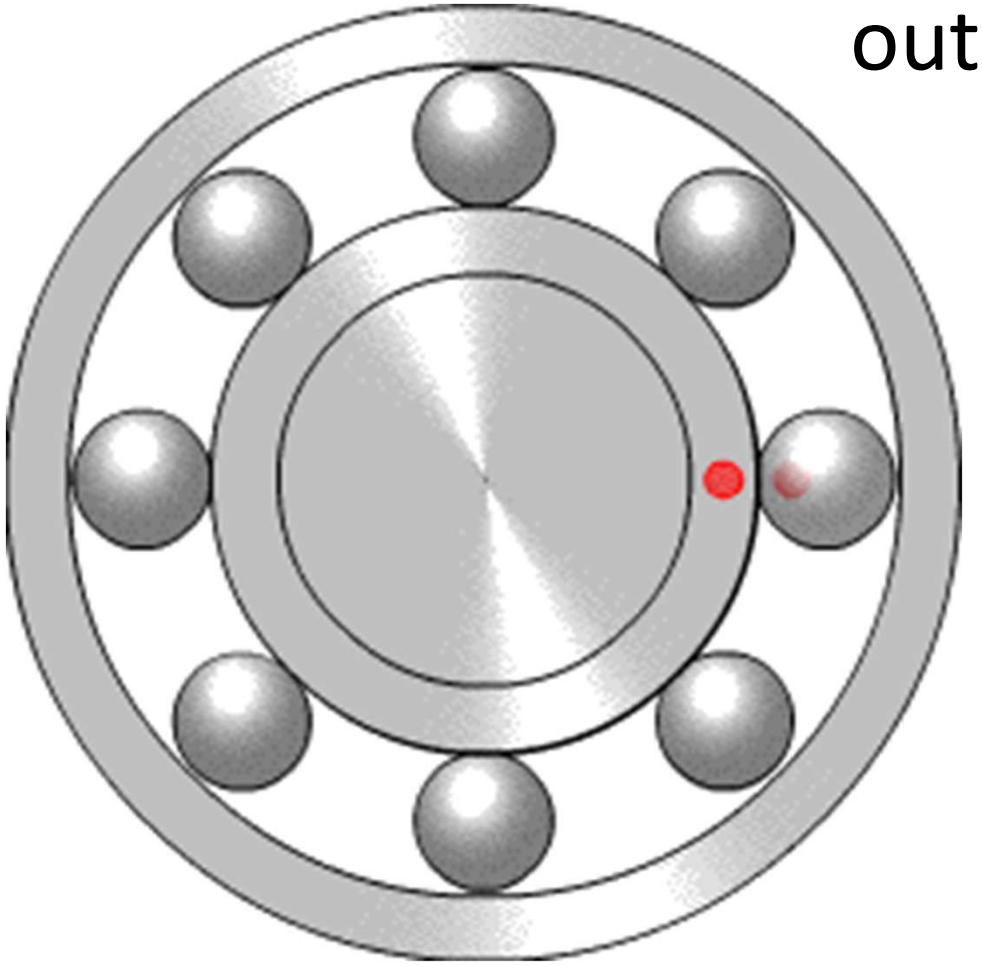
What if the surfaces don't slide, but instead roll?



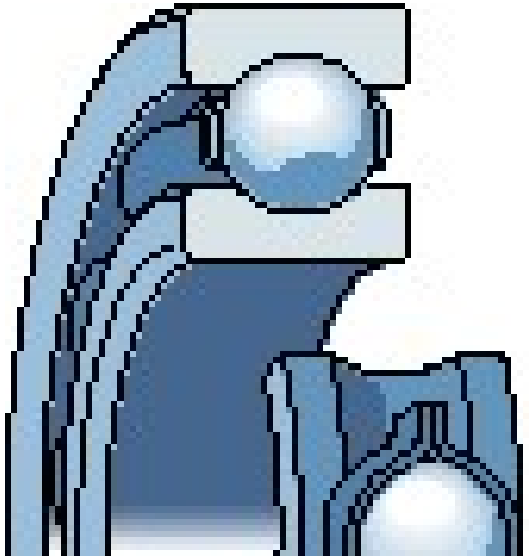
Rolling elements greatly reduce sliding

but making contact over a smaller area, <u>increasing pressure and limiting the allowable load</u>

Rolling element bearings use this principle to minimise sliding. But cannot eliminate it entirely



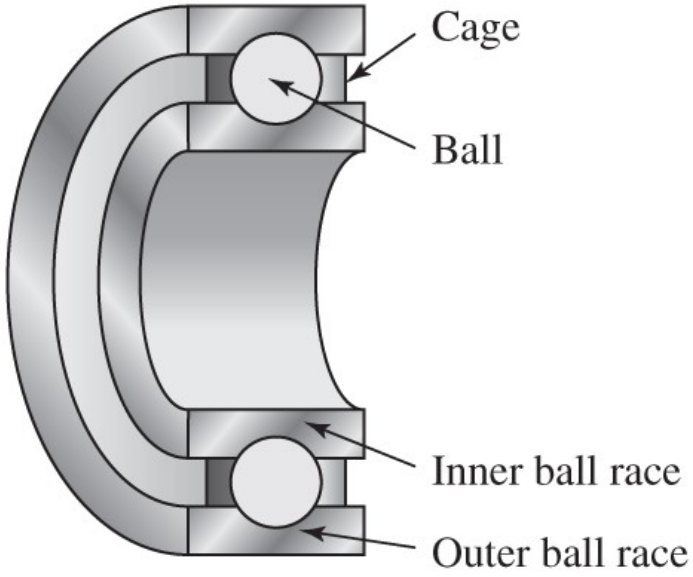
Different distances on the outside and inside bearing races, sliding on the side of the groove



Ball and Roller Bearings

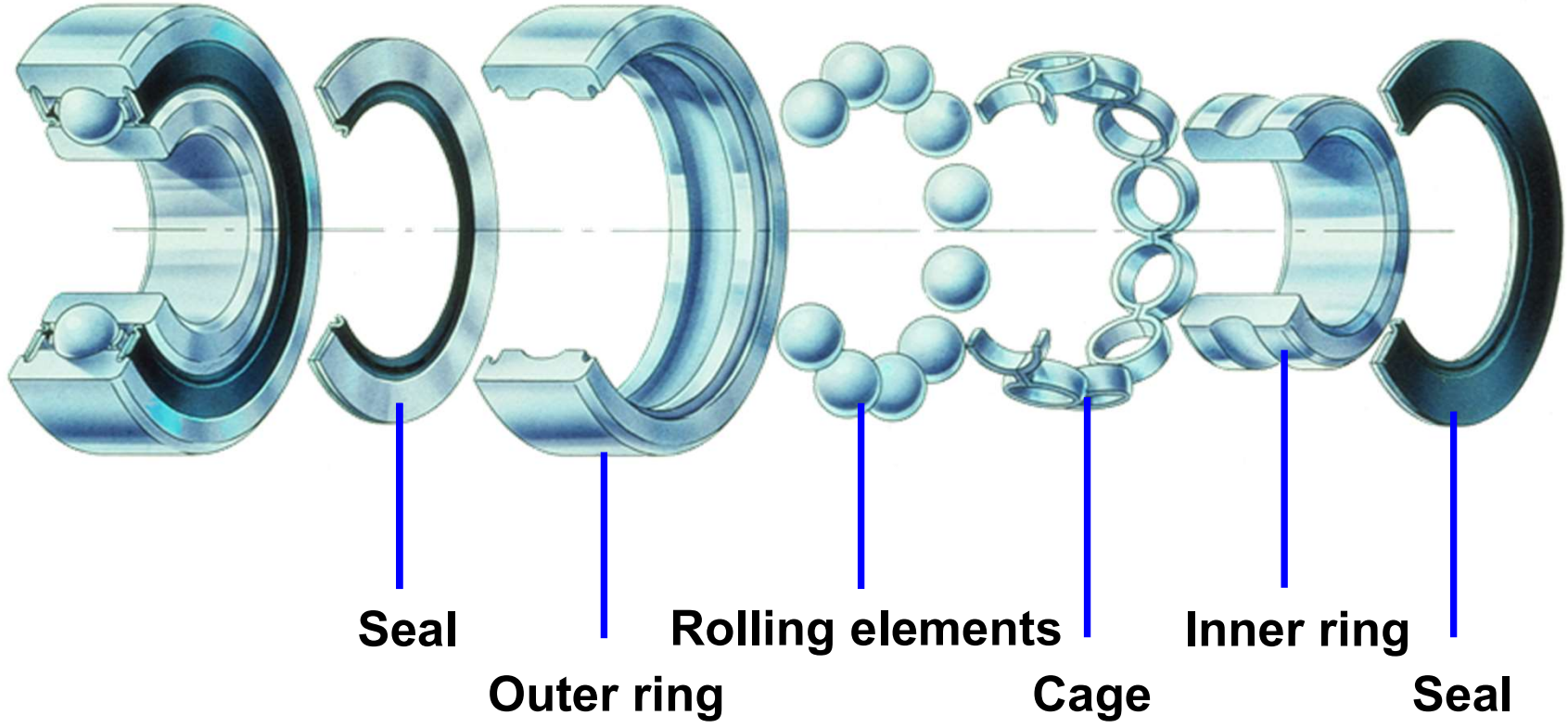
- With this type the main load is transferred from the rotating shaft to its support by rolling contact rather than sliding contact.

