

Current-Insulating Bearings

Rolling bearings for prevention
of damage due to current passage

Foreword

Damage due to current passage and its consequences

Current passage can occur in the use of rolling bearings in:

- wheelsets and traction motors (rail vehicles)
- direct current and alternating current motors (power transmission)
- generators (wind power).

Under unfavourable conditions, this causes damage to raceways and rolling elements as well as degradation of the lubricant and thus to premature, unexpected failure of a motor or generator. In addition to the repair work required, this incurs additional costs due to machine downtime and lost production.

It is significantly more cost-effective to provide for the use of electrically insulated bearings at the planning stage. As a result, customer benefit is increased through reduced maintenance costs and higher machine availability.

Normally, it is sufficient to interrupt the circuit between the housing and shaft in order, depending on the application, to insert current-insulating bearings at one or both bearing positions, *Figure 1*.



Figure 1
Application examples

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Current-insulating bearings

Features The current-insulating bearings include all rolling bearings that give insulation against current passage.

Coated bearings, in which either the inner ring or outer ring has a ceramic coating, are current-insulated bearings. The ceramic layer gives insulation against current passage.

Hybrid bearings in which the rolling elements are made from ceramic also have a current-insulating effect. In this case, the rolling elements prevent current passage.

Current-insulating bearings as a preventive measure

In general, it is difficult to eliminate the causes of electrical voltage in the rolling bearing. Nevertheless, bearing damage can be prevented if it is possible to stop or significantly reduce the flow of current. Current-insulating rolling bearings of numerous designs are now available for this purpose. The components that should be insulated are dependent on the type of voltages occurring.

Induced voltage along a shaft

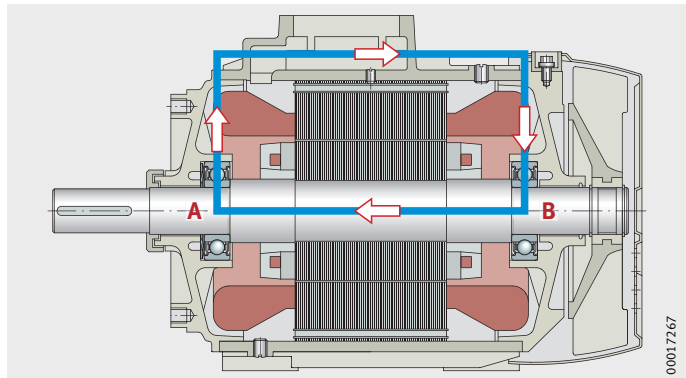
An induced voltage along a shaft leads to a circuit that is completed via bearing 1, the housing and bearing 2, *Figure 1*.

One cause of such shaft voltages is frequently the asymmetrical distribution of the magnetic flow in the motor, which is observed in particular in motors with a small number of pairs of poles. In this case, it is sufficient to interrupt the flow of current by insulating one of the two bearings. In general, the bearing on the non-driven side is insulated.

A = bearing 1
B = bearing 2

Figure 1

Induced voltage along a shaft



Voltage between shaft and housing

If a voltage occurs between the shaft and housing, the currents flow in the same direction through each of the two bearings. The main cause to be considered is the common mode voltage in converters. It is recommended here that both bearings should be insulated, *Figure 2*.

The decisive factor in selecting current insulation is the time behaviour of the voltages present. This depends in the case of direct current voltage or slowly varying alternating current voltage on the Ohm resistance and in the case of higher frequency alternating current voltage (which is often found in converters) on the capacitive resistance of the bearing.

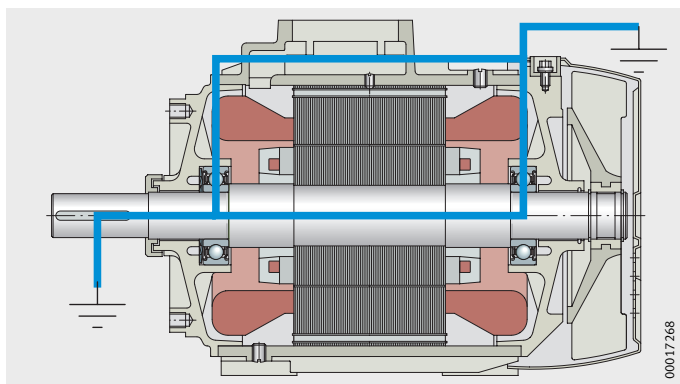


Figure 2

Voltage between shaft and housing

Current-insulating bearings

Design and safety guidelines Typical bearing damage in current passage

Marks on raceways and rolling elements

The same surface changes always occur irrespective of whether a bearing is subjected to direct current or alternating current (up to frequencies in the MHz range).

