The Design of Rolling Bearing Mountings

PDF 4/8:
Rail vehicles
Shipbuilding
The Design of
Rolling Bearing Mountings

Design Examples covering
Machines, Vehicles and Equipment

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This publication presents design examples covering various machines, vehicles and equipment having one thing in common: rolling bearings.

For this reason the brief texts concentrate on the rolling bearing aspects of the applications. The operation of the machine allows conclusions to be drawn about the operating conditions which dictate the bearing type and design, the size and arrangement, fits, lubrication and sealing.

Important rolling bearing engineering terms are printed in italics. At the end of this publication they are summarized and explained in a glossary of terms, some supplemented by illustrations.
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Axle box roller bearings of an Intercity train carriage

The type of axle box roller bearings presented here is used for Intercity traffic in Europe. The bogie frame is supported on the bearing housing by a central coil spring, arranged above the bearings. The wheelsets are guided by plate-type guiding arms which are bolted on one side.

Operating data

Deadweight of the carriage plus maximum payload: 64,000 kg; two bogies, each with two wheelsets, implies 4 wheelsets per car.
Resulting axle weight per wheelset: \( A = \frac{64,000}{4} = 16,000 \) kg; weight of wheelset \( G_R = 1,260 \) kg;
acceleration due to gravity \( g = 9.81 \) m/s\(^2\);
supplementary factor for dynamic loads occurring during operation \( f_z = 1.3\);
thrust factor for cylindrical roller bearings \( f_a = 1\);
number of bearings per wheelset \( i_R = 4\).

Thus the equivalent dynamic load per bearing is:

\[
P = \frac{(A - G_R)}{i_R \cdot g \cdot f_z \cdot f_a}
\]

\[
P = \frac{(16,000 - 1,260)}{4 \cdot 9.81 \cdot 1.3 \cdot 1} = 46,990 \text{ N}
\]

\[
P = 46.99 \text{ kN}
\]

Wheel diameter \( D_R = 890 \) mm;
maximum speed \( v_{max} = 200 \) km/h (possible speed 250 km/h).

Bearing selection

Cylindrical roller bearings installed as axle box roller bearings offer important advantages:

Mounting is simple and they are easy to check and maintain in main inspections.

Axial clearance is irrelevant for radial clearance. Cylindrical roller bearings are pure radial bearings, but the lips allow the safe accommodation of all thrust loads (guiding forces) occurring in operation.

Of all the roller bearing types cylindrical roller bearings have the lowest friction. Their speed suitability is therefore greater than in the case of other roller bearings.

Cylindrical roller bearings do not, however, compensate for misalignment between axle and bogie frame. Therefore misalignment must be corrected by angular freedom of the housing.

The same cylindrical roller bearings are used for passenger cars and freight cars. This simplifies stockkeeping.

Each axle box accommodates two cylindrical roller bearings, one FAG WJ130x240TVP and one FAG WJP130x240P.TVP.

The bearing dimensions \((d \times D \times B)\) are 130 x 240 x 80 mm; the dynamic load rating \( C \) of one bearing is 540 kN.

The nominal rating life \( L_{h10} \) is checked in kilometres when dimensioning the axle box bearings:

\[
L_{h10km} = \left(\frac{C}{P}\right)^{3.33} \cdot D \cdot \pi = \left(\frac{540}{46.99}\right)^{3.33} \cdot 890 \cdot \pi = 3,397 \cdot 2,497.6 \approx 9.5 \text{ million kilometres}
\]

Under these conditions the bearings are sufficiently dimensioned. 5 million kilometres (lower limit) applies today as a basis for dimensioning axle box bearings for passenger train carriages.

Machining tolerances

Bearing inner rings carry circumferential load; therefore they are press-fitted: axle journal p6, housing H7.

Bearing clearance

The tight fit expands the bearing inner rings which reduces radial clearance. The air stream cools the outer rings to a greater extent than the inner rings during travel which leads to a further reduction in radial clearance. Therefore the bearings have a radial clearance of 120 to 160 microns.

Lubrication, sealing

The bearings are lubricated with a lithium soap base grease. Lamellar rings at the wheel side provide for effective non-rubbing sealing. A baffle plate at the cover end keeps the grease close to the bearing. Despite the small amount of grease (≈ 600 g) high running efficiency (800,000 km and more) can be reached due to the polyamide cages without changing the lubricant.
42: Axle box roller bearings of an Intercity train carriage
The car body is supported by laminated springs on the wheelset. The laminated springs have the additional job of guiding the wheelset. To limit the swaying motion of the car body and to accommodate the thrust peaks, the housing features guiding surfaces in which the axle support of the frame is engaged. Cylindrical or spherical roller bearings are used as axle box roller bearings. The housing boundary dimensions of the UIC bearing are standardized. According to the latest UIC conditions 130 mm diameter journals are specified for cylindrical and spherical roller bearings. In some cases 120 mm journals are used for cylindrical roller bearings.

Clearance

The tight fit expands the inner ring thus reducing radial clearance. A further clearance reduction results from the air stream developed during travel which cools the outer ring more than the inner ring. Therefore, cylindrical roller bearings with a radial clearance of 130 to 180 microns and spherical roller bearings with increased radial clearance C3 are chosen.

Lubrication, sealing

The axle box roller bearings are lubricated with a lithium soap base grease. Felt seals combined with a labyrinth have proved most effective for cylindrical roller bearings. UIC axle boxes with spherical roller bearings invariably use only labyrinth seals.

