Selection of Rolling Element Bearings

SKF Roller Bearing Catalogue

https://www.skf.com/binaries/pub12/Images/0901d196802809de-Rolling-bearings---17000_1-EN_tcm_12-121486.pdf

History of rolling element bearings -

https://ntrs.nasa.gov/api/citations/19810009866/downloads/19810009866.pdf

Preliminaries - Contact Stresses

- Load-resisting members are typically designed on the basis of stresses far away from the point of application of the loads.

- This is based on the assumed that the failures of the members are associated with stresses and strains in portions of the body far removed from the points of application of the loads.

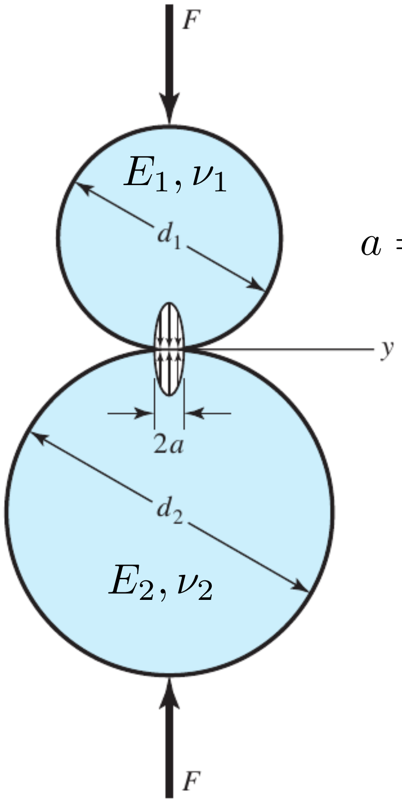
- In some problems, the contact stresses created when surfaces of two bodies are pressed together by external loads are the major cause of failure of one or both of the bodies. For example:
  - Locomotive wheel on a rail
  - Mating gear teeth
  - Cam and follower
  - Rolling bearings

Hertz Contact Stresses

- The analysis of elastic contact stresses was published in 1881 by Heinrich Hertz

- The analysis was made using the following assumptions:
    - The contact is frictionless.
    - The surfaces are continuous, smooth and nonconforming
    - The size of the contact is small compared to the size of the bodies
    - The strains are small and within elastic limit

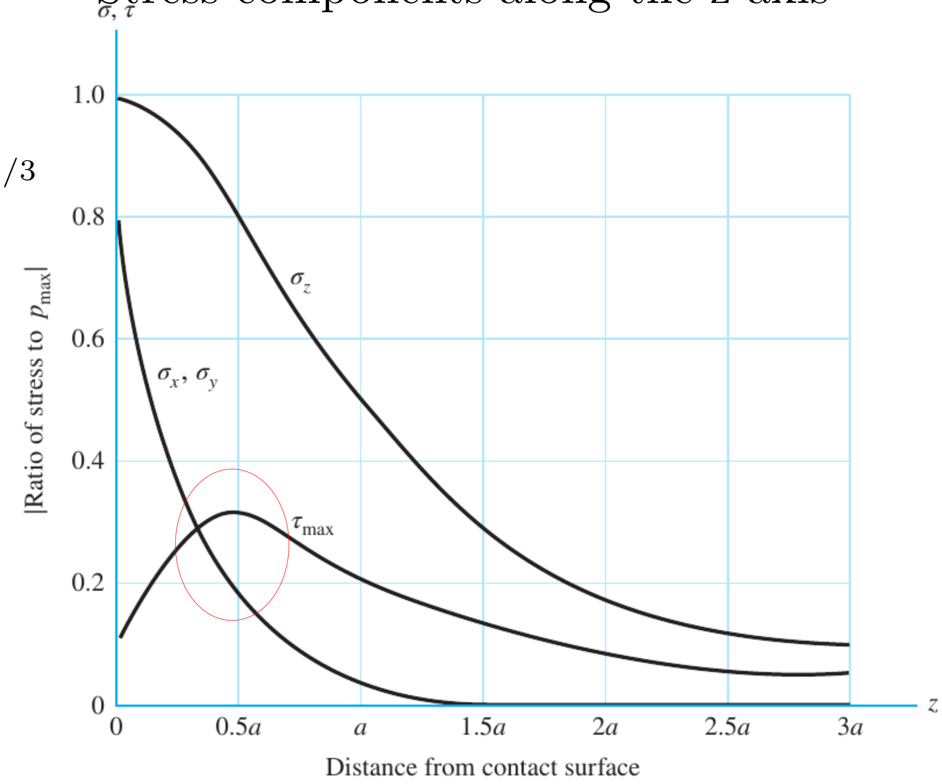
Spherical Contact



$$a = \left(\frac{3F}{8} \frac{(1-\nu_1^2)/E_1 + (1-\nu_2^2)/E_2}{1/d_1 + 1/d_2} \right)^{1/3}$$

$$p_{max} = \frac{3F}{2\pi a^2}$$

Stress components along the z-axis



Maximum shear stress occurs at a depth of approximately $0.5a$ from the contact surface

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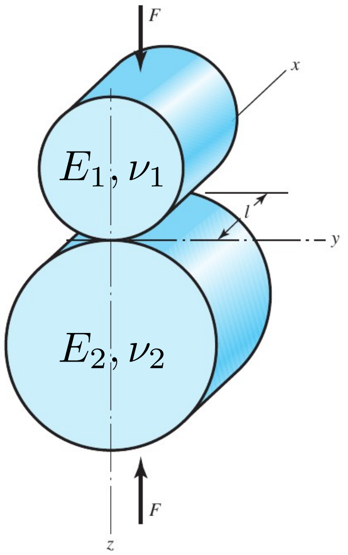
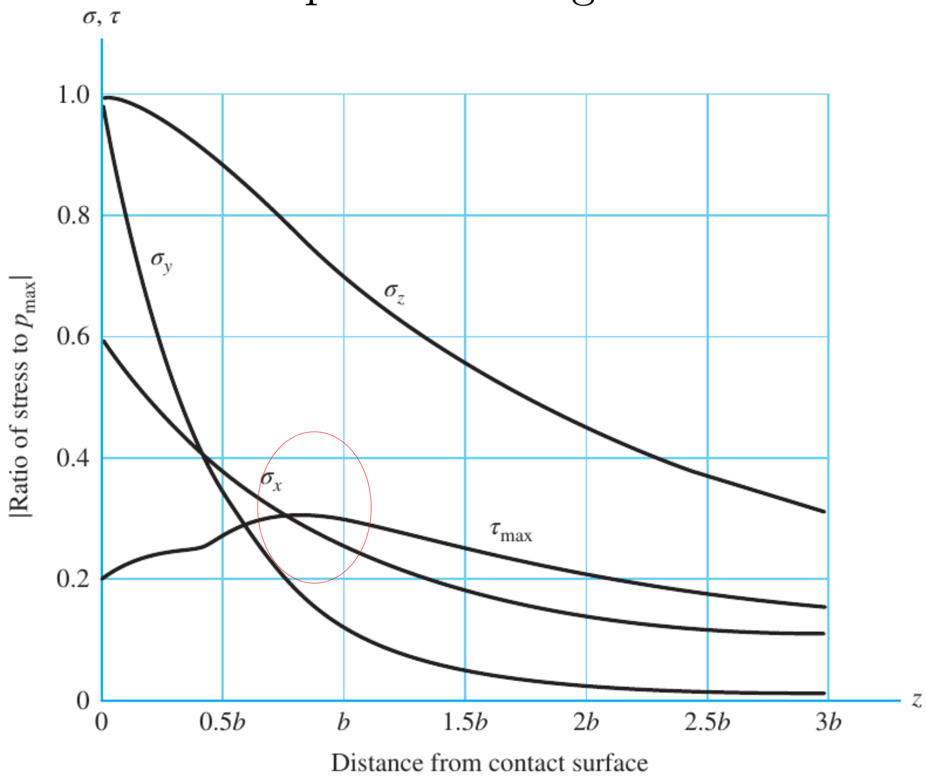
Cylindrical Contact