In many cases, uniformly matt grey marks are seen on the raceways and rolling element surfaces. This visual characteristic is non-specific and can also be caused by other influences, for example oil containing abrasives, *Figure 3*.

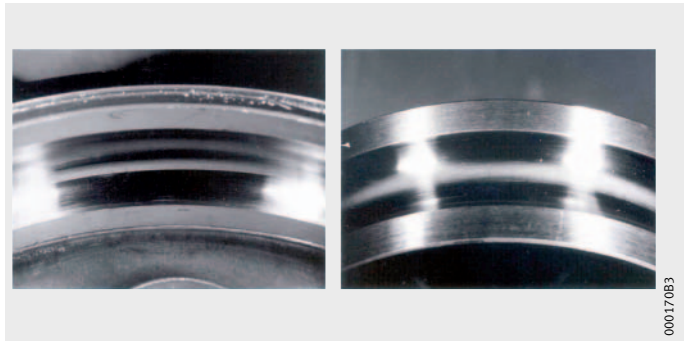


Figure 3
Marks on raceways and rolling elements

Fluting

The so-called fluting consists of periodic patterns running in the direction of rolling on areas of the surface of different depth. This surface pattern can in most cases be attributed to current passage, *Figure 4*.

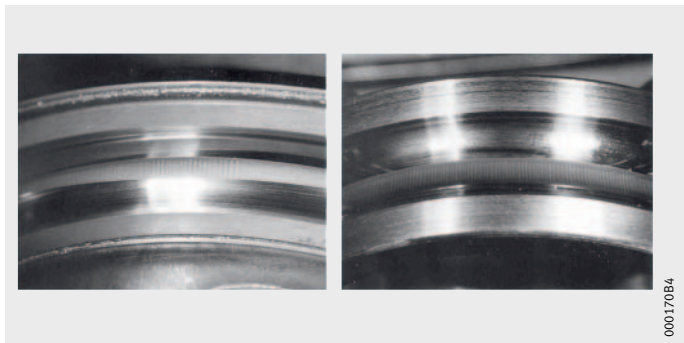


Figure 4
Fluting

Damage structures

It is only with the aid of scanning electron microscopy (SEM) that it becomes apparent that both damage structures are characterised by melt craters and welding beads of μm size that cover the overrolled surfaces in a tightly packed form, *Figure 3* and *Figure 4*, page 6. This demonstrates current passage, *Figure 5*.

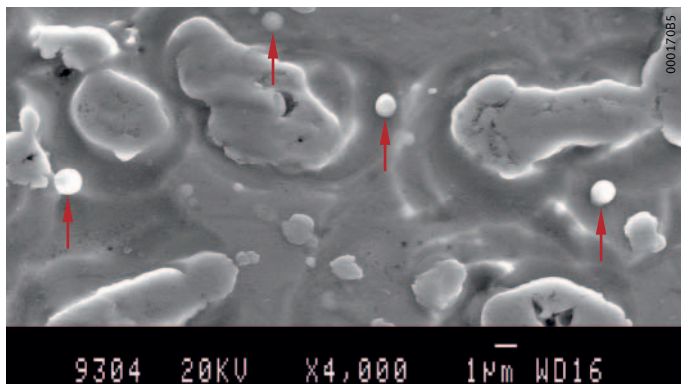


Figure 5
Damage structures
under the scanning electron
microscope (SEM)

Development of bearing damage

The melt craters and welding beads develop during electrical discharge between the micropeaks that are always present on raceways and rolling element surfaces. Where a lubricant film is fully formed, this is punctured by the spark at a bottleneck and the base points of the spark are melted for a short period.

In the mixed friction range (metal-to-metal contact), the surfaces involved become fused together and are then immediately broken apart again by the rotation of the bearing. In both cases, material is also detached from the surfaces and immediately solidifies again as welding beads. Some of these are mixed with the lubricant and some are deposited on the metal surfaces. As overrolling continues, craters and welding beads can be flattened and smoothed. Under a continuing flow of current, the (thin) surface layers involved are melted again and again over time.

