Angular contact bearings
Angular contact bearings
General description
Architecture of angular contact bearings

Load support on a cone, unilateral actions $\rightarrow$ axial load transmitted in a single direction, determined by mounting.
Angular contact bearings

Gap between the two raceways

Contact angle = angle between the load direction (between the 2 contact points) and the radial direction
- Typical bearing: $\alpha = 40^\circ$
- Precision bearing: $\alpha = 15^\circ$ or $25^\circ$

- mounted by pair
- Support axial loads
- Axial load in a single direction
- Equivalent to a unilateral spherical joint
Angular contact ball bearings

Characteristics
- Mounted by pairs in opposition
- Rings cannot be separated
- Large number of balls → large load capacity
- Axial load increases with loading angle
- Permissible misalignment: 1 to 2’

Applications
- Vertical axis electrical engines
- Car front wheels …
Taper roller bearings

Description

Rollers and raceways are cone portions
Rollers and raceways are slightly rounded
All cones have the same apex to ensure rolling and limit sliding
Linear contact

- Designed for combined loads
- Axial force transmission on a single direction
- Equivalent to a unilateral spherical joint
Roulement à rouleaux coniques

Characteristics

- Mounted by pairs in opposition
- Rings can be separated
- Linear contact → large load capacity
- Load capacity increases with loading angle
- Permissible misalignment: 1 to 4’
- Shaft and housing must be really coaxial

Applications

- Car back wheels
- Reducers …
Mounting

1 complete rotation + 2 limited rotations (permissible misalignment) + axial locating in a single direction

« Half » spherical joint
Revolute joint

X mounting = face-to-face mounting
Load centers are closer
Shaft is more rigid

Locating:
- Inside on the shaft
- Outside in the housing

O mounting = back-to-back:
Load centers are distant
Assembly is more robust to external radial forces

Locating:
- Outside on the shaft
- Inside in the housing
Consequences on mounting

- Internal (inside) locating preferably by a shoulder
- Rings with interference fits preferably mounted on shoulders

- X mounting (face to face) better when shafts rotates with respect to the load direction
- O mounting (back to back) better when housing rotates with respect to the load direction
Examples – Automotive gearbox

Gear box
Examples

Electrical linear actuator
Guiding wheel for the subway
Examples

Truck rear axle driver gear

http://barreau.matthieu.free.fr/cours/Liaison-pivot/pages/roulements-2.html
Examples

Car rear axle

http://barreau.matthieu.free.fr/cours/Liaison-pivot/pages/roulements-2.html
Examples

http://barreau.matthieu.free.fr/cours/Liaison-pivot/pages/roulements-2.html
Campervan wheel

Hub and brake drum

Flange for brake shoe

Fix axle
Loading angular contact bearings
Axial load equally distributed on all rolling elements
Inner ring comes closer to the outer ring
Radial load

Radial load only supported by rolling elements placed along the loading direction.
Axial equilibrium requires the presence of the second bearing mounted in the opposite direction.
Radial load puts apart inner ring from outer ring → fewer and fewer rolling elements support the load → higher and higher load on those rolling elements
Preload: condition for a good functioning

At least half of the rolling elements should support the load

Mounting condition: create an axial preload to bring inner and outer rings closer and increase the number of rolling elements to support the load.
Preload: condition for a good functioning

Preload must ensure that axial load on a bearing is higher than the induced axial load $a_i$ due to external radial load and geometry.

$$a_i = \frac{Fr}{2Y_i}$$

Induced axial load corresponds to the minimum load for half of the rolling elements to be loaded.
Sizing of angular contact bearings
Static equilibrium of the shaft → determine radial loads supported by bearings (Fy and Fz) BUT NOT the axial loads (Fx)
For sizing, we **assume** that axial load is supported by one bearing and the other supports only the induced axial load.

\[ +F_a^M - F_a^N + F_a = 0 \]

\[ F_a^M = a_M \text{ et } F_a^N \geq a_N \text{ OR } F_a^M \geq a_M \text{ et } F_a^N = a_N \]
How to determine which bearing supports only its induced axial load?
Calculation of axial loads