$$b = \left(\frac{2F}{\pi l} \frac{(1-\nu_1^2)/E_1 + (1-\nu_2^2)/E_2}{1/d_1 + 1/d_2} \right)^{1/2}$$

$$p_{max} = \frac{2F}{\pi b l}$$

Stress components along the z-axis



Maximum shear stress occurs at a depth of approximately b from the contact surface

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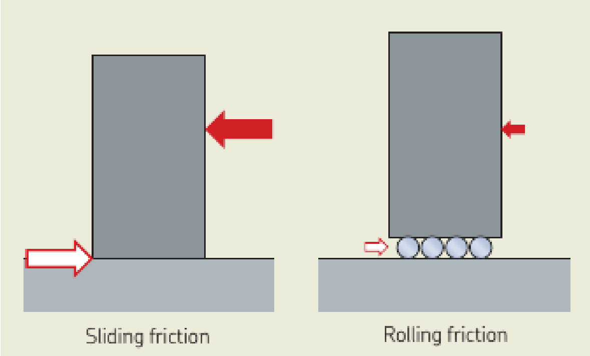
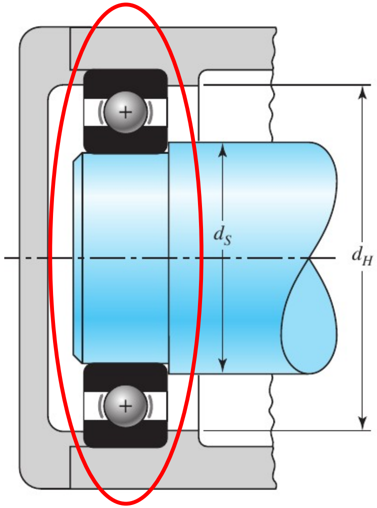
Rolling Bearings





Rolling bearings support and guide, with minimal friction rotating or oscillating machine elements – such as shafts, axles or wheels

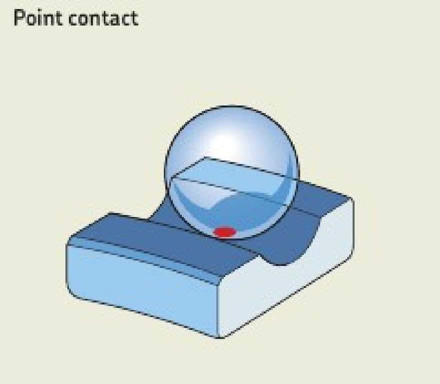
Rolling bearings provide high precision and low friction and therefore enable high rotational speeds while reducing noise, heat, energy consumption and wear.

They are cost-effective and exchangeable machine elements that typically follow national or international dimension standards.

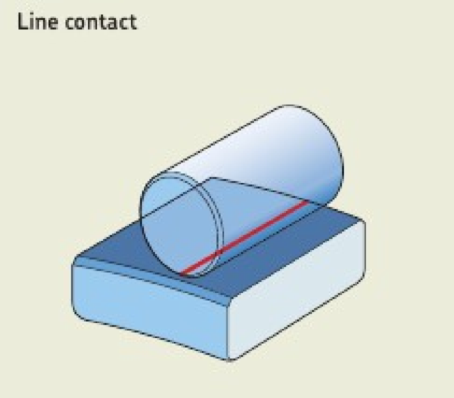
SKF – Rolling bearing catalogue
PUB BU/P1 17000/1 EN · October 2018