Dimensioning, bearing selection

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<th>44: UIC axle boxes with spherical roller bearings</th>
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<td>40,000 kg</td>
<td>40,000 kg</td>
</tr>
<tr>
<td>Top speed $v_{\text{max}}$</td>
<td>100 km/h</td>
<td>100 km/h</td>
</tr>
<tr>
<td>Wheel diameter $D_R$</td>
<td>1 m</td>
<td>1 m</td>
</tr>
<tr>
<td>Number of wheelsets</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>Wheelset weight $G_R$</td>
<td>1,300 kg</td>
<td>1,300 kg</td>
</tr>
<tr>
<td>Weight on axle $A$</td>
<td>20,000 kg</td>
<td>20,000 kg</td>
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<td>Number of bearings per wheelset $i_R$</td>
<td>4 cylindrical roller bearings</td>
<td>4 spherical roller bearings</td>
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Equivalent load:

$P = (A – GR) \cdot g \cdot f_s \cdot f_a/i_R$  
$V_{\text{Fm}} = 0.75 \cdot v_{\text{max}}$  
$V_m = 5,310 \cdot V_{\text{Fm}} (\text{km/h})/D_R (\text{mm})$  
$3.5$  

Required dynamic load rating of one bearing:

$C = f_L/f_n \cdot P$  
Bearing mounted:

Bore x outside diameter x width  
Dynamic load rating  
Machining tolerances of journals  
Machining tolerances of housing bores  
Radial clearance

<table>
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<th>Bore x outside diameter x width</th>
<th>Dynamic load rating</th>
<th>Machining tolerances of journals</th>
<th>Machining tolerances of housing bores</th>
<th>Radial clearance</th>
</tr>
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<tbody>
<tr>
<td>130 x 240 x 80 mm</td>
<td>540 kN</td>
<td>p6</td>
<td>H7</td>
<td>130…180 µm</td>
</tr>
<tr>
<td>130 x 220 x 73 mm</td>
<td>585 kN</td>
<td>p6</td>
<td>H7</td>
<td>Clearance group C3</td>
</tr>
</tbody>
</table>
43: UIC axle boxes with cylindrical roller bearings

44: UIC axle boxes with spherical roller bearings
The frame is supported by coil springs and spring seats which are integrated in the bearing housing. The spring seats are arranged at different heights. The bearing is guided by an arm on each side which is linked diagonally to the housing. The arms are supported by elastic damping springs.

**Technical data**

- Vehicle weight: 84,000 kg
- Number of wheelsets: 4
- Wheelset weight: 2,250 kg
- Axle load: 22,000 kg
- Supplementary factor \( f_z = 1.5 \)

The locomotive reaches top travelling speeds up to 200 km/h.

**Bearing selection**

Please refer to example number 42 to determine the equivalent dynamic load \( P \).

Cylindrical roller bearings of the type NJ and NJP with the dimensions 180 x 320 x 75 mm are mounted. Dynamic load rating of one bearing: \( C = 735 \) kN. The outer and inner rings of both bearings are separated by spacer rings. The inner spacer ring is 2 mm wider than that of the outer rings.

The axial clearance which arises thereby, is necessary to compensate for bogie production tolerances. The bearing can always be mounted without preload.

**Machining tolerances**

The bearing inner rings have circumferential load and are therefore given a tight fit: Journals to p6. The housing material, an aluminium cast alloy, has a greater coefficient of expansion than cast steel which is why the tolerance field J7 was selected and not the housing tolerance H7 usually taken for cast steel housings.

**Bearing clearance**

Due to the tight fit the bearing inner rings expand; the radial clearance becomes smaller. The outer ring is cooled more than the inner ring by the wind resistance during travel which leads to a further reduction of clearance. For this reason bearings with increased radial clearance C4 have been selected.

**Lubrication, sealing**

A lithium soap base grease is used for lubrication. On the wheel side the bearing is sealed by a two-web labyrinth seal. A V ring seal protects from contaminants on the opposite side.
Axle box roller bearings for the ICE driving unit

The bogie frame is supported by 2 coil springs each on the bearing housings. The wheelset with the housings is connected to the bogie by an arm. A setting mechanism enables the mounting of the wheelsets in the bogies without preload. The bearing units are axially located by a cover.

### Operating data

Axle load: 19,900 kg  
Weight of unsprung weight: 2,090 kg  
Diameter of wheel 1,040 mm  
Maximum speed 250 to 280 km/h.

### Bearing selection

FAG tapered roller bearing units TAROL 150/250 are mounted in the wheelset housings of the series vehicles with the designation ET 401. The main component of these units is a double row tapered roller bearing with the dimensions: 150 x 250 x 160 mm.

### Machining tolerances

The cones carry *circumferential load* and therefore have a tight *fit: journal* to p6.

### Housing to:

- H7 (for GGG material)  
- J7 (for aluminium alloys).

### Bearing clearance

A slight *axial clearance* is required for ideal running behaviour of the bogies at top speeds. It is between 0.2 and 0.5 mm after mounting.

### Lubrication, sealing

The TAROL 150 is supplied as a complete unit which is sealed. The *sealing* system consists of two parallel outer diameter seated lamellar rings and one single-web labyrinth acting as a pre-seal. The labyrinth is shaped as a *seal cap* and pressed into the cup.  

The *seal caps* are each provided with four discharge holes through which excess *grease* escapes. This is particularly important directly after relubrication. *O rings* protect the bearing unit from the penetration of water in the seating area of the cup.
Axle box roller bearings of the Channel tunnel’s freight engine, class 92

Class 92 is used for freight traffic in the Euro tunnel between Great Britain and the Continent. It is a two-system engine which means it can be operated on direct current (750 V) as well as on alternating current (25 kV). The engine with six axles (CoCo) draws loads weighing up to 1,600 t.