In most bearing failures, however, fluting is responsible, *Figure 4*, page 6. These periodic structures on raceways and rollers are due to the combined action of continuing flow of current and the vibration characteristics of bearing components. When a rolling element rolls over any sufficiently large melt crater, it undergoes purely radial motion whose parameters are dependent on the internal geometry, speed and load of the bearing. When the rolling element swings back, the lubricant film thickness is reduced and new sparkovers occur in this area as a result, initiating a self-sustaining process. After a time, the raceway of the ring can become covered over its entire circumference with fluting. These lead to further increases in bearing vibration and ultimately to failure of the bearing.

Current-insulating bearings

In practice, a reliable criterion for assessing the level of hazard presented by current passage has been found to be the calculated current density, in other words the effective amperage divided by the total contact area between the rolling elements and, respectively, the inner or outer ring of the bearing. This is dependent on the bearing type and the operating conditions. At current densities with effective amperages below approx. $0,1 \text{ A mm}^{-2}$, there is no danger of damage due to current passage according to our present level of knowledge. At effective amperages about or above 1 A mm^{-2} , however, this type of damage must frequently be anticipated.

Influence on the lubricant

Current passage also has a negative influence on the lubricant. The base oil and additives are oxidised and cracked. This can be clearly demonstrated in the infrared spectrum. Premature ageing and an increased concentration of iron particles cause a deterioration in the lubrication characteristics, which can lead to hot running of the bearing.

Ceramic-coated bearings

Ceramic-coated bearings are standard bearings in which either the inner ring or outer ring has the ceramic coating Insutect, *Figure 6* and *Figure 7*.



Figure 6
Ceramic-coated
deep groove ball bearing

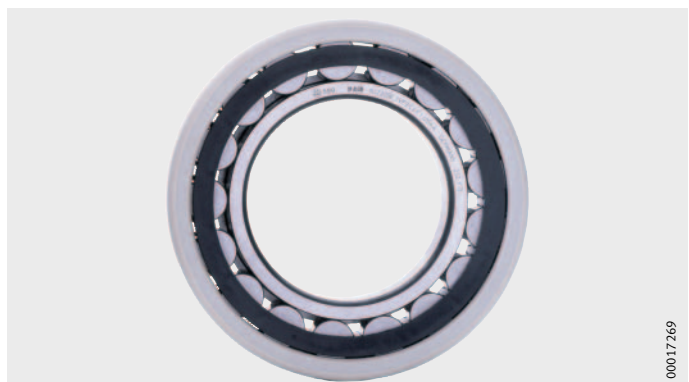
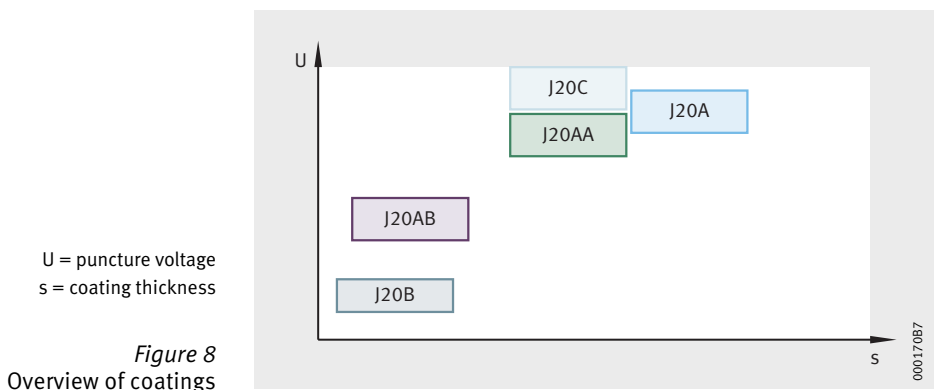


Figure 7
Ceramic-coated
cylindrical roller bearing

FAG bearings with the Insutect coating have the following advantages:

- High insulation protection:
 - Bearings with oxide ceramic coating are identified by the suffix (J20). These layers are applied to the bearing surfaces using the plasma spray method, *Figure 9*, page 10. The oxide ceramic layer is very hard, resistant to wear and has good thermal conductivity.
- The insulation J20AB gives excellent protection against current passage due to induced voltage along the shaft. Due to a special sealing process, the J20AB coating achieves an insulating effect even in damp environments.
- The insulation J20AA is applied to the outer ring and is twice as thick as the J20AB coating. It therefore gives additional security even at higher frequency current.
- The thickness of the J20AA insulation is the same as the insulation J20C. In this case, however, the inner ring is coated. Since the coated surface is smaller, it gives even better protection against high frequency currents. It is particularly suitable in applications with high frequency currents and a rotating outer ring.
- The Insutect family is completed by the insulations J20B and J20A, which are used in special cases where simpler protection (J20B) or special protection principally for large diameters (J20A) is required, *Figure 8*.
- The external dimensions of the current-insulated rolling bearings correspond to the dimensions in accordance with DIN 616 (ISO 15). Current-insulated bearings are therefore interchangeable with standard bearings.
- Coated deep groove ball bearings are available in series 62 and above. In addition to the open design, the variants are available with lip seals on one or both sides. As a result, the user can run the lubricated-for-life bearing for even longer. In addition, a range of special types are possible.