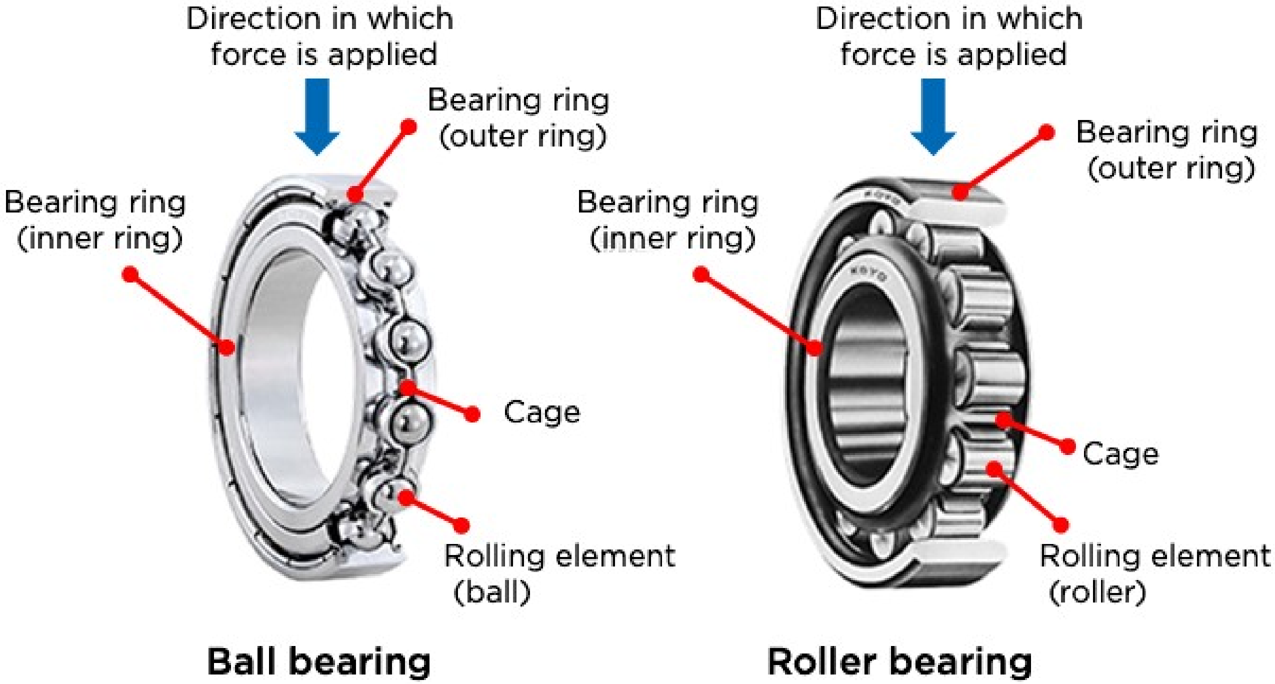
Types of Rolling Elements

Balls → Ball bearings



Rollers → Roller bearings





https://koyo.jtekt.co.jp/en/uploads/column01_03_02.png

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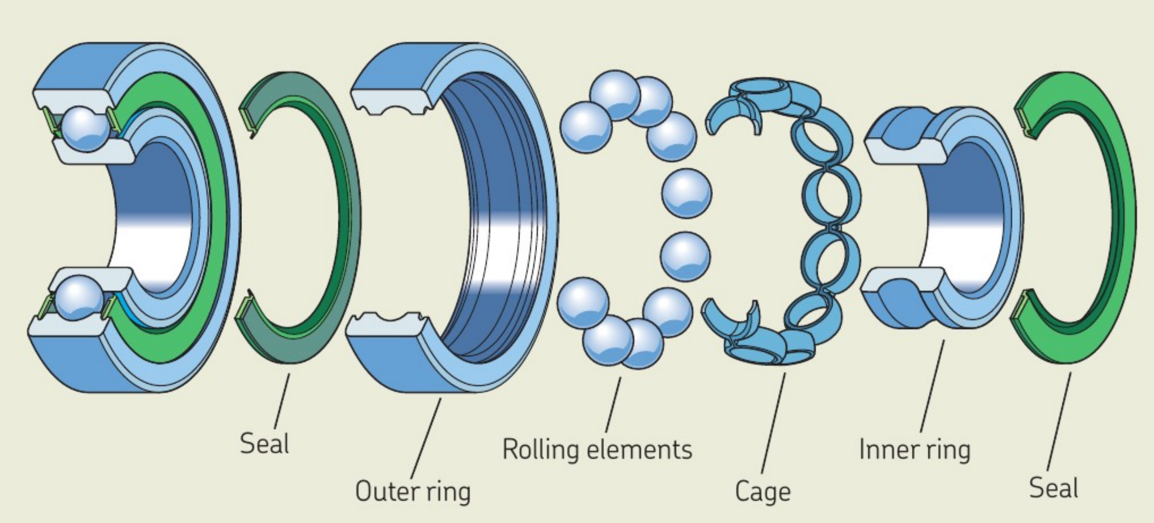
Bearing Components

Four main components:

- Outer ring
- Inner Ring
- Rolling elements – transfer the load between inner and outer rings. Typically, the same steel is used for rolling elements as for bearing rings
- Cage – Primary purpose is



  - separating the rolling elements to reduce the frictional heat generated in the bearing
  - keeping the rolling elements evenly spaced to optimize load distribution
  - guiding the rolling elements in the unloaded zone of the bearing
  - retaining the rolling elements of separable bearings when one bearing ring is removed during mounting or dismounting

<u>Seals</u>: Keep in the lubricants in and contaminants out – help to significantly prolong the life of the bearing

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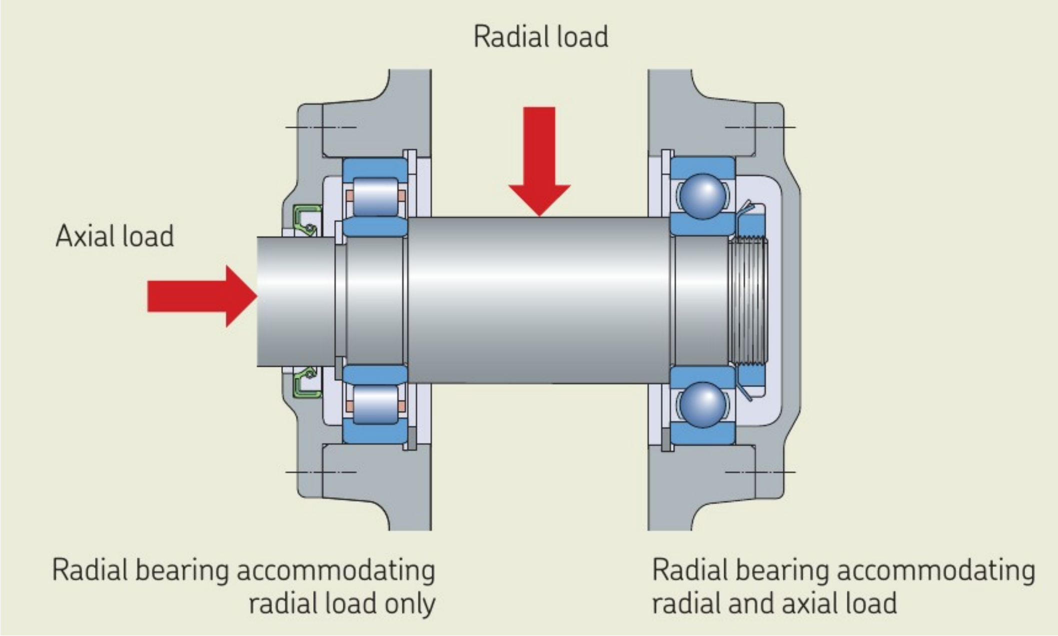
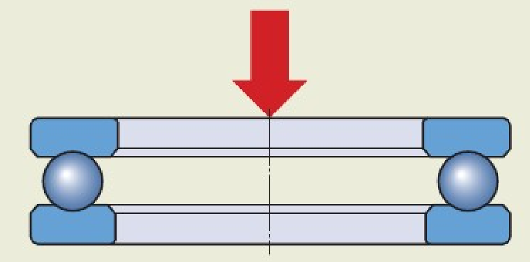
Types of Rolling Bearings

- **Radial Bearings** – Accommodate loads that are predominantly perpendicular to the shaft. Most can accommodate some load in the axial direction.
- **Thrust Bearings** – Accommodate loads that are predominantly parallel to the shaft.