The vertical loads of the bogie are accommodated by two lateral coil springs on the housing of the axle box bearings. All lateral and longitudinal forces act via the guiding journals and sleeves which are attached to the bogie frame and the housing.

The middle axle of each triple axle bogie is designed as a floating axle box to insure trouble-free operation in narrow curves. The two outer axles are designed as standard axles as customary.

Operating data

Vehicle weight 126,000 kg; two bogies each with three axles; wheel diameter 1,120 mm; top speed $v_{\text{max}} = 140 \text{ km/h}$;
Power $P = 5,000 \text{ kW at 25 kV AC}$
  $4,000 \text{ kW at 750 V DC}$

Bearing selection

Tapered roller bearing units TAROL 150/250 with pressed cages (JP) are mounted to the outer standard axles of the vehicles. The bearings are clearance-adjusted, greased and sealed by the manufacturer. Fey lamellar rings provide for sealing on the side facing the wheel. A gap-type seal prevents rough dirt from penetrating the bearings.

The floating axle is accommodated in two cylindrical roller bearings whose dimensions are 150 x 250 x 80 mm. The extended inner ring allows axial displacement within the bearing of ± 20 mm at a maximum.

Sealing is achieved at the wheel end by means of long-webbed labyrinths.

Machining tolerances

The inner rings carry circumferential load and have a tight fit to p6 on the journal. The housing bores (point load) are machined according to H7.

Bearing clearance

Prior to mounting, the TAROL units of the standard axle have an axial clearance of 0.665...0.740 mm and the cylindrical roller bearing units a radial clearance to C4 in order to compensate for heat expansion.

Lubrication

Both bearing types are lubricated with a lithium soap base grease. While the lubricant in the TAROL bearings is only changed during the main inspections, the floating axle bearings must be relubricated in between. Due to the constant right to left displacement of the axle lubricant is removed from the bearing area and therefore has to be replaced regularly.
47: Axle box roller bearings of the Channel tunnel’s freight engine, class 92
A car has two bogies. Each axle box roller bearings is cushioned and guided by rubber-metal silent blocks. These are arranged between the axle box roller bearing and the frame opening. They are inclined to the vertical and have an angular cross-section.

**Operating data**

Weight and maximum payload of one car: 34,000 kg.
Number of wheelsets per bogie: 2.
Wheelset weight $G_R$: 1,400 kg.
Supplementary factor $f_z$: 1.3.
Equivalent dynamic load $P = 22.6$ kN.
Wheel diameter $D_R = 900$ mm.
Top speed $v_{max} = 80$ km/h.

**Bearing selection**


**Machining tolerances**

The bearing inner rings carry circumferential load and are therefore given a tight fit: journal to m6, housing to H7.

**Bearing clearance**

The inner rings increase due to the tight fit: the radial clearance decreases. The outer rings are cooled more than the inner rings due to the air stream during travel. This leads to a further reduction in clearance and therefore a radial clearance C3 was selected.

**Lubrication, sealing**

A lithium soap base grease is used for lubrication. A combination of a felt ring and a labyrinth was selected as a means of sealing. The labyrinth is provided with two axial webs since the axle boxes are subjected to extreme dirt.
Axle box roller bearings for a city train

The bogie frame is supported by Chevron springs on the axle boxes.

Operating data

The equivalent dynamic load \( P_m = 37 \) kN (calculated from the various load conditions).
Mean wheel diameter 640 mm.
Maximum speed \( v_{\text{max}} = 80 \) km/h.

Bearing selection

The main component of the FAG bearing units TAROL 90 used here is a double row tapered roller bearing whose main dimensions are \( (d \times D \times B) \) overall widths cones/cup \( 90 \times 154 \times 106/115 \) mm.

Bearing clearance

Prior to mounting, the axial clearance of the bearing unit TAROL 90 is 530 – 630 microns.

Machining tolerances

The bearing cones carry circumferential load and are therefore given a tight fit: journal n6.

Lubrication, sealing

Lubrication is with a lithium soap base grease. The TAROL 90 is sealed at both ends with lamellar rings. The backing ring also has a collar which forms a gap-type seal with the lid on the wheel side.
Axle box roller bearings according to AAR standard*) and modified types

The FAG TAROL unit according to AAR standards is a compact bearing unit with a double row tapered roller bearing as the main component. Seals at both sides of the bearing, accessories and the grease filling make the FAG TAROL a ready-to-mount unit. Neither is the adjustment of the bearing clearance required. The so-called NFL design (no field lubrication) is considered standard today. These TAROL units are no longer relubricated during operation. The bearing grease is only renewed during a main inspection.

TAROL units do not have to be mounted into a housing. An adapter is attached between the TAROL unit and the bogie frame to transmit the loads and support the bearing cup on the loaded part of the circumference.

FAG supply NARROW and WIDE adapters according to the AAR standards as well as special adapters designed for the particular cases of application.

AAR has stipulated the admissible loads for the various sizes of TAROL units.

Components of the FAG tapered roller bearing unit TAROL

1 Locking plate
2 Cap screw
3 End cap
4 Bearing cup
5 Bearing cone with roller set
6 Spacer
7 Seal wear ring
8 Seal
9 Backing ring

FAG use two types of seals: the rubbing radial shaft seal (fig. a) corresponds to the design used by AAR. The non-rubbing lamellar seal ring (fig. b) was developed by FAG and tested and approved by AAR.