- A rolling element bearing consists of four main elements: an inner race, an outer race, the rolling element of either balls or rollers and a cage to keep the rolling elements apart.



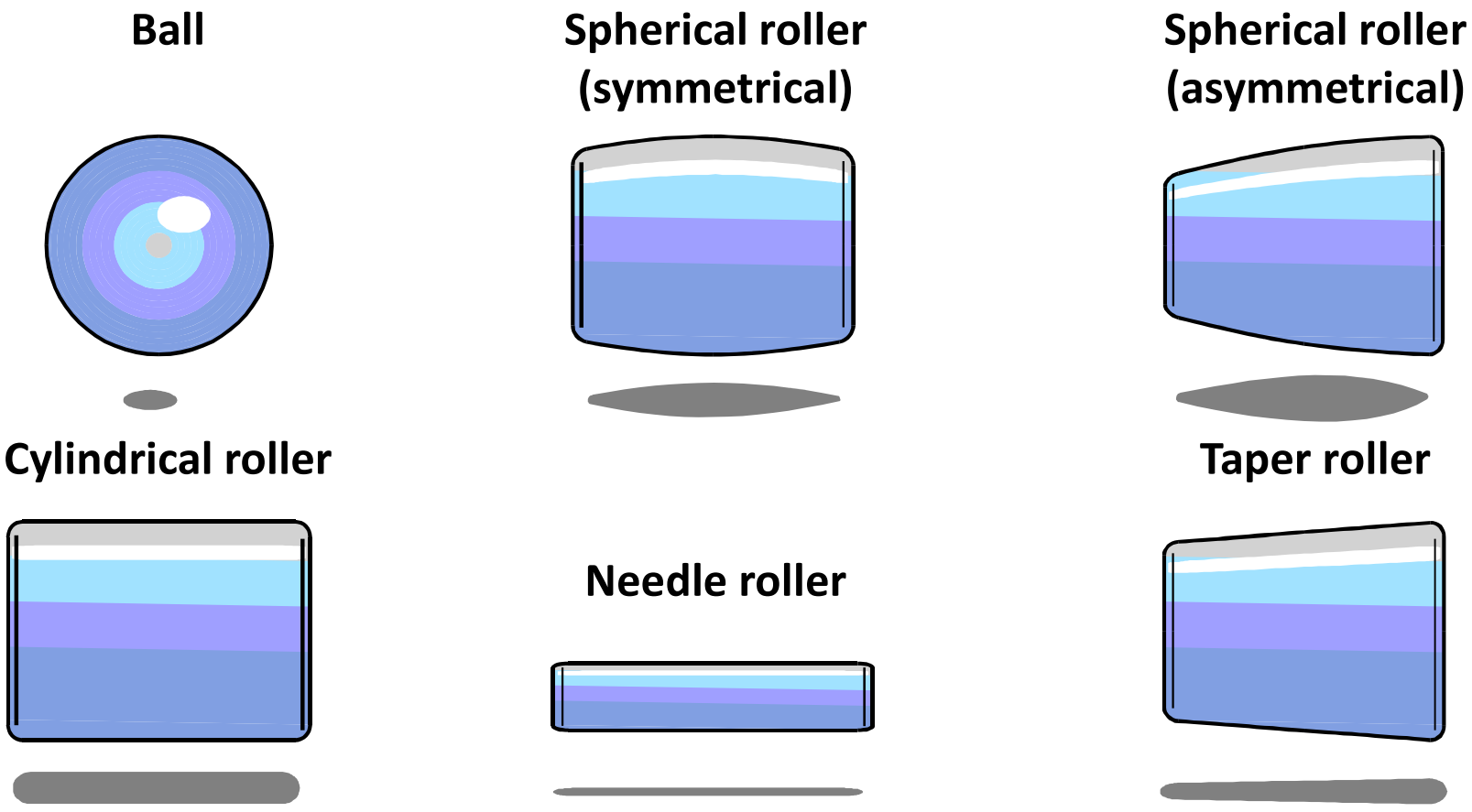
Rolling Element Bearings –
Use rolling action to reduce friction

Typical configuration



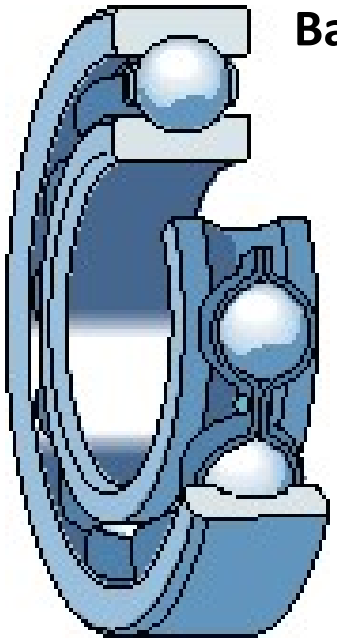
Deep groove ball bearing – ball/spherical rolling elements

To achieve balance between the load support, i.e. contact area, and the amount of sliding, there are a number of different element types:

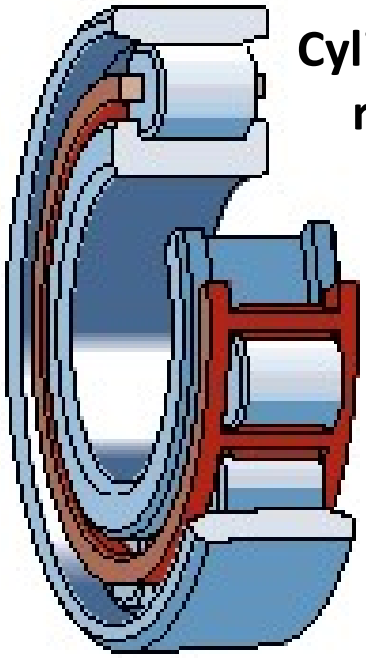


from SKF

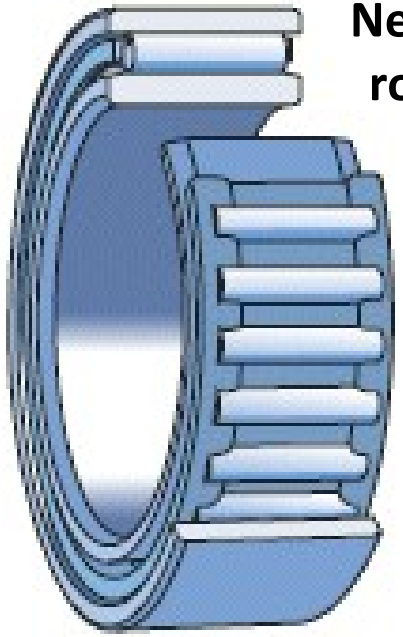
Ball – deep groove



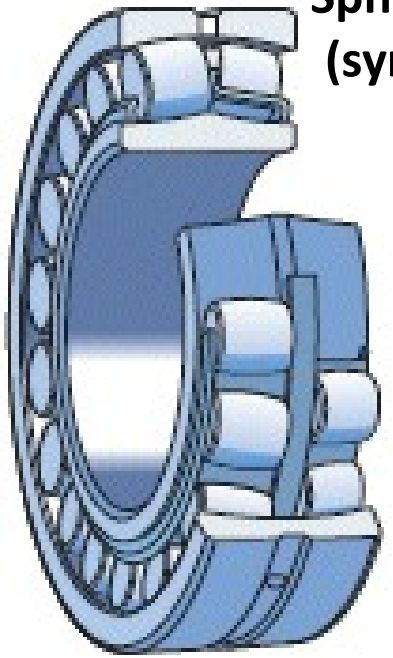
Cylindrical roller



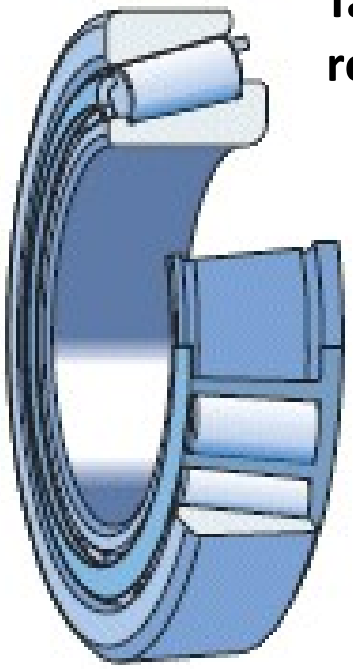
Needle roller



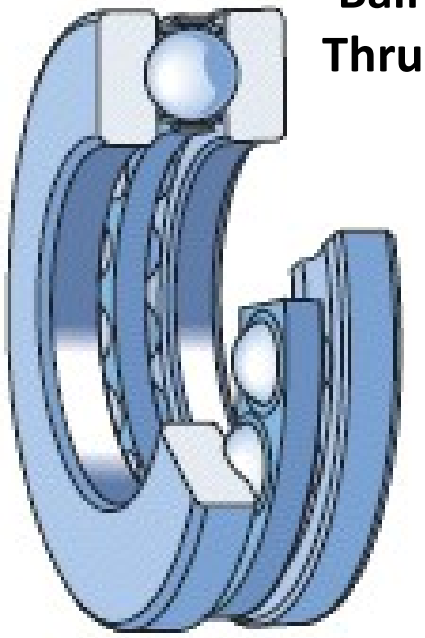
Spherical roller (symmetrical)