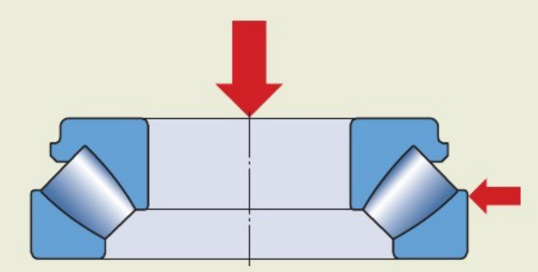
Radial Bearing



Thrust Bearing – Pure Thrust Load



Thrust Bearing – Thrust + Radial Load



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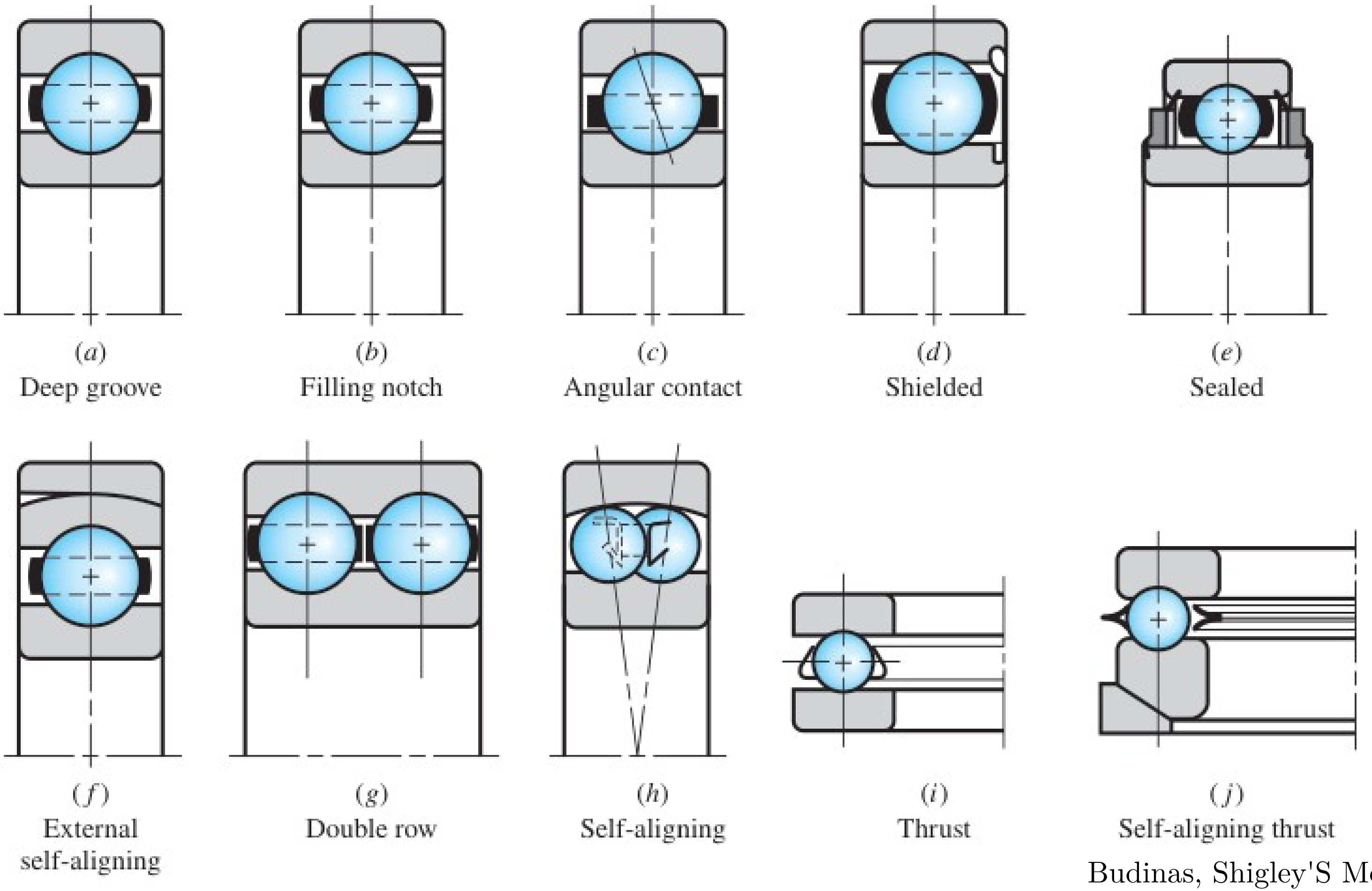
Types of Ball Bearings



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Types of Roller Bearings

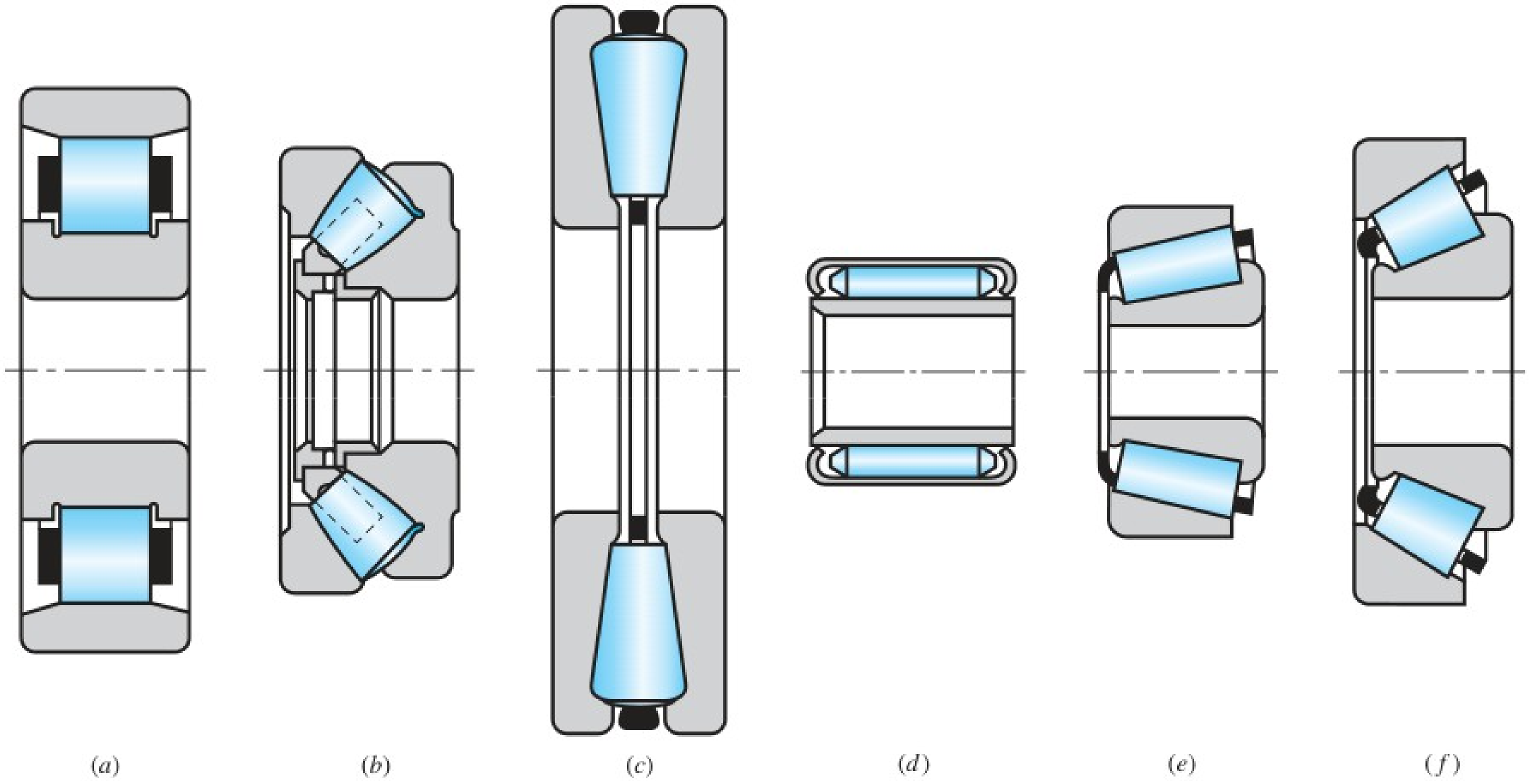

Figure 11–3

Types of roller bearings: (*a*) straight roller; (*b*) spherical roller, thrust; (*c*) tapered roller, thrust; (*d*) needle; (*e*) tapered roller; (*f*) steep-angle tapered roller. *(Source: Redrawn from material Furnished by The Timken Company*