FAG also supply TAROL units in metric dimensions. They (fig. c) have narrower tapered roller bearings and smaller sealing and retaining components than the AAR design. The relevant journals are also shorter resulting in lower bending stresses with the same shaft diameter than in the case of the AAR arrangement. Higher wheel loads are therefore admissible.

*) Association of American Railroads
Kiln trucks for sand lime brick works

Operating conditions

In sand lime brick autoclaves the wheelset bearings of the kiln trucks are exposed for many hours to hot steam of approximately 200 °C at 16 to 22 bars. Due to corrosion hazard the bearing location should be protected against penetration of the steam which is strongly alkaline.

Bearings

Sealing requires major attention when designing the bearing arrangement. The best solution is the use of pulverized synthetic FAG sealing agent and solid lubricant Arcanol DF. This lubricant is suitable for temperatures ranging between –200 °C and +300 °C and resists almost any chemical even at high temperatures. It is non-ageing and water repellent. The powder is packed into the bearing location penetrating into all cavities of the arrangement and forming a lubricating film between balls and raceways, balls and cage and also between outer ring and housing bore. The film in the housing bore ensures easy bearing displaceability, even after prolonged operation. This protects the bearing against detrimental axial preload. In addition to lubrication Arcanol DF also acts as a sealing agent. It settles in the sealing gaps of the axle passage and protects the inside of the bearings against the ingress of alkaline condensate.

The bearings are designed for a truck with two wheelsets accommodating a total weight $F_r$ of 43 kN. The bearing load for each bearing is relatively low at $F_r/4$ allowing the use of inexpensive FAG 6208.R200.250.S1 deep groove ball bearings. Considering the high operating temperatures the bearings have a particularly large radial clearance (200...250 or 250...350 microns), are heat-treated according to S1 (200 °C) and are dimensionally stable.

The bearings of the kiln trucks are mounted on the shaft as far as its shoulder by means of a punching cap and fastened securely with a shaft end washer and screw. They have a loose fit in the housing bore of the FAG series housing SUB6208. Two bolts attach the housings to the frame of the trucks. Strips inserted between housing and frame compensate for any differences in height due to warping of the truck frame.

Machining tolerances

Shaft: bearing seat j6.
Housing: the diameter of bearing seat is between 0.5 mm and 0.8 mm larger than the bearing O.D.

Sealing

Heat-resistant aramide stuffing box packings seal the bearing area at the axle passage. The cover flange is also provided with a heat-resistant seal.
All four wheelsets of series 120’s three-phase current locomotives are driven. The traction motor arranged transversely to the direction of travel is connected to the bogie at three points. The torque of the traction motor acts via pinion and bullgear on a universal quill drive which is linked to the bullgear and driving wheel by the articulated lever coupling. The driving wheel transmits the tractive force to the rails.

Operating data
Top speed: 200 km/h; number of motors: 4; nominal power per motor: 1,400 kW; motor speed: max. 4,300 min⁻¹.

Bearing selection
The bullgear is supported on the universal quill drive in two tapered roller bearings FAG 534052 (dimensions: 381.03 x 479.475 x 49.213 mm) which are mounted in O arrangement. Even with a small bearing distance there is a relatively large spread and as a result tilting rigidity is high. The quill drive housing is stationary. The cones, which carry point load, have a loose fit. The cups carry circumferential load and have therefore a tight fit in the rotating bullgear. The axial clearance of the bearing pair depends on the machining tolerances of the bearing seats and the operating conditions. With inner and outer spacer sleeves bearing adjustment is not necessary when mounting.

Lubrication
During mounting the bearings and the space between the webs of the outer spacer sleeves are completely filled with a lithium soap base grease of the NLGI class 2. They are relubricated after every 150,000 km. The grease is fed through the holes of the sleeve’s web.
The torque of the traction motor is transmitted to the wheelset axle via pinion and bullgear. The traction motor arranged transversely to the direction of travel is supported directly on the wheelset axle in two bearing locations. The reaction torque is taken up by another support point at the bogie frame.

Operating data

Six driven wheelsets, power per traction motor: 500 kW. Max. speed: 100 km/h.

Bearing selection, dimensioning

For a suspension bearing to have a long service life (nominal life over 2 million kilometres) roller bearings with a high load carrying capacity are selected. A medium drive torque and a medium speed are taken as a basis for dimensioning. The index of dynamic stressing $f_L$ should be 3.5 at least. Usually it is well above it.

Two FAG tapered roller bearings are mounted their dimensions being 230.188 x 317.5 x 47.625 mm and 231.775 x 336.55 x 65.088 mm. They are abundantly dimensioned because of the large shaft diameter. High loads due to vibrations and shocks are accommodated by special tapered roller bearings with reinforced pressed cage (reduced number of rollers).

Both tapered roller bearings are mounted in $O$ arrangement with little axial clearance (0.2...0.3 mm). When the shaft has a maximum load the cups and cones are tilted by up to 3' against each other. The profile of the tapered rollers or raceways are modified (slightly crowned) in order to avoid edge stressing.

Machining tolerances

The cups have circumferential load and an interference fit on the shaft. The cup or the angle sleeve in the housing is given a tight fit (perhaps a drive seat).