Assuming external loads are on the shaft

Identify external loads on the shaft
Locate the load centers A and B

Identify the direction of the load exerted by bearings on the shaft
Calculation of axial loads

Loads in bearings are applied at the load center

Write the radial static equilibrium:
\[ \vec{F}_r + \vec{F}_{rA} + \vec{F}_{rB} = \vec{0} \]
\[ \vec{M}_r + \vec{AO} \times \vec{F}_r + \vec{AB} \times \vec{F}_{rB} = \vec{0} \]

Deduce the norm of radial loads in the bearings:
\[ R_A = |\vec{F}_{rA}| \]
\[ R_B = |\vec{F}_{rB}| \]

Calculate the norm of induced axial loads:
\[ a_A = \frac{R_A}{2.Y_A} \]
\[ a_B = \frac{R_B}{2.Y_B} \]
Calculation of axial loads

Determine the direction of the resultant axial load: \( \vec{F}_{\text{res}} = \vec{F}_a + \vec{a}_A + \vec{a}_B \)

Determine the bearing that can support this load from the load direction.
Calculation of axial loads

The other bearing supports its induced axial load only.
Calculation of axial loads

\[ F_{aA} = a_A \]

\[ -a_A + F_{aB} + F_a = 0 \rightarrow F_{aB} = a_A - F_a \]

\[ F_{aA} = a_B \]

\[ a_B - F_{aA} + F_a = 0 \rightarrow F_{aA} = a_B + F_a \]

\[ F_{aB} = a_B \]

\[ -a_B + F_{aA} + F_a = 0 \rightarrow F_{aA} = a_B - F_a \]

\[ a_A - F_{aB} + F_a = 0 \rightarrow F_{aB} = a_A + F_a \]
Calculation of axial loads

Assuming external loads are on the housing

- Identify external loads on the housing
- Locate the load centers

Identify the direction of the load exerted by the bearings on the housing
Calculation of axial loads

Proceed the same way
Calculation of axial loads

Take home message:
One bearing supports its induced axial load.
The other supports the external axial load.
General method for angular contact bearing sizing

Static equilibrium helps determining axial and radial loads on each bearing.

1. Determine equivalent static bearing load $P_0$.

2. Check: $C_0 > s_0 \times P_0$

where $s_0$ depends on loading conditions and $C_0$ is the static basic load rating,

3. Determine the equivalent dynamic bearing load $P$: $P > P_{min}$

4. Check it is large enough

5. Calculate the bearing rating life:

$$L_{10} = \left(\frac{C}{P}\right)^n$$
Mounting
Clearance and preload
For angular bearing arrangements

- They are always mounted by pairs

- Axial locating is done on 4 points which place is determined by arrangement type (X or O)
Examples

Campervan wheel

- Shoulders
- Locking nut
https://pierreprovot.wordpress.com/2008/01/23/sance-de-tp-du-23012008-g2/
Locating radial dimensions are provided by the manufacturer
Preload

- Requires setting the axial fit by acting on the free ring
Preload setting - examples

Small shaft – fix load

• Laminated shims

http://barreau.matthieu.free.fr/cours/Liaison-pivot/pages/roulements-2.html

http://joho.monsite.orange.fr/
Preload setting - examples
Preload setting - examples

Long shaft – Fix load

- Use springs: spring washer, Ringspann washer, etc.
Preload setting - examples

Rotating housing – fix load

• Use a washer and a nut
Clearance or preload is influenced by loading conditions: increase of temperature \(\rightarrow\) thermal expansion, elasticity, etc.
Preload setting

Better distribution of the load on rolling elements

- Better guiding of rolling elements
  - less noise
  - better shaft guiding

- Decreases chocks
  - Increases rating life

- Increases arrangement stiffness
  - Better shaft guiding
PreLoad – Rigidity
Principle on a single angular contact bearing

Force - Displacement nonlinear relation
Depends on internal bearing geometry intern
Principle on a single angular contact bearing

Introduction of a preload

Axial Preload ($F_a$)

Displacement ($\delta a$)