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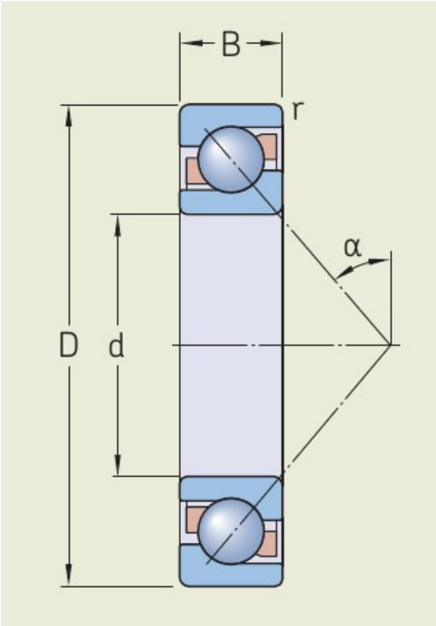
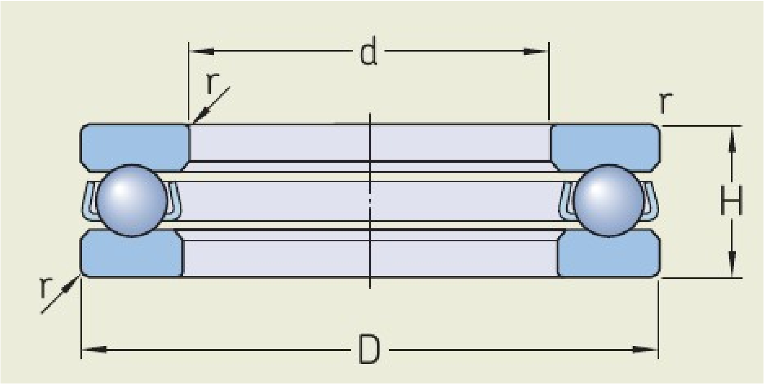
Boundary Dimensions

d – Bore diameter
D – Outside diameter
B – Bearing width
H – Bearing height
r – Chamfer dimension
α – Contact angle

Radial Bearing



Thrust Bearing



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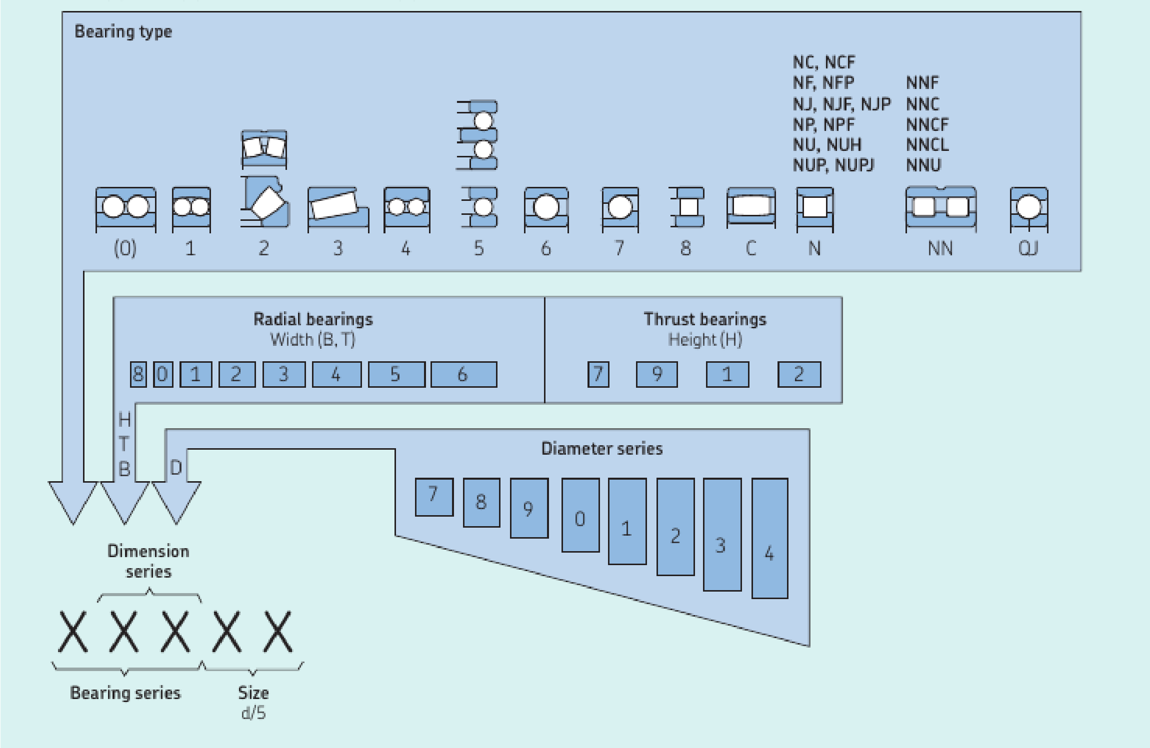
Bearing Designation System – SKF



Code	Bearing type
0	Double row angular contact ball bearing
1	Self-aligning ball bearing
2	Spherical roller bearing, spherical roller thrust bearing
3	Tapered roller bearing
4	Double row deep groove ball bearing
5	Thrust ball bearing
6	Single row deep groove ball bearing
7	Single row angular contact ball bearing
8	Cylindrical roller thrust bearing
C	CARB toroidal roller bearing
N	Cylindrical roller bearing. Two or more letters are used to identify the number of the rows or the configuration of the flanges, e.g. NJ, NU, NUP, NN, NNU, NNCF
QJ	Four-point contact ball bearing
T	Tapered roller bearing in accordance with ISO 355

- The first digit or letter or combination of letters identifies the bearing type and eventually a basic variant.
- The following two digits identify the ISO dimension series. The first digit indicates the width or height series (dimensions B, T or H). The second digit identifies the diameter series (dimension D).
- The last two digits of the basic designation identify the size code of the bearing bore. The size code multiplied by 5 gives the bore diameter (d) in mm.