Lubrication, sealing

The suspension bearings are lubricated with a lithium soap base grease of penetration class 3 with anti-corrosion additives. Baffle plates hold the grease at the bearing (grease storage). The relubrication interval is about 200,000 to 300,000 km depending on the type of operation. Labyrinth gap-type seals protect the bearing from contaminants.
The drive of modern suburban vehicles should provide for a high degree of travel comfort, low noise, and be economical at the same time. These requirements are fulfilled by a new compact drive package which is completely supported on springs in the bogie.

**Operating data**

Two step parallel shaft drive, helical/double helical gearing. Drive speed (input shaft) \( n_{\text{max}} = 5,860 \text{ min}^{-1} \), step-up \( i = 11.025 \).

The drive motor is flanged on to the transmission. A universal joint coupling transmits the torque directly to the wheelset from the transmission. The gearbox case, which is split at axis height, is made of high-strength cast aluminium. This is 25 % lighter than spheroidal graphite cast iron.

**Bearing selection**

**Input shaft**
The rotor of the drive motor is firmly attached to the input shaft of the transmission. An elastic coupling which can be subject to bending, avoids constraining forces in the shaft line which is supported in three positions by a locating-floating bearing arrangement. The floating bearing in the motor is a cylindrical roller bearing FAG NU212E (not illustrated). A second floating bearing, a cylindrical roller bearing FAG NJ215E, is at the motor end of the input shaft. The locating bearing arrangement of the input shaft is an angular contact ball bearing pair FAG 7215B.UA70 in \( X \) arrangement. Both angular contact ball bearings are fitted in an angle sleeve made of steel. Therefore different heat expansion coefficients of steel and light metal cannot have a direct effect on the bearings. The bearings accommodate high speeds with a close axial guidance at the same time. This means tight fits for the bearing rings on the shaft and in the bore of the angle sleeve. The demand for a sufficient axial operating clearance in addition to the tight fit is met with angular contact ball bearings in universal design. The axial clearance of the bearing pair prior to mounting is 70 microns.

**Intermediate shaft**
A spherical roller bearing FAG 22218E is mounted as the locating bearing of the intermediate shaft. Its outer ring is in a steel angle sleeve. The spherical roller bearing accommodates chiefly axial forces from the gearing. The floating bearing, a cylindrical roller bearing FAG NJ2216E.C3, is directly in the light-metal housing with the outer ring. The very tight fit in the housing necessitates a bearing with increased radial clearance (C3).

**Output shaft**
The output shaft whose large spur gear has a double helical gearing, is axially guided by the spherical roller bearing of the intermediate shaft. The floating bearing arrangement with two cylindrical roller bearings FAG NUZ1848 is therefore sufficient for the output shaft. The NUZ design with an extended inner ring raceway allows a large axial displacement of the hollow shaft.

**Machining tolerances**

Angular contact ball bearing pair
- Shaft k5; pair housing K6
Spherical roller bearing
- Shaft m5; housing K6
Cylindrical roller bearing/
intermediate shaft
- Shaft m5; housing N6
Cylindrical roller bearing/
output shaft
- Shaft n5; housing N6...P6

**Lubrication**
All the bearings of the transmission are lubricated by the oil circuit of the gearings.
Spur gear transmission for the underground or subway
Bevel gear transmission for city trains

With a so-called two-axled longitudinal drive in underground and metropolitan vehicles the traction motor (usually direct current motor) is arranged in the bogie in the direction of travel. A bevel gear transmission is flanged onto both sides of the motor’s face. The drive unit firmly attached to the bogie frame is elastically supported by the wheel sets. The drive power is transmitted from the pinion shaft to the hollow ring gear shaft and then via rubber couplings to the driving wheel shaft. This drive design leads to good running behaviour and moderate stressing for the traction motor, transmission and track superstructure.

Dimensioning, bearing selection

Mean torques and speeds (hourly torque, hourly speed) are calculated from the tractive force – surface speed diagram and the time shares for the various running conditions. By means of the gearing data the tooth loads of the hypoid bevel gear step are calculated and, depending on the lever arms, are distributed to the bearing locations.

A life of 20,000 to 30,000 hours is assumed for bearing dimensioning. Assuming an average travel speed this corresponds to 1.2 – 1.3 million kilometers.

To check the static safety of the bearings the maximum torque (slippage torque) is taken as a basis.

Pinion shaft

A single-row cylindrical roller bearing FAG NJ2224E.M1A.C3 (120 x 215 x 58 mm) is mounted as a floating bearing at the pinion end. It accommodates the high radial loads. The machined cage of the bearing is guided at the outer ring. The bearing has the increased radial clearance C3 since the bearing rings have a tight fit on the shaft and in the housing. Two tapered roller bearings FAG 31316 (80 x 170 x 42.5 mm) are used as locating bearings. They are mounted in pairs in O arrangement. The bearing at the motor end accommodates the radial loads as well as the axial loads from the gearing; the other tapered roller bearing only accommodates the axial loads arising during a change in direction of rotation. A minimum bearing load is a requirement in order to avoid harmful sliding motion (slippage) and premature wear. The cups of the tapered roller bearings are therefore preloaded with springs.

Ring gear shaft

There is a tapered roller bearing with the dimensions 210 x 300 x 54.5 mm at each side of the ring gear. Both bearings are adjusted in X arrangement.

Machining tolerances

Cylindrical roller bearing: Shaft m6, housing M6
Tapered roller bearing/motor end: Shaft m6, sleeve M6
Tapered roller bearing with mantle ring: Shaft m6, ring R6 (S7)
Tapered roller bearing of ring gear shaft: Shaft n6 – p6 housing K6 – M6

The axial clearance of the tapered roller bearing pair depends on gearing and the operating conditions.