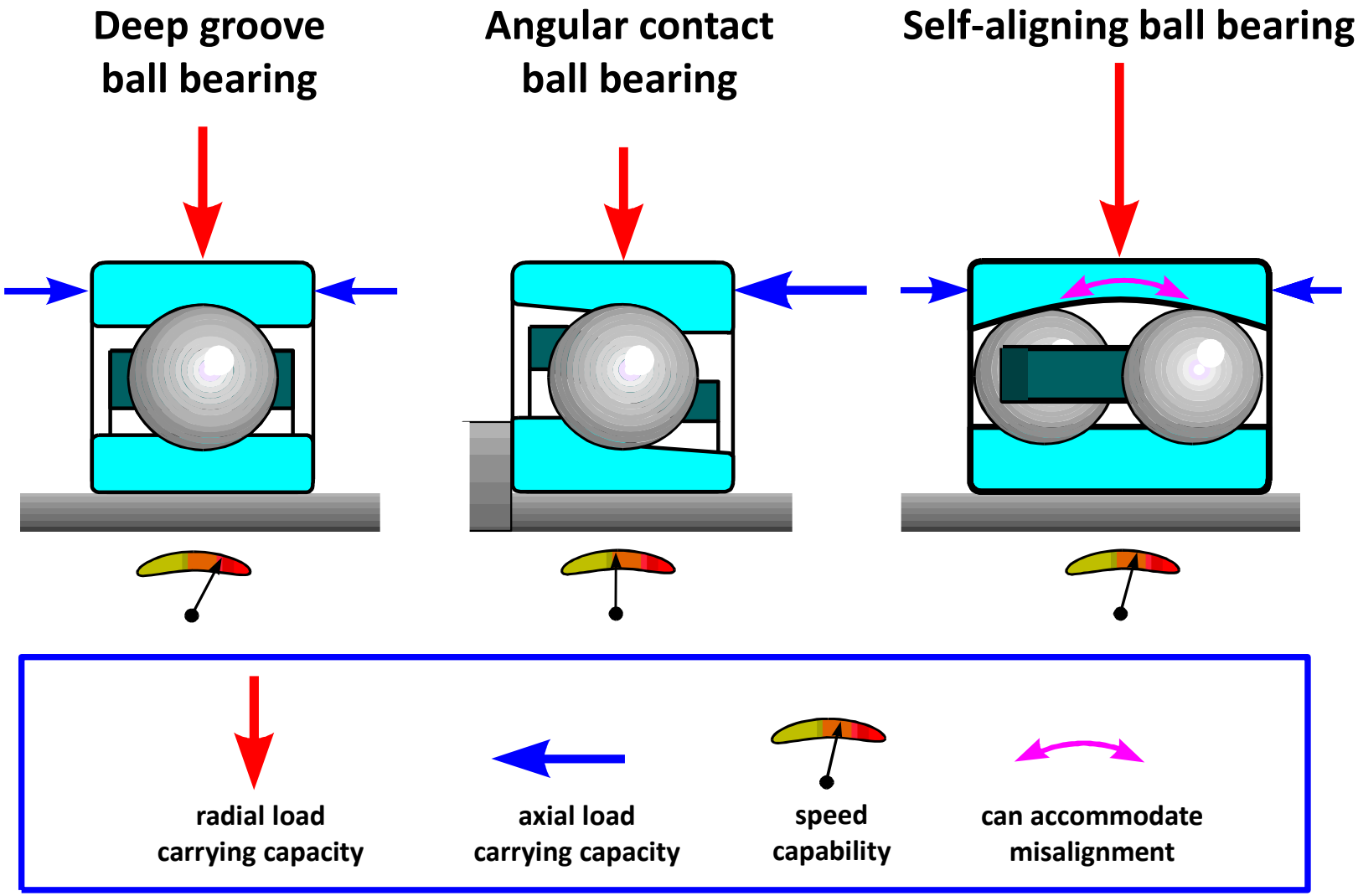
Taper roller



Ball - Thrust



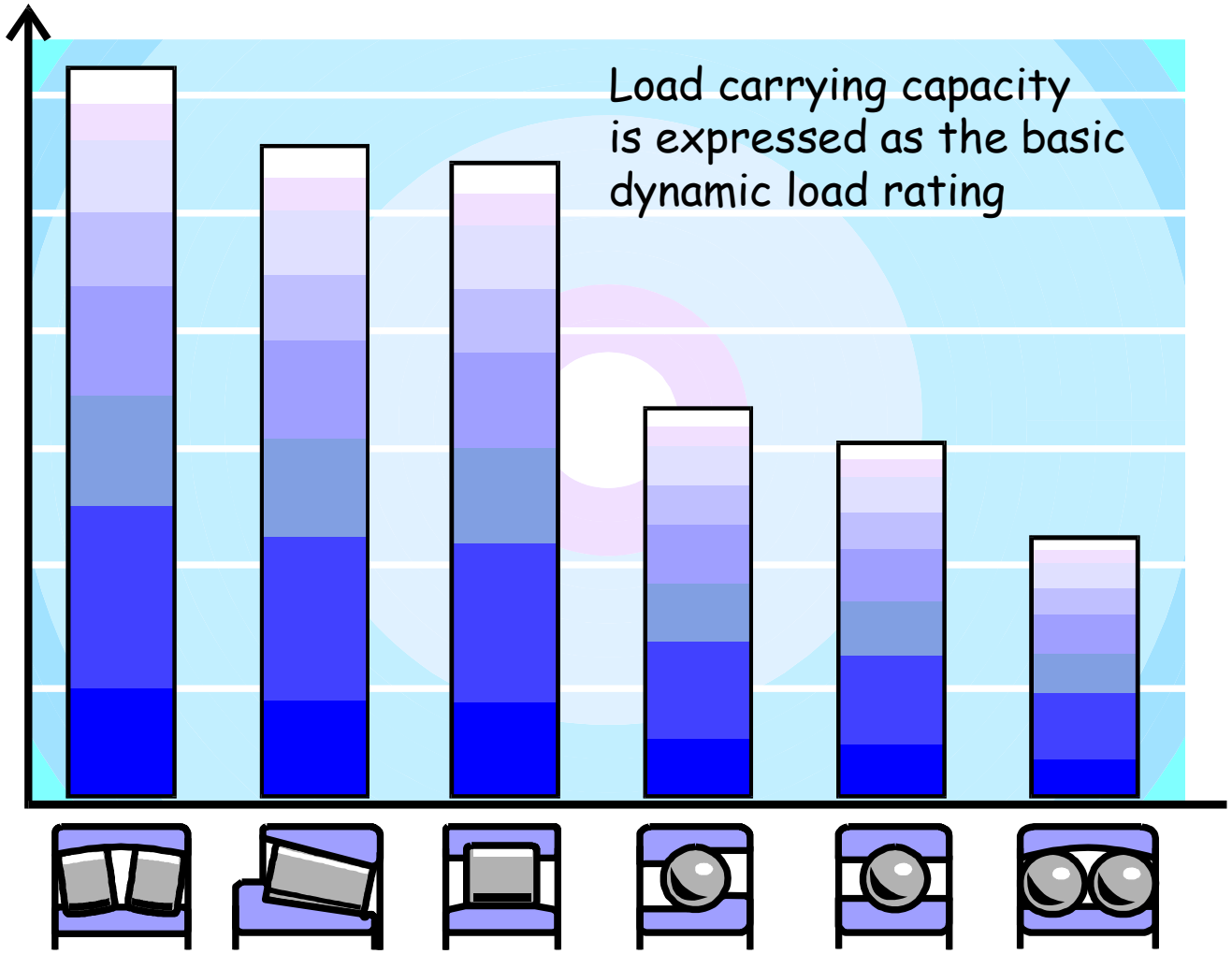
Ball Bearing Properties



From SKF

Load Carrying Capacity

Different bearing types with same bore diameter



from SKF

Characteristics of Rolling Contact Bearings

Based on SKF bearingcatalogue

Symbols

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

Characteristics Suitability of bearings for	Purely radial load	Purely axial load	Combined load	Moment load	High speed	High running accuracy	High stiffness	Quiet running	Low friction	Compensation for misalignment in operation	Compensation for errors of alignment (initial)	Locating bearing arrangements	Non-locating bearing arrangement	Axial displacement possible in bearing
Deep groove ball bearings	+	+ ←→	+ ←→	- b+	+++ b+	+++ b+	+	+++	+++	-	-	++ ←→	+	--
Angular contact ball bearings	+	+ ←	++ ←	-	++	+++	+	++	++	-	-	++ ←	--	--
	++	+ ←→	++ ←→	+	+	++	++	+	+	--	--	++ ←→	+	--
	-	++ ←→	+ ←→	+	++	+	+	+	+	--	--	++ ←→	-	--
Self-aligning ball bearings	+	-	-	--	+++	++	-	++	+++	+++	+++	+ ←→	+	--
Cylindrical roller bearings	++	--	--	--	++	++	++	++	++	-	-	--	+++	+++
	++	a+ ← b ←→	a+ ← b ←→	--	++	++	++	+	++	-	-	a++ ← b ←→	a+ ←	a+ ←
full complement	+++	-	+ ←	--	-	+	+++	-	-	-	-	+ ←	+	+
	+++	-	a+ ←→ b ←	+	-	+	+++	-	-	--	--	a+ ←→ b ←	c+	b+ c ←→
Needle roller bearings	++	--	--	--	+	+ a++	a++ b++	+	-	--	-- c++	--	+++	+++
	++	--	--	--	+	+	++	+	-	--	--	--	+++	+++
	+	c+ ←++	+ ←	-	+	+	++	+	-	--	--	+ ←	--	--
Tapered roller bearings	++	++ ←	+++ ←	-	+	+	++	+	+	-	-	+++ ←	--	--
	+++	++ ←→	+++ ←→	+	+	+	+++	+	+	-	--	+++ ←→	-	--
Spherical roller bearings	+++	+ ←→	+++ ←→	--	+	+	++	+	+	+++	+++	++ ←→	+	--
CARB bearings	+++	--	--	--	+	+	++	+	+	+++	+++	--	+++	+++
full complement	+++	--	--	--	-	+	+++	+	+	+++	+++	--	+++	+++
Thrust ball bearings	--	+ a← b ←→	--	--	-	++ a	+	-	+	-	--	++ a← b ←→	--	--
	--	+ a← b ←→	--	--	-	+	+	-	+	-	++	++ a← b ←→	--	--
Needle Cylindrical roller thrust bearings	--	++ ←	--	--	-	a+ b++	++	-	-	--	--	++ ←	--	--
Spherical roller thrust bearings	--	+++ ←	+ ←	--	-	+	++	-	+	+++	+++	+++ ←	--	--

Characteristics of Rolling Contact Bearings

Based on SKF bearingcatalogue

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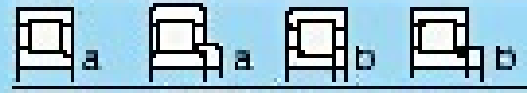
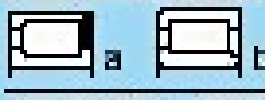
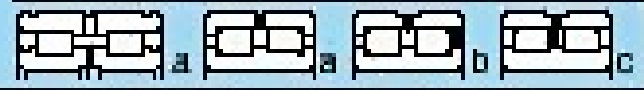
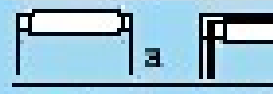
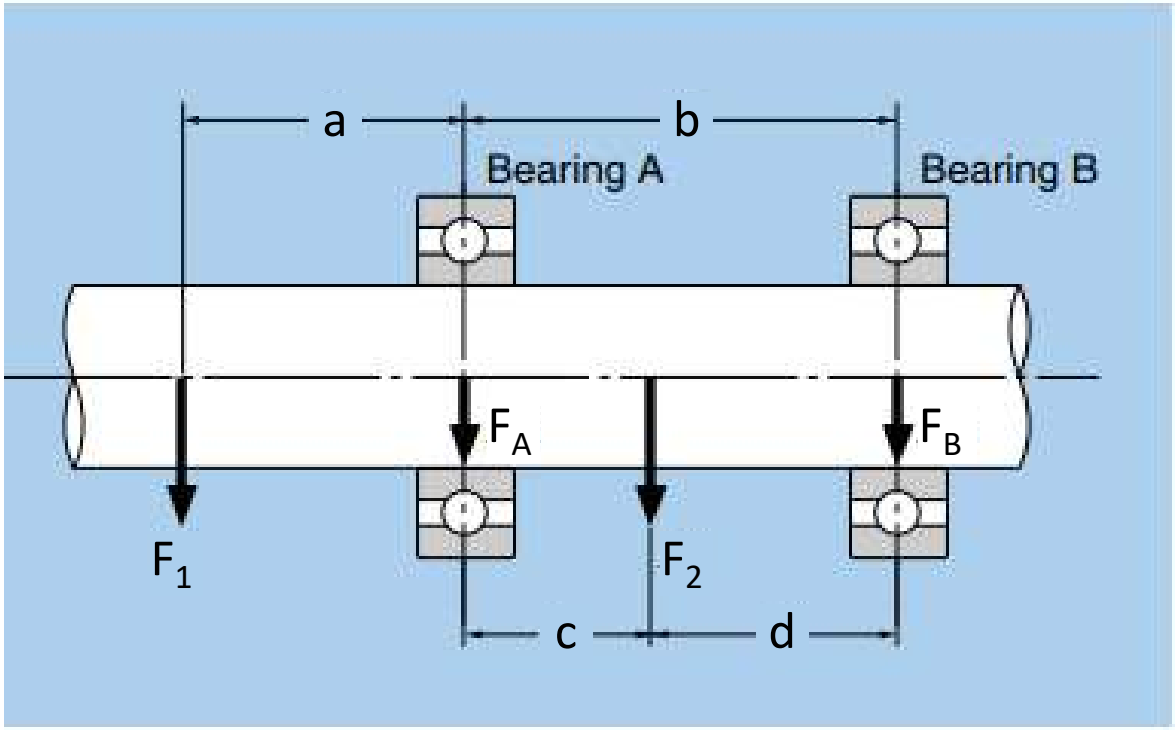
Characteristics Suitability of bearings for	Purely radial load	Purely axial load	Combined load	Moment load	High speed	High running accuracy	High stiffness
Deep groove ball bearings 	+	+ ←→	+ ←→	– b+	+++ b+	+++ b+	+
Angular contact ball bearings 	+	+ ←	++ ←	–	++	+++	+
	++	+ ←→	++ ←→	+	+	++	++
	–	++ ←→	+ ←→	+	++	+	+
Self-aligning ball bearings 	+	–	–	––	+++	++	–
Cylindrical roller bearings 	++	––	––	––	++	++	++
	++	+ a← b←→	+ a← b←→	––	++	++	++
full complement 	+++	–	+ ←	––	–	+	+++
	+++	–	+ a←→ b←	+	–	+	+++
Needle roller bearings 	++	––	––	––	+	+ a++	a++ b++
	++	––	––	––	+	+	++
	+	+	+	–	–	–	–

Sizing a bearing for your application

Estimating bearing loads

The first step in sizing a bearing, determine the loads. Begin with a free body diagram.



For this example all loads are radial.