$\delta a$

$Q_0$

$X_0$
Principle: 2 bearings
Principle: 2 bearings

Preload $Q_0$ (N) $\rightarrow$ displacement $X_0$

The two bearings are axially loaded at $Q_0$
Determine X₀ knowing the preload Q₀

\[ X₀ = \delta₁ + \delta₂ + \delta₀ \]

Principle: 2 bearings

Internal clearance
Principle: 2 bearings

How to determine Qo

The bearing – shaft – housing « at rest »

The bearing – shaft – housing « operating »
**Principle: 2 bearings**

**Loads supported by the bearings**

**Objective is to have Q2 > QLimit**

**Loads applied on the shaft, axial equilibrium**

\[ Fa + Q2 - Q1 = 0 \]
Principle: 2 bearings

Graphical analysis

Axial load (Fa) vs. Displacement (δa)

Q1
Q0
QL

Fa = external axial load

Δ
Δ
Principle: 2 bearings

Determine which of the 2 bearing will be unloaded when the axial external action $Fa$ is applied, Position QL and $Fa$
Principle: 2 bearings

Do a « miror » with the other curve and position it with Fu
Principle: 2 bearings

The two curves cross at a point that correspond to the preload Qo
Principle: 2 bearings

Determine which bearing that is unloaded
Principle: 2 bearings

Bearing 2 is unloaded

(Fa)

Fa1

Fu

Fa2

(δa)
Principle: 2 bearings

Bearing 1 is unloaded

Charge (Fa)

Déformation (δa)
How to obtain the curves « Axial load - displacement » ?

Models established by de Palmgren - 1967

<table>
<thead>
<tr>
<th>Type of bearing</th>
<th>Radial ( \delta_r = 0 )</th>
<th>Axial ( \delta_r = 0 )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Radial ( Q = \frac{F_r}{i \cdot \cos \alpha} )</td>
<td>Axial ( Q = \frac{5F_a}{z \cdot \sin \alpha} )</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Bearing Type</th>
<th>Radial Formula</th>
<th>Axial Formula</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ball bearing</td>
<td>( \delta_r = 0.0032 \frac{Q^2}{\cos \alpha D_w} )</td>
<td>-</td>
</tr>
<tr>
<td>Shaft-mounted</td>
<td>( \delta_r = 0.002 \frac{Q^2}{\cos \alpha D_w} )</td>
<td>-</td>
</tr>
<tr>
<td>Contact oblique</td>
<td>( \delta_r = 0.002 \frac{Q^2}{\cos \alpha l_a} )</td>
<td>( \delta_a = 0.002 \frac{Q^2}{\sin \alpha l_a} )</td>
</tr>
<tr>
<td>Linear contact on both tracks</td>
<td>( \delta_r = 0.0006 \frac{Q^{0.9}}{\cos \alpha l_a^{0.8}} )</td>
<td>( \delta_a = 0.0006 \frac{Q^{0.9}}{\sin \alpha l_a^{0.8}} )</td>
</tr>
<tr>
<td>Linear contact on one track, one linear bearing on the other</td>
<td>( \delta_r = 0.0012 \frac{Q^{0.6}}{\cos \alpha l_a^{0.5}} )</td>
<td>( \delta_a = 0.0012 \frac{Q^{0.6}}{\sin \alpha l_a^{0.5}} )</td>
</tr>
<tr>
<td>Linear contact on both tracks</td>
<td>-</td>
<td>( \delta_a = 0.024 \frac{Q^{2}}{\sin \alpha D_w} )</td>
</tr>
</tbody>
</table>
How to obtain the curves « Axial load - displacement » ?

\[ F_r : \text{radial load (daN)} \]
\[ F_a : \text{axial load (daN)} \]
\[ D_w : \text{rolling element diameter (mm)} \]
\[ l_a : \text{effective length of the roller (mm)} \]
\[ Z : \text{number of rolling element} \]
\[ i : \text{number of row of rolling element} \]
\[ \alpha : \text{contact angle (when loaded)} \]

\[ Q : \text{maximum force on rolling element (daN)} \]
\[ \delta r : \text{radial displacement (mm)} \]
\[ \delta a : \text{axial displacement (mm)} \]