Lubrication

Oil sump lubrication provides the transmission bearings with lubricant. The flinger oil is conveyed via the ring gear from the oil sump and fed directly to the transmission bearings via oil collecting bowls and supply ducts. The special driving conditions for city trains demand highly doped oils which are resistant to heat and corrosion.
The rudders of ships make slow intermittent slewing motions. The maximum slewing angle is about 35° to both sides. The rudder shaft bearings accommodate the radial and axial loads arising from the rudder and the steering engine. The bearings are also subjected to the vibrations created by the propeller jet. There are numerous types of rudders the most common of which are illustrated in figs. a to c.

Rolling bearings are only used for the bearing positions of the rudders inside ships. They are not suitable for the bearing positions located outside the ship due to mounting difficulties and problems with sealing and lubricating. For such locations, plain bearings made of stainless steel, bronze, plastic etc. are used and water or a mixture of grease and water is used for lubrication.
Spherical roller bearings as rudder shaft bearings

Operating data
Axial load 115 kN (weight of rudder and shaft), radial load 350 kN (driving force of steering engine and rudder).

Bearing selection, dimensioning
Due to the heavy loads and unavoidable misalignment spherical roller bearings are used. They have a high load carrying capacity and are self-aligning. The rudder shaft diameter depends on size and speed of the ship as well as on the type and size of the rudder used. The bearing bore and the size of the bearing are determined by the shaft diameter specified. A spherical roller bearing FAG 23052K.MB.R40.90 or FAG 23052K.MB.C2 (radial clearance 150...220 microns) is mounted. During mounting the bearing inner ring is pressed onto the tapered shaft seat so that the bearing operates under a light preload. Vibrations can thus be adequately accommodated. The hydraulic method facilitates dismounting particularly in the case of bearings with C2 bearing clearance. For this purpose the shaft must have oil ducts and the tapered seat a circular groove.

The housings of rudder shaft bearings FAG RS3052KS.1..... or FAG RS3052KW.1..... are made of welded shipbuilding steel plates.

The static safety of a rudder shaft bearing is checked because of the few slewing motions. An index of static stressing $f_s$ between 4 and 5 is suitable for spherical roller bearings.

Machining tolerances
Shaft taper 1 : 12, housing H7.

Lubrication, sealing
During mounting, the cavities of the spherical roller bearings and housings are completely filled with lithium soap base grease of consistency number 2 which contains EP additives.

Rudder shaft bearing FAG RS3052KS.1.....
The bearing is grease lubricated. It sits in the pot-like housing which is attached to the housing base plate by sturdy webs. A stuffing box seal is mounted in this base plate. Its packing runs on a sleeve of seawater-resistant steel.

Due to the separation between the upper half and the base any spray water which could penetrate runs along the side and does not get into the rolling bearing. The stuffing box can be inspected at any time during operation and if necessary readjusted. The bottom end of the bearing is provided with a spring seal. A felt seal and V ring suffice for sealing at the top end. This bearing arrangement with stuffing box seal is maintenance-free.

Rudder shaft bearing FAG RS3052KW.1.....
Bearing and seal are in one and the same housing and are lubricated with grease. The bearing arrangement can also be below the waterline. Sealing consists of three seawater-proof shaft sealing rings with an intermediate grease chamber. An automatic grease pump holds the latter under permanent pressure.
Spherical roller thrust bearings as rudder carriers

Spherical roller thrust bearings are used when the top bearing mainly has to take up the weight of the rudder and shaft. This is the case for all rudder drives not loaded by lateral forces, such as for rotary vane steering gears and four-cylinder engines, which do not operate spade-type rudders.

The two designs, N and W, for rudder carriers, differ only in their sealing.

**Bearing selection, dimensioning**

The shaft diameter is determined according to formulae of the Classification Societies. Thus the bore diameter of the rolling bearing is fixed. Due to the high axial load carrying capacity a spherical roller thrust bearing FAG 29284E.MB with the dimensions 420 x 580 x 95 mm is mounted directly on the shaft. The bearing’s index of static stressing $f_s \geq 10$.

The welded housings are extraordinarily flat – they protrude just slightly beyond the deck or mounting base. This provides advantages especially for larger steering engines, since the rudder shaft extension can be kept short due to the low mounting and dismounting height.

**Powerful springs** under the bearing outer ring provide a permanent positive contact of rollers and raceways. The supplementary plain bearing also accommodates radial forces, if for example a cylinder in a four-cylinder steering engine fails.

**Machining tolerances**

Shaft h7. The housing is relief turned to ensure axial spring preload via the housing washer.

**Lubrication, sealing**

During mounting, the cavities of the spherical roller thrust bearings and housings are completely filled with lithium soap base grease (consistency number 2 with EP additives). As with radial spherical roller rudder bearings, there are also two designs (N and W) in the case of rudder carrier bearings. Only the seal differs: FAG RS9284N.1..... rudder carrier bearings have felt seals, the rudder carrier bearings FAG RS9284W.1..... are sealed with seawater-proof shaft sealing rings. Both designs have a V-ring seal at the housing cover.
Spade-type rudder

Design

The slewing motion is accommodated by a top bearing and a bottom bearing. Both bearing locations are equipped with rolling bearings since they are inside the ship’s hull. The top bearing or rudder carrier is designed as the locating bearing due to the locating ring between cover and bearing outer ring. The bottom bearing is the floating bearing. Spherical roller bearings are used at both locations and the bearing arrangement is therefore statically defined and not affected by misalignment of housing bores, warping of the ship’s hull and rudder shaft deformation. Both spherical roller bearings are mounted on adapter sleeves which are mounted and dismounted by means of the hydraulic method. The relevant adapter sleeves (HG design) have connecting holes and grooves for the pressure oil.