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Bearing Life

Bearing life is defined as the number of revolutions (or the number of operating hours) at a given speed that the bearing is capable of enduring before the first sign of metal fatigue (spalling) occurs on a rolling element or the raceway of the inner or outer ring.

The **basic rating life**, $\mathbf{L_{10}}$, is the fatigue life that 90% of a sufficiently large group of apparently identical bearings, operating under identical operating conditions, can be expected to attain or exceed.

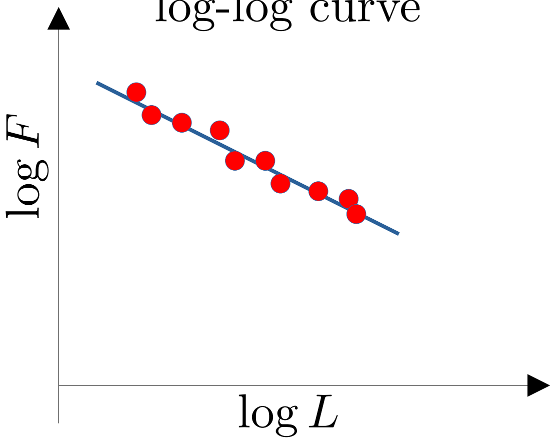
Each bearing manufacturer will choose a specific rating life for which load ratings of its bearings are reported. The most commonly used rating life is 10^6 revolutions.

The Timken Company is a well-known exception, rating its bearings at 90×10^6 revolutions

Bearing Load Life at Rated Reliability

Typical bearing load-life

log-log curve



$$L \propto \frac{1}{F^a} \qquad \begin{aligned} a &= 3 \text{ (ball bearing)} \\ a &= 10/3 \text{ (roller bearing)} \end{aligned}$$

A **catalogue load rating**, C_{10}, (**basic dynamic load rating**) is defined as the bearing load that causes 10% of a group of bearings to fail at the bearing manufacturer's rating life, usually 10^6. It is assumed that the load is constant in magnitude and direction and is radial for radial bearings and axial, centrically acting, for thrust bearings.

If identical bearings are run at loads F_1, F_2, ... and if L_1, L_2, ... are their rated lives then

$$L_{10}C_{10}^a = L_1F_1^a = L_2F_2^a = \ldots \text{constant}$$

Problem

Consider SKF, which rates its bearings for 1 million revolutions. If you desire a life of 5000 h at 1725 rpm with a load of 1792 N with a reliability of 90 percent for a ball bearing, for which catalogue rating would you search in an SKF catalogue?

We have $F_1 = 1762$ N, $L_1 = 5000 \times 60 \times 1725 = 517.5 \times 10^6$ revolutions

$L_{10} = 10^6$ revolutions. $C_{10} = ?$

We have $L_{10}C_{10}^3 = L_1F_1^3$ Therefore $C_{10} = F_1\left(\dfrac{L_1}{L_{10}}\right)^{1/3} = 14.15$ kN

For the above bearing, find the radial load for a rating life of 500 h at 1500 rpm

$L_{10} = 10^6$ revolutions. $C_{10} = 14.15$ kN

We have $L_2 = 500 \times 60 \times 1500 = 45 \times 10^6$ revolutions

$$\text{Therefore } C_2 = C_{10}\left(\frac{L_{10}}{L_2}\right)^{1/3} = 42.59 \text{ kN}$$

Design for Variable Loading

Let radial loads F_1, F_2,...,F_k act on bearing for successive intervals of a work cycle. Let L_i be the life of the bearing (revolutions) if operated exclusively at load F_i. Let n_i revolutions be the actual application of load F_i

Then as per Miner's rule

$$\sum_{i=1}^{k} \frac{n_i}{L_i} = 1 \qquad \text{Here } L_i = \frac{L_{10} C_{10}^3}{F_i^3}$$

or

$$\sum_{i=1}^{k} n_i F_i^3 = L_{10} C_{10}^3 = n_T F_e^3 \qquad n_T = n_1 + n_2 + \ldots + n_k$$

where F_e is the equivalent load that causes the bearing to fail in n_T revolutions

or

$$F_e = \left(\sum_{i=1}^{k} \alpha_i F_i^3 \right)^{1/3} \qquad \sum_{i=1}^{k} \alpha_i = 1$$

$\alpha_1, \alpha_2, \ldots, \alpha_k$ are the fraction of the total revolutions spent at $F_1,\ F_2, \ldots F_k$

Load Application Factor

- Accounts for the actual operating conditions of the bearing that may differ from the ideal conditions. Ensures that the selected bearing can handle unexpected loads, misalignments, vibrations, etc.
- Adjusts the calculated or nominal load to account for the actual loading condition.
- The factor is typically determined based on empirical data and experience. It varies depending on the type of machinery, operating conditions, and the nature of the load (e.g., steady, variable, shock loads).

Similar to design factor

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

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Problem - Design for Variable Loading

A ball bearing is run at four piecewise continuous steady loads as shown in the following table. Find the equivalent radial load the bearing is subjected to.

Time Fraction	Speed (rpm)	Radial Load (N) F_i	Load Factor a_i
0.1	2000	3531.71	1.1
0.1	3000	2784.45	1.25
0.3	3000	3905.34	1.1
0.5	2400	2971.26	1.25

Problem - Design for Variable Loading

A ball bearing is run at four piecewise continuous steady loads as shown in the following table. Find the equivalent radial load the bearing is subjected to.

Time Fraction	Speed (rpm)	Radial Load (N) F_i	Load Factor a_i	Rev in time fraction	Revolution Fraction α_i	$\alpha_i(a_iF_i)^{1/3}$
0.1	2000	3531.71	1.1	200	0.077	4.51014E+09
0.1	3000	2784.45	1.25	300	0.115	4.86515E+09
0.3	3000	3905.34	1.1	900	0.346	2.74425E+10
0.5	2400	2971.26	1.25	1200	0.462	2.36461E+10
				2600		6.04639E+10

The equivalent load the bearing is subjected to is $(6.04639\text{E+}10)^{1/3} = 3924.9$ N

Basic Static Load Rating C_0

- The basic static load rating C_0 is defined in as the load that results in a certain value of contact stress at the centre of contact of the most heavily loaded rolling element/raceway. The contact stress values are:
    - 4600 MPa for self-aligning ball bearings
    - 4200 MPa for all other ball bearings
    - 4000 MPa for all roller bearings

Bore, mm	OD, mm	Width, mm	Fillet Radius, mm	Shoulder Diameter, mm		Load Rat Deep Groove	
				d_S	d_H	C_{10}	C_0
10	30	9	0.6	12.5	27	5.07	2.24
12	32	10	0.6	14.5	28	6.89	3.10
15	35	11	0.6	17.5	31	7.80	3.55

- It represents the maximum load that a bearing can withstand when stationary, without causing permanent deformation of the rolling elements and raceways.
- *It is approximately equal to 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.*
- This rating is essential for ensuring the bearing's performance and longevity under static conditions.
- It is tabulated along with the basic dynamic load rating C_{10}, in bearing manufacturer's catalogues.