Current-insulating bearings

The coating method

In the plasma spray method, an electric arc is generated between two electrodes and the inert gas introduced is ionised. The resulting plasma jet is then used as the carrier jet for the aluminium oxide powder. This is melted and sprayed at high velocity onto the inner or outer ring, *Figure 9*. The oxide layer thus applied has excellent adhesion to the base material, which must be roughened in advance. The oxide layer is then sealed.

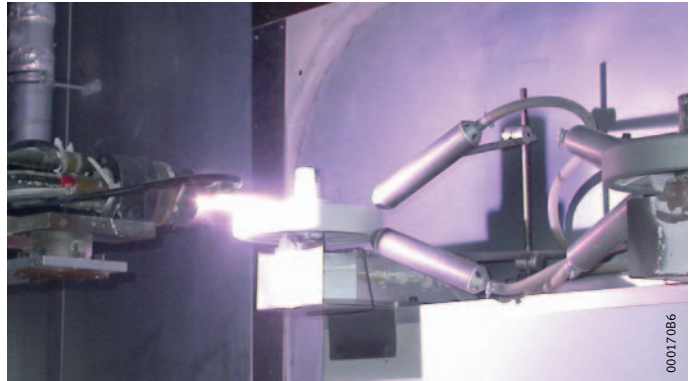


Figure 9
Plasma spray method

Dielectric breakdown strength

The coatings are subjected to 100% quality inspection and ensure a dielectric breakdown strength of at least:

- J20AB as insulation up to 1000 VDC
- J20AA, J20C as insulation up to 3 000 VDC
- J20B as insulation up to 500 VDC.

Below this voltage, the insulating layer allows only very small flows of current through the bearing.

In principle, a current-insulating bearing can be integrated as a parallel circuit between resistance and capacitance, *Figure 10*. For good insulation, the Ohm resistance should be as high as possible and the capacitance as low as possible.

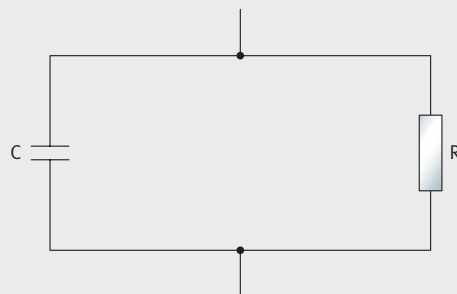


Figure 10
Parallel circuit
Resistance and capacitance

A distinction must be drawn between two mechanisms:

■ Direct current voltage resistance:

- At room temperature, this is typically 1 GΩ to 10 GΩ, depending on the bearing size. With increasing temperature, it decreases exponentially, typically by approx. 40% to 50% per 10 K. At operating temperatures of +60 °C or +80 °C, there is a resistance of several MΩ which, on the basis of Ohm's Law $I = U/R$ at voltages up to 1 000 V, means only currents significantly below 1 mA, which are non-critical for bearings.

■ Alternating current voltage resistance:

- The insulated unit represents a capacitance C, which can accumulate charges. Under the influence of an alternating current voltage, this leads to an alternating current due to direct contact between the rolling element and raceway. For the effective values of current and voltage under a harmonic time curve with a pulsance ω , the formula $I = U \cdot \omega \cdot C$ applies.
- On a similar basis to Ohm's Law, $Z = 1/(\omega \cdot C)$ is designated as the capacitive resistance of the bearing. The capacitance of a bearing with oxide ceramic is typically 2 nF to 20 nF, depending on the bearing size. Its capacitive resistance at a frequency of 50 Hz is thus in the range 0,15 MΩ to 1,5 MΩ, in other words significantly lower than its direct current voltage resistance. At higher frequencies, this value is reduced even further. Nevertheless, it will in most cases be significantly higher than the resistance of the non-insulated bearing, which is only very low at voltages at or above approx. 1 V (1 Ω or less).