Operating data

Top bearing:
Axial load 380 kN (weight of rudder and shaft).
Radial load 1,700 kN (load from rudder and steering engine).

Bottom bearing:
Radial load 4,500 kN (load from rudder and steering engine).

Bearing selection, dimensioning, sealing

Bearing selection is based on the specified shaft diameter and the given loads. Since the bearings only make slewing motions they are selected according to their static load carrying capacity. An index of static stressing \( f_s \geq 4 \) is a must.

The bottom spherical roller bearing, an FAG 230/750K.MB.R60.210 (or 230/750K.MB.C2), is located on an adapter sleeve FAG H30/750HG. Since this bearing is permanently below the waterline, special sealing must be provided for the shaft passage.

The radial sealing rings run on a sleeve made of seawater-resistant steel. The lips form a grease chamber permanently pressurized by an automatic grease pump. Some of the grease (lithium soap base grease of the consistency number 2 with EP additives) penetrates into the housing keeping the initial grease packing under constant pressure.

The seal above the bearing (shaft sealing ring and V ring) protects it against water which may either run down the shaft or collect in the rudder trunk.

The top spherical roller bearing, an FAG 23188K.MB.R50.130 (or 23188K.MB.C2), is mounted on the shaft with an adapter sleeve FAG H3188HG. The adapter sleeve is fixed axially; below by the shaft shoulder and above by a split holding ring which is bolted into a circular groove in the shaft. This upper bearing also takes up the weight from rudder and shaft as well as the radial loads. A shaft sealing ring is fitted at the upper and at the lower shaft diameter for sealing purposes. There is also a V ring at the upper shaft passage.

When relubricating with an automatic grease press, the initial grease filling is kept under pressure and the seal rings are lubricated at the same time.

Machining tolerances

Rudder shaft h8, cylindricity tolerance IT5/2 (DIN ISO 1101). Housing H7.

Bearing clearance

The bearings have a particularly small radial clearance: the lower bearing has 60 to 210 microns or 390 to 570 microns and the upper bearing has 50 to 130 microns or 230 to 330 microns. During mounting, the bearings are pressed onto the adapter sleeve so far that they obtain a preload of 20 to 30 microns. With these preloaded bearings vibrations are easily accommodated.
60: Spade-type rudder bearings
The propeller shaft of a ship is carried by so-called support bearings. Since length variations of the shaft are considerable, particularly with long shafts, the bearings must have axial freedom. The last part of the shaft supporting the propeller, runs in the so-called stern tube or tail shaft bearings.

Operating data
Shaft diameter 560 mm; nominal speed of propeller shaft 105 min\(^{-1}\).
Radial load from shaft and coupling 62 kN, no axial load – the propeller thrust is taken up by the propeller thrust block (figs. 63 and 64). With a supplementary factor of 100 % on the radial load (f\(_z\) = 2), shocks or other dynamic forces are sufficiently taken into consideration when determining the bearing stress.

Bearing selection, dimensioning, sealing
Since the diameter of the ship shaft is specified, the bearings are overdimensioned for the loads to be accommodated. Thus the index of dynamic stressing f\(_L\) ranges from 4 to 6 and therefore a high nominal life (L\(_n\)) is obtained. With very good cleanliness in the lubricating gap, endurance strength is reached in the adjusted life calculation (L\(_{hna}\)) for ship shaft and stern tube bearings.

A spherical roller bearing FAG 239/600BK.MB (dimensions 600 x 800 x 150 mm, dynamic load rating C = 3,450 kN) is used as ship shaft bearing. By means of the hydraulic method the bearing is attached to the shaft with an adapter sleeve FAG H39/600HG and is located in a plummer block housing FAG SUC39/600H.1..... (fig. 61a). The housing is made of grey cast iron GG-25 and consists of an unsplit housing body with two split covers.

The housing's sealing is provided for by the radial shaft sealing rings in the cover. For small quantities, welded housings are generally more economical than cast housings. Fig. 61b is an alternative ship shaft bearing arrangement made up of a spherical roller bearing FAG 23048K.MB with adapter sleeve H3048 and a split plummer block housing S3048KBL.1..... (material GG-25).

The ship shaft is surrounded by the stern tube at the stern. Fig. 62 shows a stern tube bearing arrangement, both bearings are designed as floating bearings. The tail bearing is also loaded by propeller weight and wave action. Spherical roller bearings are applied here also whose inner rings, with adapter sleeves, are attached to the shaft. A special stern tube sealing protects the bearings from seawater.

Machining tolerances
The inner rings carry circumferential load.
Adapter sleeve seat on the shaft h8. Cylindricity tolerance IT5/2 (DIN ISO 1101); housing bore H7.
Flanged housings are used for the tail shaft bearings.

Lubrication
The bearings are lubricated with a non-aging oil with EP additives (viscosity 150 to 300 mm\(^2\)/s at 40°C). The lower parts of the support bearing housings have viewing glasses or oil dip sticks on which the permissible maximum and minimum oil levels are marked. The stern tube is filled with oil. The oil pressure is kept a little higher than that of the surrounding water.