F1 is a radial force from the load and acts outside the bearing spacing

F2 is a radial force from the weight of the shaft assembly and acts between the bearing

$$F_A = \frac{a+b}{b}F_1 + \frac{d}{c+d}F_2$$

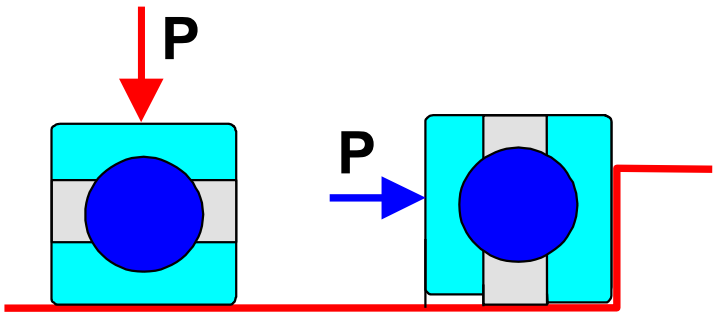
$$F_B = -\frac{a}{b}F_1 + \frac{c}{c+d}F_2$$

As **b** becomes small the bearing loads increase proportionally

Sizing a bearing for your application

Load Carrying Capacity - Static

- ISO bearing life equation standardizes the terms used
- Maximum acceptable load on a non-rotating bearing is limited by plastic deformation
- C_0 is the radial load which causes permanent deformation of the raceway & element equivalent to 0.00001



$$s_0 = \frac{P_0}{C_0}$$

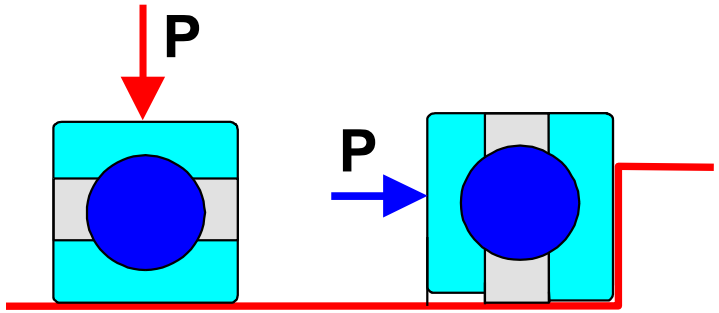
s_0 = static safety factor
P_0 = equivalent static bearing load, N
C_0 = basic static load rating, N

when load $P_0 = C_0$, static safety factor $s_0 = 1$

Sizing a bearing for your application

Load Carrying Capacity - Dynamic

- ISO bearing life equation standardizes the terms used
  - L_{10} is the number of revolutions 90% of elements will exceed before evidence of fatigue
  - average life is 5 times this
  - C is the constant radial load which can be withstood for 1 million cycles



$$L_{10} = \left(\frac{C}{P}\right)^{q}$$

L_{10} = basic rating life, millions of revolutions
C = basic dynamic load rating, N
P = equivalent dynamic bearing load, N
q = exponent of the life equation
= 3 for balls, 10/3 for rollers

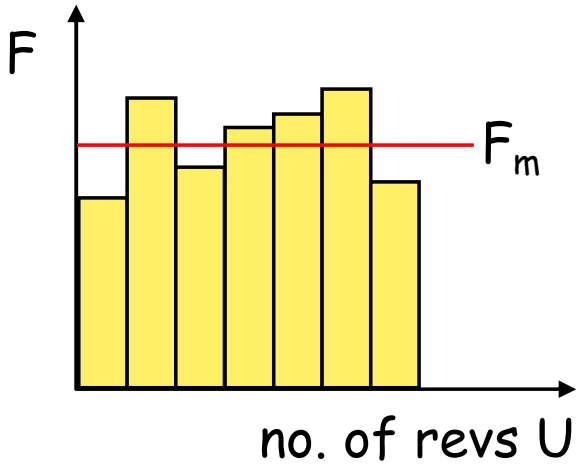
Equivalent Dynamic Load

- P factors in the load type:
  - constant magnitude & direction. $P = F$

    Pure axial (thrust) or pure radial (journal)
  - combined axial & radial load $P = XF_r + YF_a$

    X & Y come from manufacturer's data (for 6201-2Z X= 0.56 Y = 1)
  - for roller bearings $P = F_r$
  - for fluctuating loads

$$F_m = \sqrt[3]{\frac{F_1^3 U_1 + F_2^3 U_2 + F_3^3 U_3 \ldots .}{U}}$$



Factors Adjusted Life Rating

Life Rating L_{10} is determined experimentally for average conditions. When your conditions are not average you must apply adjust life factors and Life Rating becomes $L = a_1 a_2 a_3 L_{10}$

reliability factor a_1

Reliability (%)	a_1
90	**1**
95	**0.62**
96	**0.53**
97	**0.44**
98	**0.33**
99	**0.21**

material factor a_2

- 1 for steels to ISO281
- higher for more exotic materials

Operating conditions & environmental factors a_3

<1 when

- Temperature is high
- Vibration is high
- Risk of water ingress
- Risk of corrosion

Good practise

Installation Requirements

1. provide support to races (adequate stiffness)
2. loads – axial and/or radial
3. thermal expansion – temperatures, materials, coefficient of expansion
4. alignment – poor gives pinching & means sliding not rolling
5. location –radial & axial (with nuts, circlips, etc. even when interference fitted)

Good practise

Installation Requirements

6. installation – interference fit on one race, clearance on the other
7. assembly:
   - don’t apply force across the elements to interference fit
   - lubricate bearing sets
   - provide for removal of the interference fitted race (e.g. slots for extractors)

Good practise

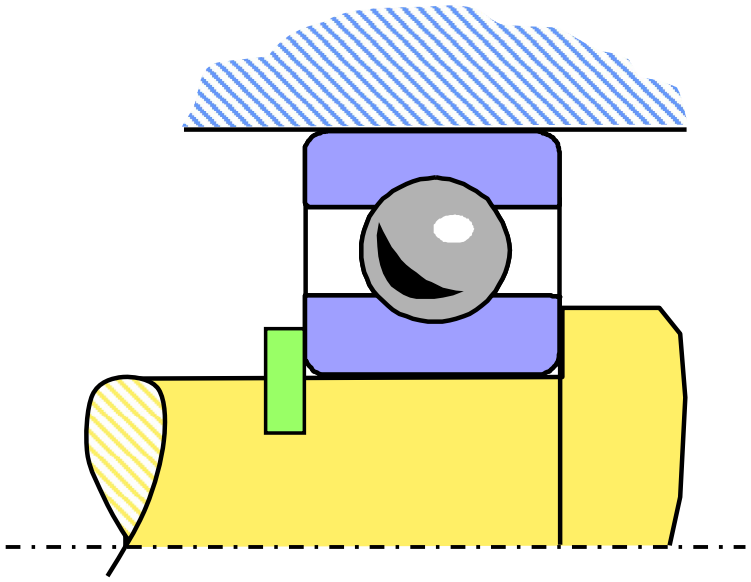
Installation Requirements

8. Lubrication:
    - grease for low speeds/temperatures
    - oil for medium speeds
    - oil mist for high speeds
9. Cleanliness – additional contact stress is introduced with dirt leading to premature fatigue

Location

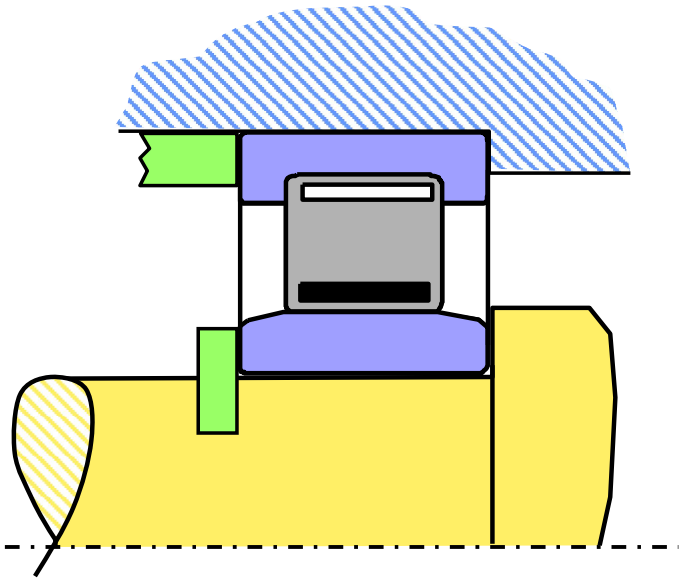
- Use 1 floating & 1 Locating bearing (usually) to avoid unwanted preload