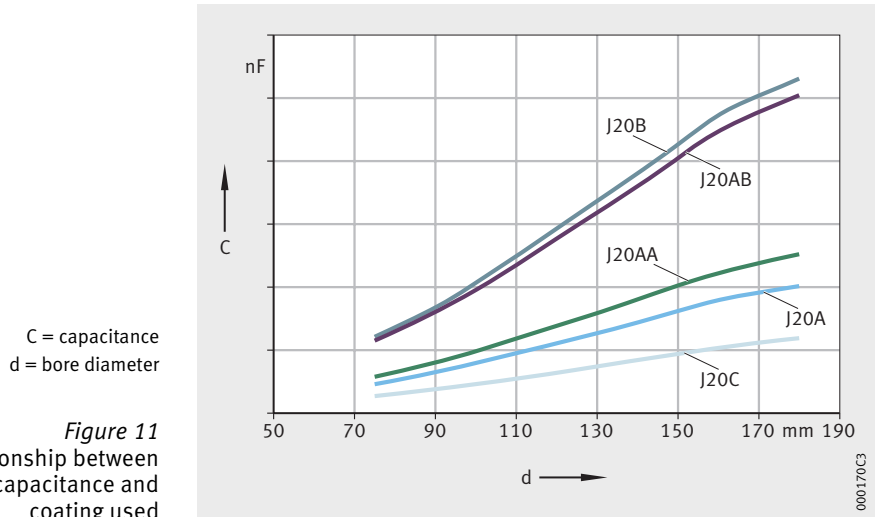
At the same voltage and same frequency, the flow of current is determined by the capacitance of the system. A large coating thickness s and a small coated contact area A relative to the bearing leads to a low capacitance and thus to a lower current density, see formula.

$$C = \epsilon_0 \cdot \epsilon_r \cdot \left(\frac{A}{s} \right)$$

C	F
Capacitance of the bearing arrangement	
ϵ_0	$FV^{-1}m^{-1}$
Dielectric constant	
ϵ_r	$FV^{-1}m^{-1}$
Relative dielectric factor, dependent on material	
A	m^2
Contact area relative to the bearing	
s	μm
Coating thickness.	

Current-insulating bearings

The relationship between the electrical capacitance of a bearing and inside diameter as well as the coating used is shown in the diagram, *Figure 11*.

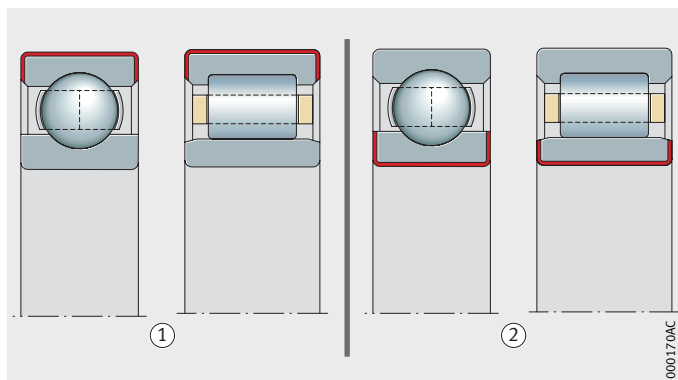


Types of coatings and value ranges

The various type of coatings for bearings are shown in cross-section, *Figure 12*. The parameters and value ranges are shown in a comparison, see table.

- ① External coating J20B, J20B, J20AB, J20AA
- ② Internal coating J20C

Figure 12
Types of coatings



Parameters Types of coatings

Parameter	J20AB	J20AA	J20C
Puncture voltage	1 000 VDC	3 000 VDC	3 000 VDC
Operating environment	Dry, damp	Dry, damp	Dry, damp
Layer thickness	100 µm	200 µm	200 µm
Possible dimensions	70 mm – 1400 mm outside diameter	70 mm – 500 mm outside diameter	70 mm – 340 mm inner ring bore

Parameters Types of coatings continued

Parameter	J20B	J20A
Puncture voltage	500 VDC	1 000 VDC
Operating environment	Dry	Dry
Layer thickness	≤ 100 µm	> 300 µm
Possible dimensions	70 mm – 1400 mm outside diameter	70 mm – 1400 mm outside diameter ¹⁾