62: Stern tube or tail shaft bearing arrangement
The thrust block is located directly behind a ship's engine. It transmits the propeller thrust to the ship. Apart from a small radial load from the shaft weight the bearing is loaded by a purely concentric thrust load. Depending on the direction of rotation of the propeller, it acts either forward or backward. During sternway the thrust load is lower and usually occurs only seldom. Three bearing arrangements are commonly used for these requirements:

Fig. 63a illustrates a thrust block arrangement with two spherical roller thrust bearings for small shaft diameters in a SGA plummer block housing.

Fig. 63b illustrates a thrust block arrangement with two spherical roller thrust bearings and one radial spherical roller bearing in an FKA flanged housing.

Both bearing arrangements are used when the axial load carrying capacity of a radial spherical roller bearing is insufficient when sternway is very frequent. The spherical roller thrust bearings accommodate the propeller thrust during forward motion and the propeller pull during sternway. In 63a the thrust bearings accommodate the weight also while in 63b the weight of shaft and propeller is supported by a radial spherical roller bearing.

Fig. 64 shows ship shaft thrust blocks each with a spherical roller thrust bearing and a radial spherical roller bearing:

- a: – in SGA housing, b: – in SUB housing

The curvature centres of the outer ring raceways of the radial and axial bearings coincide. The bearings are therefore self-aligning and thus misalignment and bending of the shaft and hull are compensated for. In these thrust blocks only the propeller thrust is accommodated by the spherical roller thrust bearing during forward motion. The radial spherical roller bearing transmits the weight of the shaft and the propeller pull during sternway. The spherical roller thrust bearing not under stress is preloaded by springs so that it does not lift during sternway. A constant axial minimum load is thus ensured.

### Machining tolerances

- Fig. 63a:
  - Spherical roller thrust bearing Shaft m6; housing H7
- Fig. 63b:
  - Spherical roller thrust bearing Shaft n6; housing relief turned
  - Radial spherical roller bearing Shaft n6; housing F7
- Fig. 64a, 64b:
  - Spherical roller thrust bearing Shaft m6; housing relief turned
  - Radial spherical roller bearing Shaft m6; housing H7

### Dimensioning of bearings

The diameter of the thrust block shaft is determined according to the guidelines of the Classification Societies. Taking the power output into account the nominal life \( L_n \) [h] and the resulting index of dynamic stressing \( f_L \) are calculated. An \( f_L \) value of 3 – 4 is recommended for the rolling bearings in ship shaft thrust blocks. Particularly with utmost cleanliness in the lubricating gap, ship shaft thrust blocks reach endurance strength according to the adjusted life calculation.

### Design

Ship shaft thrust blocks are supplied as complete units FAG BEHT.DRL. The unit includes bearings, housing with sealing and thrust block shaft with loose flange. The FAG thrust block housings are supplied either in split design SGA (figs. 63a and 64a) or in unsplit design FKA (fig. 63b) or SUB (fig. 64b).

**Order example for unit FAG BEHT:GRL:110.156680, consisting of:**

- 1 Plummer block housing FAG SGA9322.156678
- 1 Thrust block shaft with loose flange FAG DRW110 x 610.156678
- 2 Spherical roller thrust bearings FAG 29322E
- 1 Locknut FAG KM26
- 1 Lock washer FAG MB26

*Oil lubrication*
## Operating data

<table>
<thead>
<tr>
<th>Operating data</th>
<th>Diameter of thrust block shaft</th>
<th>Power</th>
<th>Speed</th>
<th>Thrust</th>
<th>Forward motion</th>
<th>Sternway</th>
<th>Bearings mounted</th>
<th>Lubrication</th>
<th>Sealing</th>
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<td>63a: Ship shaft thrust block</td>
<td>110 mm</td>
<td>320 kW</td>
<td>800 min⁻¹</td>
<td>55 kN</td>
<td>50 %</td>
<td>50 %</td>
<td>2 x FAG 29322E</td>
<td>Oil sump lubrication</td>
<td>Shaft sealing rings</td>
</tr>
<tr>
<td>63b: Ship shaft thrust block with FKA flanged housing</td>
<td>600/510 mm</td>
<td>11,400 kW</td>
<td>150 min⁻¹</td>
<td>1,625 kN</td>
<td>50 %</td>
<td>50 %</td>
<td>1 x FAG 239/600B.MB.C3</td>
<td>Oil sump lubrication</td>
<td>Shaft sealing rings</td>
</tr>
<tr>
<td>64a, b: Ship shaft thrust block</td>
<td>200 mm</td>
<td>1,470 kW</td>
<td>500 min⁻¹</td>
<td>170 kN</td>
<td>95 %</td>
<td>5 %</td>
<td>1 x FAG 23140B.MB</td>
<td>Oil sump lubrication</td>
<td>Shaft sealing rings</td>
</tr>
<tr>
<td>64b: Ship shaft thrust block housing</td>
<td>110 mm</td>
<td>320 kW</td>
<td>800 min⁻¹</td>
<td>55 kN</td>
<td>50 %</td>
<td>50 %</td>
<td>2 x FAG 294/600E.MB</td>
<td>Oil sump lubrication</td>
<td>Shaft sealing rings</td>
</tr>
</tbody>
</table>

1) Non-aging oil with pressure additives (viscosity 150 to 300 mm²/s at 40°C)

63a: Complete ship shaft thrust block FAG BEHT.DRL.110.1..... (SGA plummer block housing)

63b: Ship shaft thrust block with FKA flanged housing
64a: Complete ship shaft thrust block FAG BEHT.DRL.200.1..... (SGA plummer block housing)

64b: Complete ship shaft thrust block FAG BEHT.DRL.200.1..... (SUB pot-shaped housing)