Floating



Sliding fit in housing

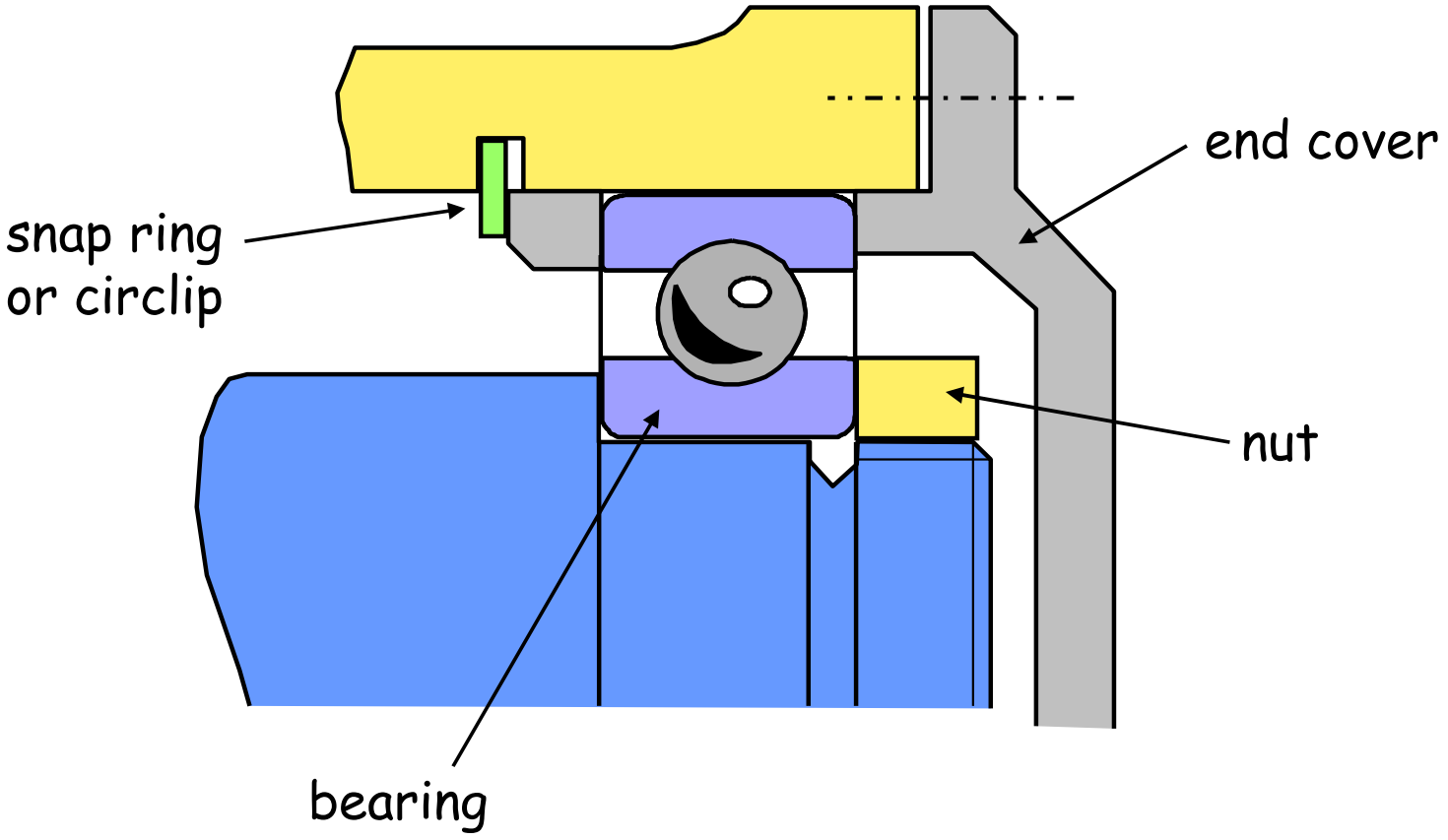
Locating



Both rings fixed axially as inner ring can be displaced relative to roller

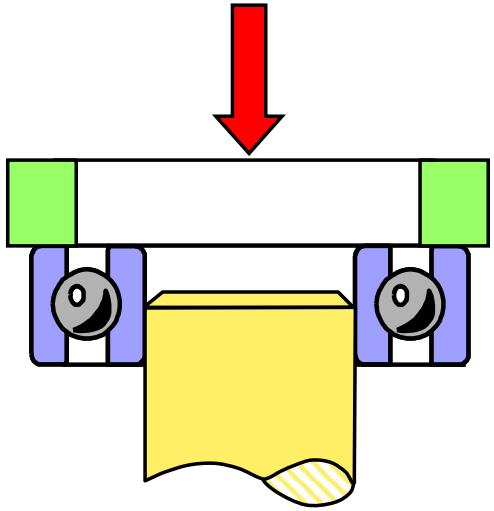
Location

You may also use a cap or cover to retain a bearing, or perhaps a nut or ring



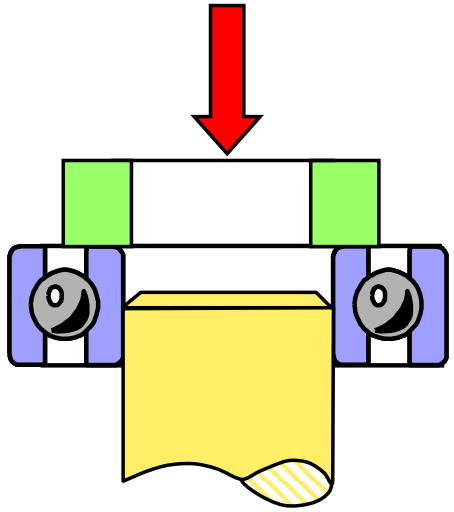
Installation

- Most rolling element failures are attributed to incorrect fitting or corrosion.



incorrect ✘

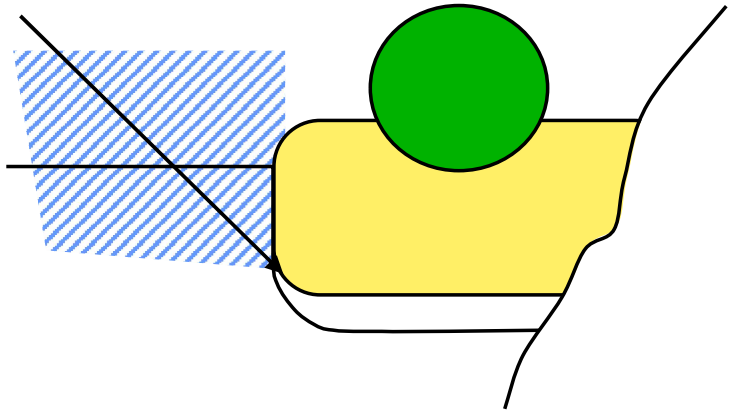
- Never impose axial load, through the rolling elements during installation