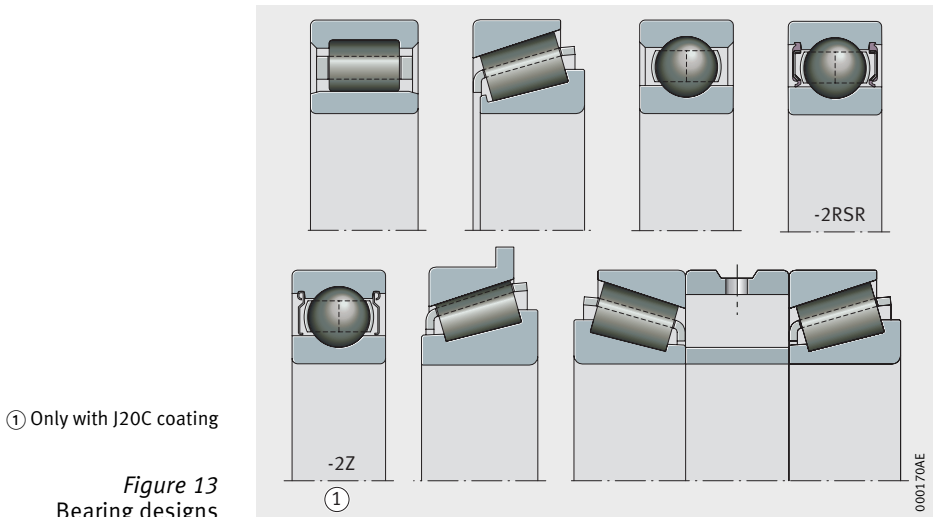
¹⁾ Preferred for use at and above 500 mm outside diameter.

The bearing surfaces of the rings to be coated must be cylindrical and must not be interrupted by lubrication holes or grooves.

Current-insulating bearings

Bearing designs with ceramic coating

The available bearing designs with ceramic coatings are shown in cross-section, *Figure 13*.



① Only with J20C coating

Figure 13
Bearing designs

Other bearing designs can be supplied coated by agreement.

Ordering example	■ Deep groove ball bearing with coated outer ring, sealed on both sides
	■ Radial internal clearance C3
Ordering designation	6220-2RSR-J20AA-C3
Ordering example	■ Cylindrical roller bearing with coated outer ring
	■ Radial internal clearance C4
Ordering designation	NU214-E-M1-F1-J20B-C4
Ordering example	■ Deep groove ball bearing with coated inner ring
	■ Radial internal clearance C3
Ordering designation	6220-2RSR-J20AA-C3

Hybrid bearings

An alternative to Insutect bearings is FAG hybrid bearings. The rings of the hybrid bearings are made from rolling bearing steel and the rolling elements are made from ceramic.

The hybrid bearings are identified by the prefix HC.

The rolling elements are extremely resistant to wear and perform the function of current insulation.

Hybrid bearings are available as ball bearings and as cylindrical roller bearings, *Figure 14* and *Figure 15*.

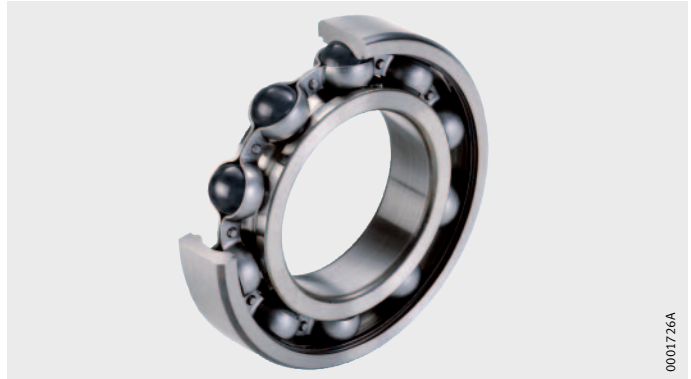


Figure 14
Hybrid ball bearing

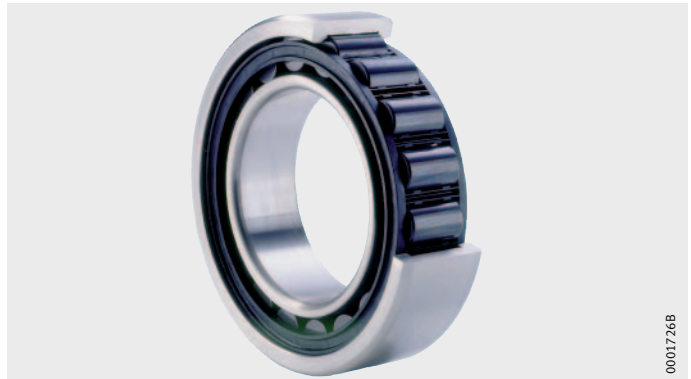


Figure 15
Hybrid cylindrical roller bearing

Current-insulating bearings

Advantages of hybrid bearings

Hybrid bearings have advantages in comparison with ceramic-coated bearings:

- Hybrid bearings offer very high resistance to current passage. Their direct current voltage resistance, even at high temperatures, is in the $G\Omega$ range. A typical value for capacitance is 40 pF and is thus lower by a factor of 100 than bearings with ceramic coating.
- Hybrid bearings allow higher speeds at lower friction and thus lower temperatures in operation.
- Hybrid bearings have better emergency running characteristics than standard bearings.