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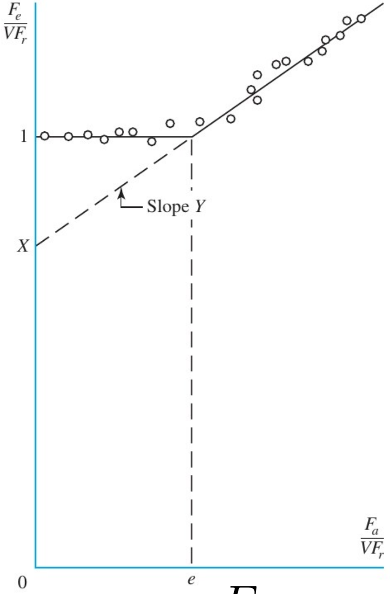
Combined Radial and Thrust Loading

- Consider a bearing subjected to both axial thrust (F_a) and radial load (F_r) that are constant in both magnitude and direction.

- Would like to find F_e, the equivalent dynamic radial load, constant in both magnitude and direction, that does the same damage as the combined radial and thrust loads together.

$$\frac{F_e}{VF_r}$$



$$\frac{F_a}{VF_r}$$

$$\frac{F_e}{VF_r} = \begin{cases} 1 & \frac{F_a}{VF_r} \leq e \\ X + Y\frac{F_a}{VF_r} & \frac{F_a}{VF_r} > e \end{cases}$$

V is the rotation factor with

$$V = \begin{cases} 1 & \text{inner ring rotates} \\ 1.2 & \text{outer ring rotates} \end{cases}$$

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Combined Radial and Thrust Loading

$$\frac{F_e}{VF_r} = \begin{cases} 1 & \frac{F_a}{VF_r} \le e \\ X + Y\frac{F_a}{VF_r} & \frac{F_a}{VF_r} > e \end{cases}$$

V is the rotation factor with

$$V = \begin{cases} 1 & \text{inner ring rotates} \\ 1.2 & \text{outer ring rotates} \end{cases}$$

		$F_a/(VF_r) \le e$		$F_a/(VF_r) > e$	
F_a/C_0	e	X_1	Y_1	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 $F_a/C_0 < 0.014$.

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Combined Radial and Thrust Loading

An SKF 6210 angular-contact ball bearing has an axial load F_a of 1779 N and a radial load F_r of 2224 N applied with the outer ring stationary. The basic static load rating C_0 is 19793 N and the basic load rating C_{10} is 35139 N. Estimate the L_{10} life at a speed of 720 rev/min.

Given

$F\_a := 1779\ \text{N}$ $\quad F\_r := 2224\ \text{N}$ $\quad V := 1.0$ $\quad rpm := 720$

$C\_0 := 19793\ \text{N}$ $\quad C\_10 := 35139\ \text{N}$

Combined Radial and Thrust Loading

An SKF 6210 angular-contact ball bearing has an axial load F_a of 1779 N and a radial load F_r of 2224 N applied with the outer ring stationary. The basic static load rating C_0 is 19793 N and the basic load rating C_{10} is 35139 N. Estimate the L_{10} life at a speed of 720 rev/min.

Given

$F\_a := 1779\ \text{N} \qquad F\_r := 2224\ \text{N} \qquad V := 1.0 \qquad rpm := 720$

$C\_0 := 19793\ \text{N} \qquad C\_10 := 35139\ \text{N}$

Solution

$$r := \frac{F\_a}{C\_0} = 0.0899 \qquad ep := 0.28 + \frac{(0.3 - 0.28)}{0.110 - 0.084} \cdot (r - 0.084) = 0.2845$$

$$r1 := \frac{F\_a}{V \cdot F\_r} = 0.7999 \qquad y1 := 1.55 + \frac{(1.55 - 1.45)}{0.084 - .110} \cdot (r - 0.084) = 1.5274$$

$$Fe := V \cdot F\_r \cdot \left(0.56 + y1 \cdot \frac{F\_a}{V \cdot F\_r}\right) = 3962.6554\ \text{N}$$

$$L\_10 := (C\_10)^3 \cdot \frac{10^6}{Fe^3} = 6.9728 \cdot 10^8 \qquad Hours := \frac{L\_10}{60 \cdot rpm} = 16140.8169$$

Reliability Aspects

For cases where one desires a higher reliability than 90% a life adjustment factor a_1 is introduced

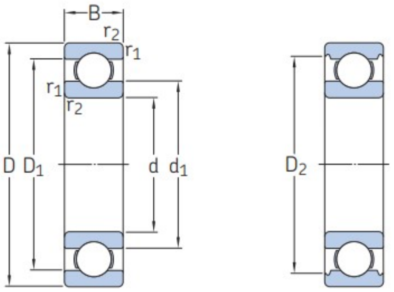
$$L_m = a_1 L_{10}$$

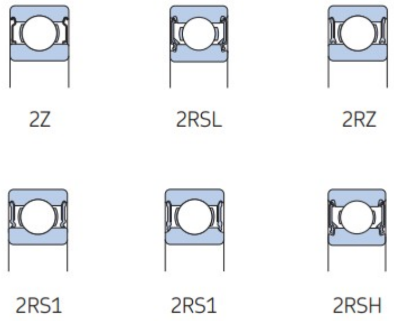
Reliability %	Factor a_1
90	1
95	0.64
96	0.55
97	0.47
98	0.37
99	0.25

Sample Catalogue Page (SKF)

1.1 Single row deep groove ball bearings
d **25 – 30** mm

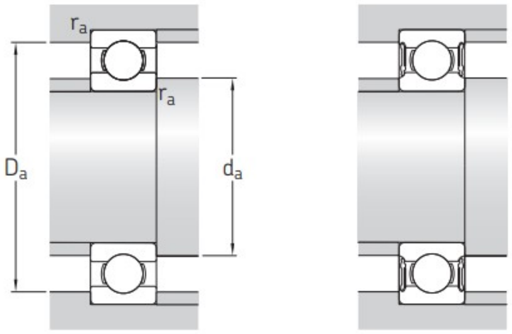
1.1





Principal dimensions			**Basic load ratings**		**Fatigue load limit**	**Speed ratings**		**Mass**	**Designations**	
			dynamic	static		Reference speed	Limiting speed[1)]		Bearing open or capped on both sides	capped on one side[1)]
d	D	B	C	C_0	P_u					
mm			kN		kN	r/min		kg	–	
25	37	7	4,36	2,6	0,125	–	11 000	0,022	▸ **61805-2RS1**	–
	37	7	4,36	2,6	0,125	38 000	19 000	0,022	▸ **61805-2RZ**	–
	37	7	4,36	2,6	0,125	38 000	24 000	0,022	▸ **61805**	–
	42	9	7,02	4,3	0,193	–	10 000	0,045	▸ **61905-2RS1**	–
	42	9	7,02	4,3	0,193	36 000	18 000	0,045	▸ **61905-2RZ**	–
	42	9	7,02	4,3	0,193	36 000	22 000	0,045	▸ **61905**	–