correct ✓

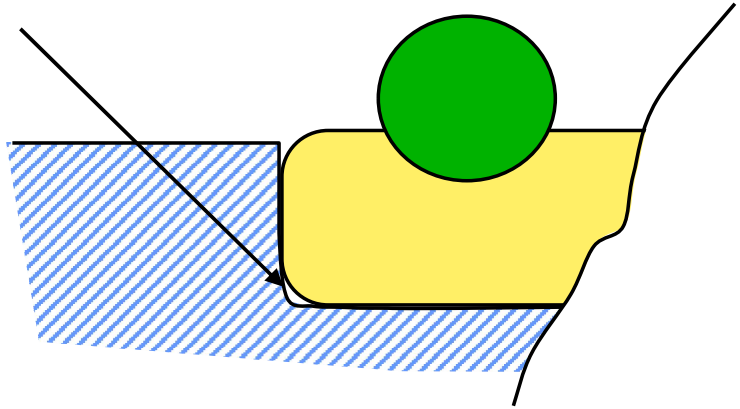
Housing radii

interference



incorrect ✘

clearance

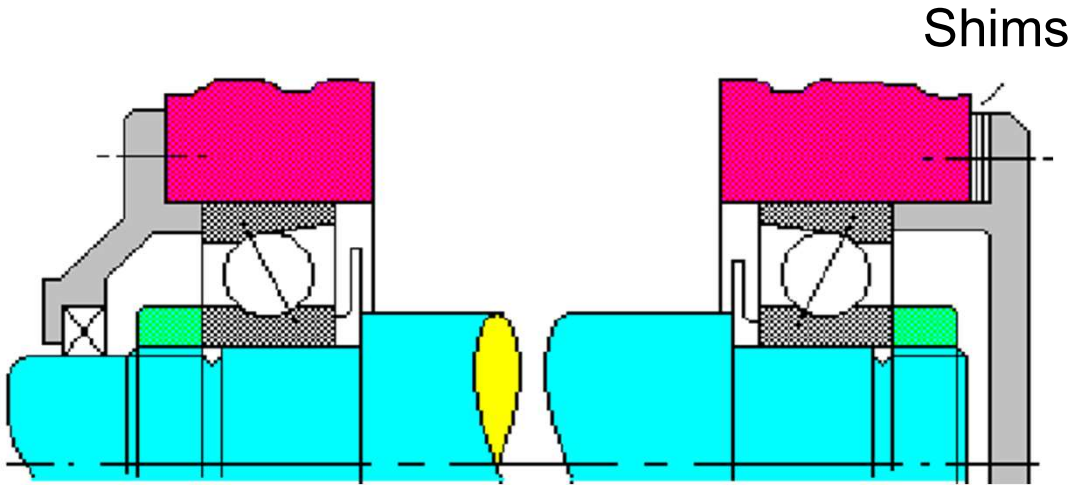


correct ✓

- Ensure radii in the housing allows clearance on the outer race of the bearing

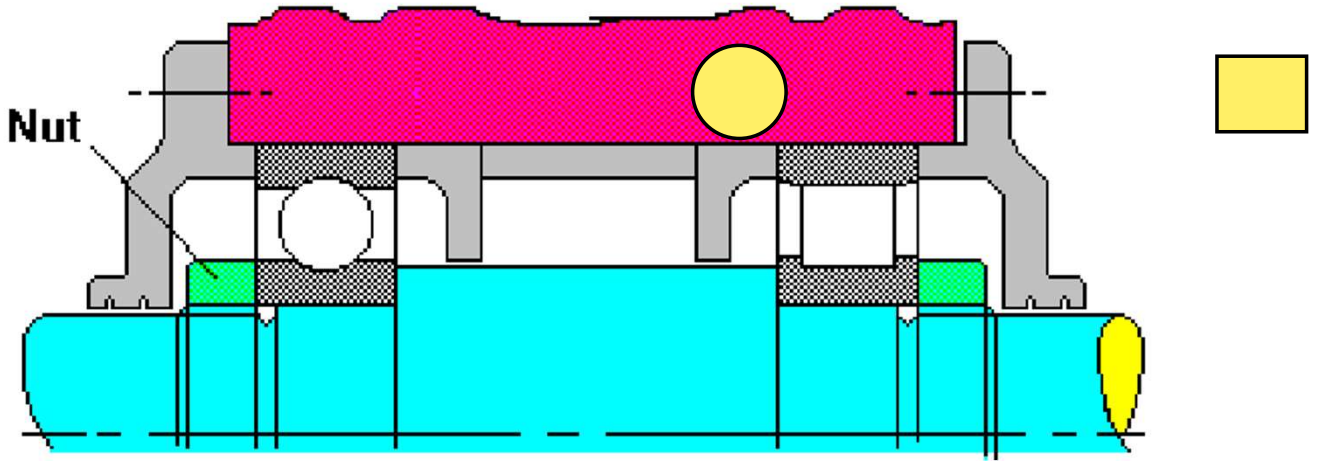
Angular contact bearings

- Constant load direction – rotating shaft
- Moderate radial and axial loads
- each locates shaft axially in one direction
- Adjusted on outer ring to obtain a suitable running clearance
- Interference fits on shaft. Free-sliding housings for axial adjustment.



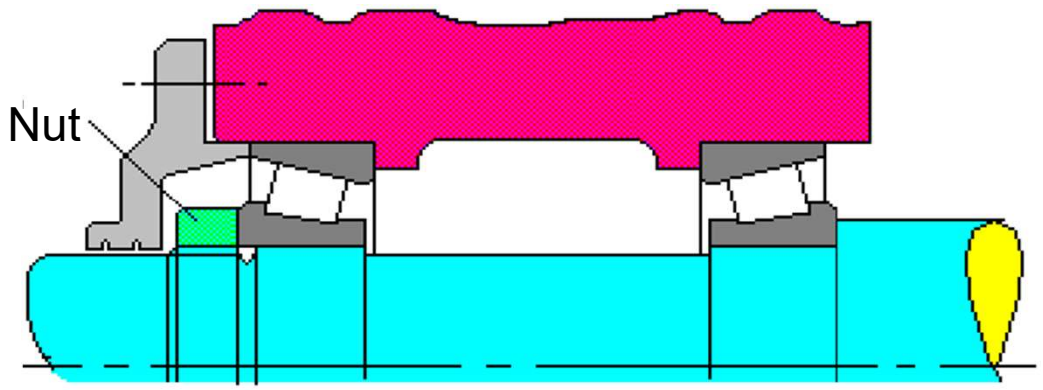
One ball & one roller

- Load direction is constant or rotating
- Shaft or housing rotates
- Roller bearing supports heavier radial load; ball bearing supports axial and radial load.
- Ball bearing locates shaft in both directions.
- Roller bearing accommodates axial thermal expansion.



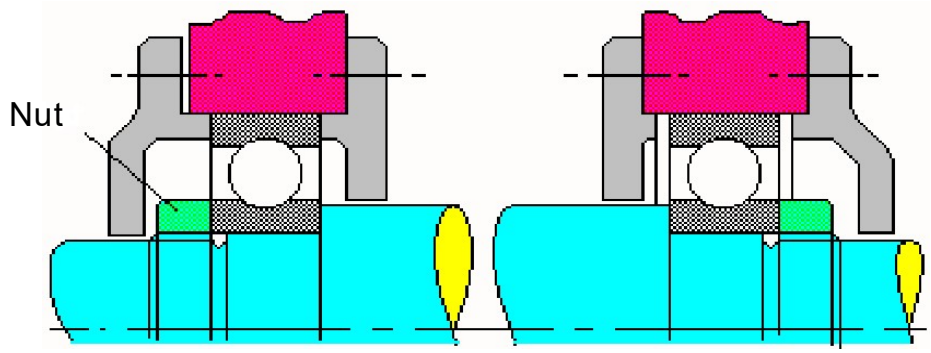
2 taper roller bearings

- Constant load direction
- Shaft or housing rotates
- Radial and axial capacity
- Left hand bearing adjusted against right hand bearing on inner ring to the required preload
- Push fit on shaft to allow for correct adjustment



2 ball bearings

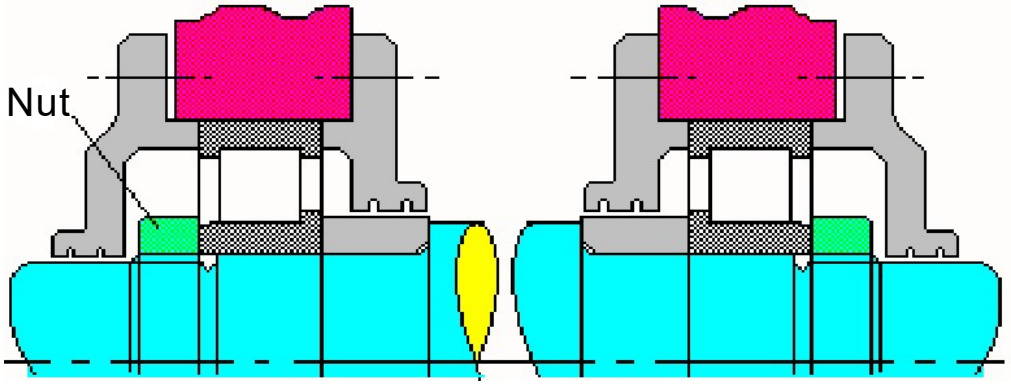
- Constant load direction
- Shaft rotating
- Radial and axial loads
- Left hand bearing clamped axially on both inner and outer races



- Right hand bearing clamped axially on inner race only. Right hand bearing is a sliding fit in housing to allow for correct axial positioning of the outer rings without inducing any preload.