Other characteristics

In comparison with steel ball bearings, hybrid ball bearings have:

- identical basic dynamic load ratings C_r
- 30% lower basic static load ratings C_{0r}
- 20% higher limiting speeds n_G .

In addition, hybrid bearings offer a longer grease operating life than standard bearings with lubrication-for-life, see TPI WL 43-1210, FAG Hybrid Deep Groove Ball Bearings.

For smaller rolling bearings, the hybrid designs are more economical than ceramic-coated bearings.

Ordering example

- Deep groove ball bearing with ceramic balls
- Solid brass cage
- Increased accuracy P6
- Internal clearance C3.

Ordering designation

HC6214-M-P6-C3

Ordering example

- Cylindrical roller bearing with ceramic rollers
- Tapered bore
- Solid brass cage
- Increased accuracy SP.

Ordering designation

HCN1020-K-M1-SP

Our Sales Engineers will be pleased to advise you in the selection of the best economic and technical solution.

Material parameters of ceramic and steel

Ceramic and steel have different material parameters. Material parameters: see table.

Material parameters

Material parameter	Unit	Ceramic (Silicon nitride Si_3N_4)	Steel (100Cr6)
Specific electrical resistance	$\Omega \cdot mm^2 m^{-1}$	10^{17}	10^{-1}
Density	g/cm^3	3,2	7,8
Coefficient of thermal expansion	$10^{-6} K^{-1}$	3,2	11,5
Modulus of elasticity	MPa	315 000	210 000
Hardness	HV 10	1 600 – 800	700 – 150

Threephase motor

In threephase motors with current direction feed, deep groove ball bearings with J20AB coating are used to prevent damage due to current passage.

Technical data

Parameter	Value
Power	375 kW
Design	Four-pole

Requirement

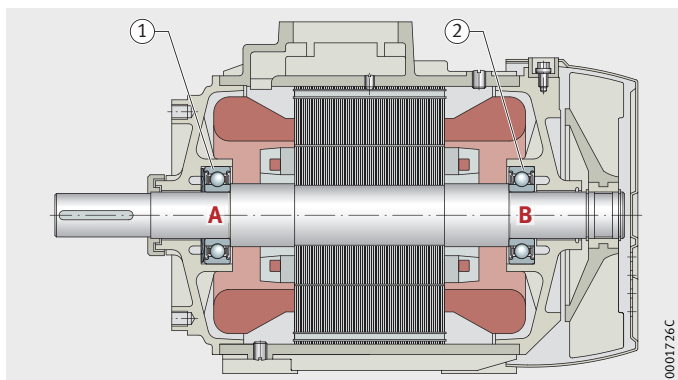
Prevention of bearing damage through induced voltage caused by current passage.

Design solution

A threephase motor with current direction feed is fitted on the fan side of a threephase motor with a current-insulated deep groove ball bearing FAG 6316-J20AB-C3 and on the drive side with a deep groove ball bearing FAG 6320-C3, *Figure 1*. The current-insulated deep groove ball bearing interrupts the flow of current that is generated by the induced voltage along the shaft. Both bearings are lubricated using grease. A relubrication facility is provided.

A = drive side
B = fan side

Figure 1
Threephase motor



Products used

- ① FAG 6320-C3
- ② FAG 6316-J20AB-C3

Axlebox bearing arrangement

In axlebox bearing arrangements in low-floor articulated tramcars, tapered roller bearings with J20B coating are used to prevent damage due to current passage.

Technical data

Parameter	Value
v_{\max}	70 km/h
Mean track wheel diameter	560 mm

Requirement

Prevention of bearing damage through induced voltage caused by current passage.

Design solution

The tapered roller bearings are fitted as non-locating bearings in the low-floor articulated tramcar, *Figure 1*.

In the non-locating bearing arrangement, the tapered roller bearings are fitted in an O arrangement:

- Outer side: tapered roller bearing FAG 580065.30228-A-J20B
- Inner side: tapered roller bearing FAG Z-803889.32224-A-J20B.