Sample Catalogue Page (SKF)

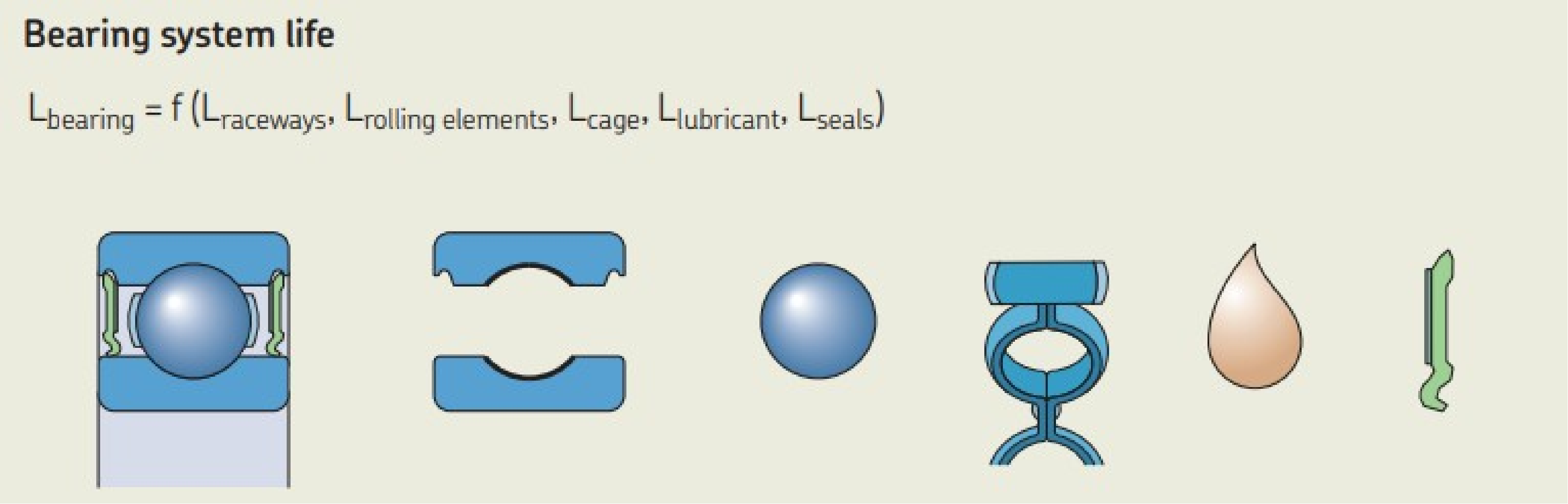


Dimensions						Abutment and fillet dimensions				Calculation factors	
d	d_1 ≈	d_2 ≈	D_1 ≈	D_2 ≈	$r_{1,2}$ min.	d_a min.	d_a max.	D_a max.	r_a max.	k_r	f_0
mm						mm				–	
25	–	27,4	–	34,2	0,6	27	27,3	35	0,3	0,015	14
	28,5	–	–	34,2	0,3	27	28,4	35	0,3	0,015	14
	28,5	–	33,2	–	0,6	27	–	35	0,3	0,015	14
	30,2	–	–	37,7	0,6	27	29	40	0,3	0,02	15
	30,2	–	–	37,7	0,6	27	29	40	0,3	0,02	15
	30,2	–	–	37,7	0,6	27	–	40	0,3	0,02	15
	33,3	–	–	42,4	0,3	27	–	45	0,3	0,02	15

Bearing Catalogue

- **Fatigue load limit $\mathbf{P_u}$**: The load level below which metal fatigue will not occur in a bearing
- **Reference Speed**: It is the speed at which the bearing can operate under specific thermal operating conditions without overheating.
  - It is based on achieving a thermal equilibrium where the heat generated by friction is balanced by the heat dissipated through the bearing's surroundings
  - It provides a quick assessment of the bearing's speed capability under typical operating conditions.
- **Limiting Speed**: It is the maximum speed at which the bearing can operate without risking mechanical failure.

Bearing System Life



Main considerations:

- Rolling contact fatigue
- Permanent deformation
- Cage type of cage material – may limit the speed, temperature
- Speed limit of contact seals
- Lubricant life

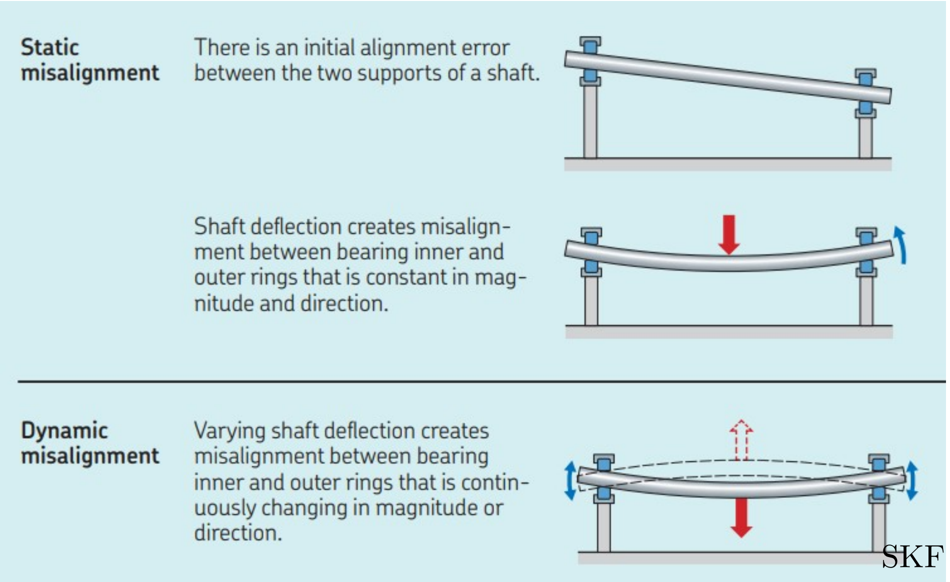
SKF – Rolling bearing catalogue
PUB BU/P1 17000/1 EN · October 2018

Bearing Selection Criteria

- **Available Space**

- **Loads** (Radial, Axial, Combined radial and axial) – Primary factor in bearing selection

- **Misalignment**



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Bearing Selection Criteria

- **Speed and friction** - The permissible operating temperature of rolling bearings imposes limits on the speed at which they can be operated.

- **Temperature** – the permissible operating temperature is limited by the dimensional stability of the races and rolling elements, seals and lubricants.

- **Stiffness** - The stiffness of a rolling bearing is characterized by the magnitude of the elastic deformation in the bearing under load and depends not only on bearing type, but also on bearing size and operating clearance.

- **Mounting and Dismounting** - Separable bearings are easier to mount and dismount.

- **Integral Sealing** – Sealing is important to keep the lubricants in and contaminants out.

- **Cost and Availability**

End