2 roller bearings

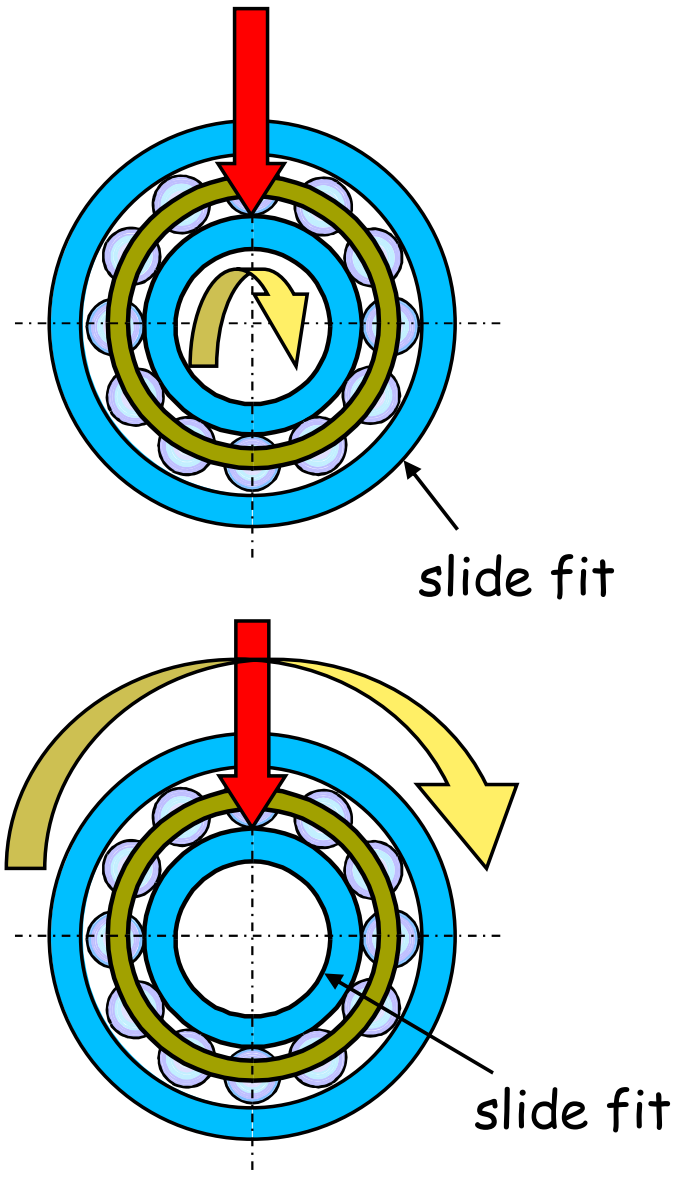
- Constant or rotating load direction.
- Shaft or housing rotates.
- Accepts heavy radial loads and *some* axial load.
- Left hand bearing locates axially in one direction with sufficient clearance to avoid preload.
  Right hand bearing locates axially in one direction with sufficient clearance to avoid preload.
- The inner and outer rings may be made
- interference fits to suit any combination of load and rotation.



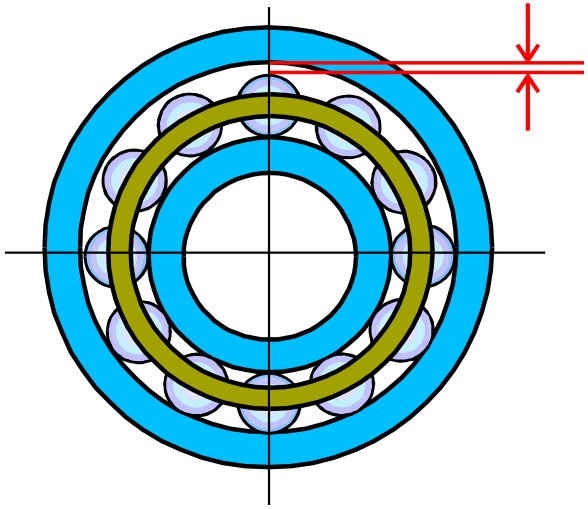
Bearing fits

- If the load relative to the casing remains constant, then slide fit the outer race in the casing

- If the load rotates with the shaft (constant relative to the shaft) slide fit the inner race to the shaft



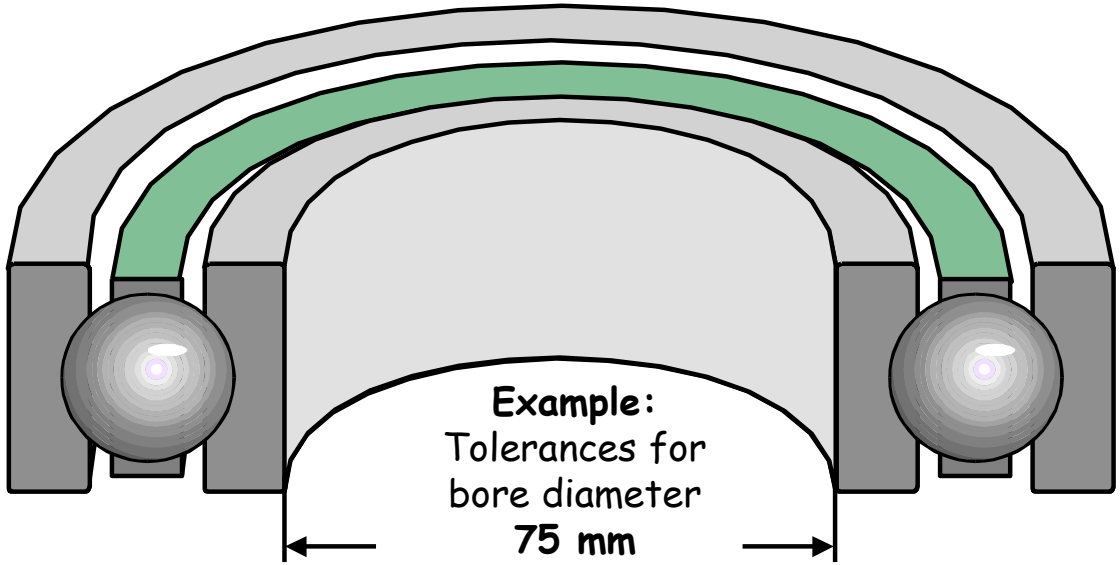
Bearing fits – Nominal clearance

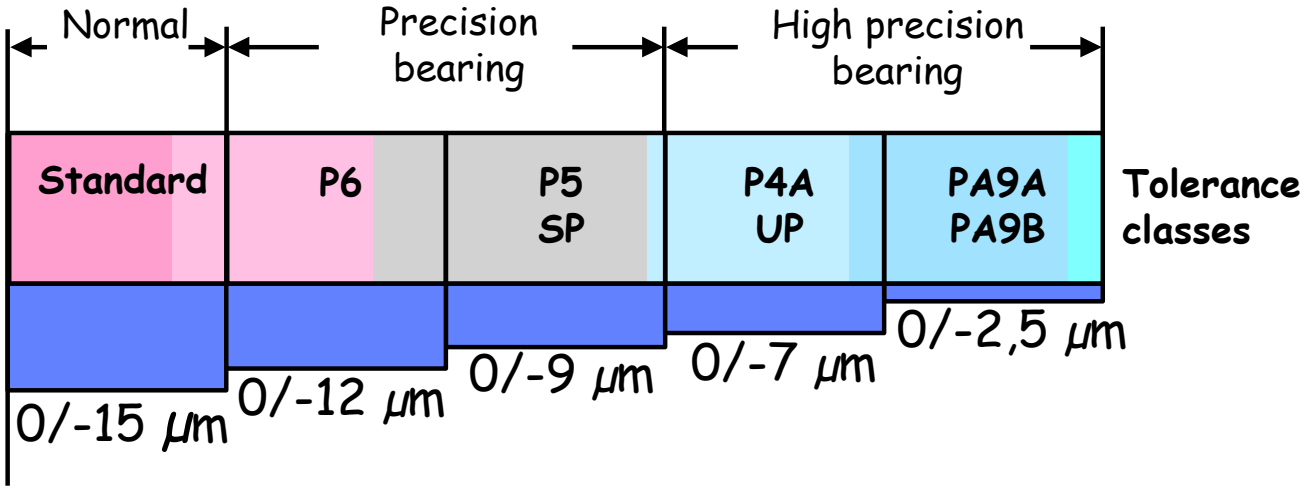


code	description	Allowable ΔT °C
C1	Below nominal clearance	
C2		
CN	Nominal clearance	10
C3	Above nominal clearance	25
C4		40
C5		

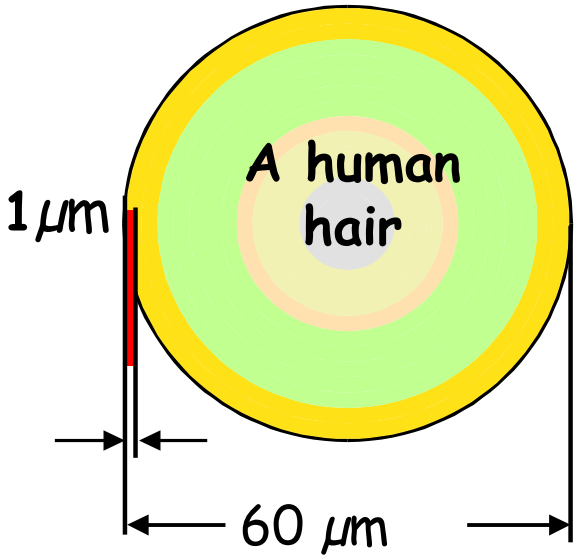
Bearings are marked with **internal clearance** except for CN

Bearing fits – precision





How much is a µm?



from SKF

Rolling Element Bearings Summary

- Bearings support loads between parts in relative motion
- Rolling element bearings minimise friction by rolling action but are limited by contact pressure
- Rolling element bearings are complex and designers are reliant on manufacturer data
- Bearing design must consider the magnitude and direction of load, environment, duty and installation
- Under most circumstances bearings must be paired and – 1 locating and 1 floating bearing

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Bearings 2 – Rolling Element Bearings

End of Session