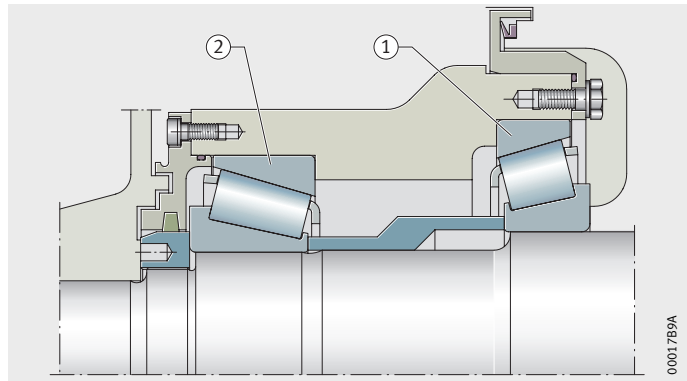


Figure 1
Axlebox bearing arrangement

Products used

- ① FAG 580065.30228-A-J20B
- ② FAG Z-803889.32224-A-J20B

Traction motor bearing arrangement in an electric tramcar

In threephase motors with a power rating of 500 kW, deep groove ball bearings and cylindrical roller bearings with J20AA coating are used to prevent damage due to current passage.

Requirement

Prevention of bearing damage through induced voltage caused by current passage.

Design solution

The rotor shaft of a threephase motor is fitted with a deep groove ball bearing FAG 6316-J20AA-C3 (fan side) and a cylindrical roller bearing FAG NU320-E-M1-F1-J20AA-C4 (drive side). The cylindrical roller bearing and the deep groove ball bearing are coated with the premium coating J20AA, *Figure 1*.

Both bearings are lubricated using grease and are protected against contamination and environmental influences by means of labyrinth seals. A relubrication facility is provided.

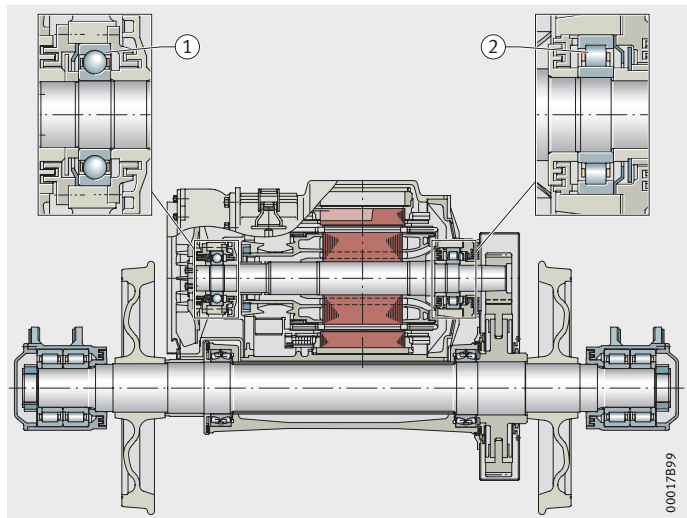


Figure 1
Traction motor bearing arrangement

Products used

- ① FAG 6316-J20AA-C3
- ② FAG NU320-E-M1-F1-J20AA-C4

Wind power generator

In wind power generators, deep groove ball bearings with J20C coating are used to prevent damage due to current passage.

Requirement Prevention of bearing damage through induced voltage caused by current passage.

Design solution Two deep groove ball bearings FAG 6332-M-J20C-C3 are fitted in this wind power generator. Due to the voltage transformation, a high frequency current would flow through both bearings. The best possible protection against flow of current for these deep groove ball bearings is the 200 μm coating on the inner ring, *Figure 1*.

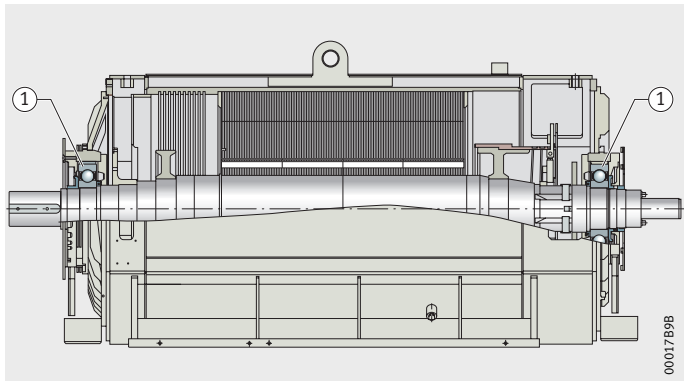


Figure 1
Wind power generator

Products used ① FAG 6332-M-J20C-C3

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