



## Current-Insulated Bearings

Rolling bearings for prevention of damage due to current passage

Technical Product Information



# 1 Foreword

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

- wheelsets, gearboxes and traction motors in the rail vehicles sector
- direct current and alternating current motors in the power transmission sector
- generators in the wind power sector

Under unfavourable conditions, current passage causes damage to raceways and rolling elements as well as degradation of the lubricant, which can lead to the premature and unexpected failure of motors and generators. In addition to the repair work required, additional costs are incurred due to machine downtime or full loss of production.

A more cost-effective approach is to include electrically insulated bearings at the design stage and thereby increase customer benefit through reduced maintenance and higher machine availability.

This publication contains application-specific recommendations as well as information on whether one or two bearings should be insulated and which method of insulation is suitable.

# Contents

1	Foreword .....	3
2	Technical principles .....	5
2.1	Rolling bearing currents – causes and remedial measures .....	5
2.2	Typical bearing damage in current passage .....	7
2.2.1	Marks on raceways and rolling elements .....	7
2.2.2	Fluting .....	7
2.2.3	Development of bearing damage .....	8
2.2.4	Influence on the lubricant .....	8
3	Current-insulated rolling bearings .....	9
3.1	Electrical behaviour of rolling bearings .....	9
3.1.1	Electrical behaviour of an uncoated rolling bearing .....	9
3.1.2	Electrical behaviour of a current-insulated rolling bearing .....	9
3.2	Ceramic-coated bearings .....	11
3.2.1	Types of coatings .....	11
3.2.2	Coating method .....	12
3.2.3	Increased insulation performance with the new J20G coating .....	13
3.2.4	Coating parameters .....	14
3.2.5	Bearing designs with ceramic coatings .....	18
3.2.6	Ordering examples .....	18
3.3	Hybrid bearing .....	20
3.4	Standard recommendation for use .....	22

## 2 Technical principles

### 2.1 Rolling bearing currents – causes and remedial measures

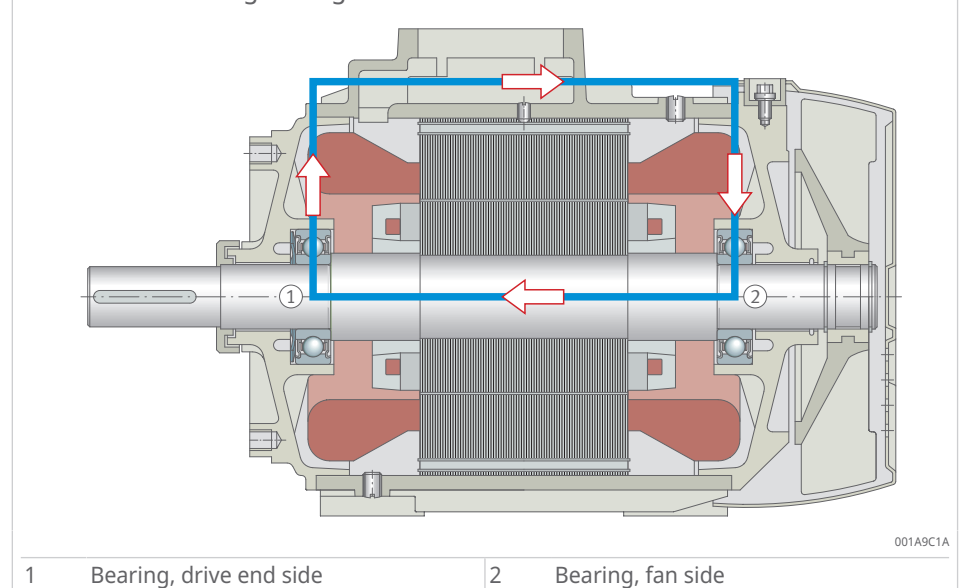
Depending on the motor, frequency converter and the operating conditions involved, there are mainly three different types of unwanted electrical currents that occur in electric motors. The resulting remedial measures are also selected on the basis of the cause or current type. Conductive elements, improved grounding and insulation for rolling bearings are among the measures that have proved successful.

#### Circular currents

In the case of very large motors or generators with a small number of poles, magnetic asymmetries can cause a low-frequency shaft voltage. For motors with a frame size of 100 mm and above that are operated by frequency converters, the high-frequency currents that flow through the slot insulation of the stator lead to a high-frequency shaft voltage.

Without insulated bearings, low-frequency shaft voltage and high-frequency shaft voltage lead to the phenomenon of circular currents. An effective and practical remedy to this issue is available in the form of rolling bearings with a ceramic oxide coating (Insutect A) and hybrid rolling bearings from Schaeffler. A rolling bearing coated with Insutect A is a particularly frequent choice of insulation for the bearing on the fan side.

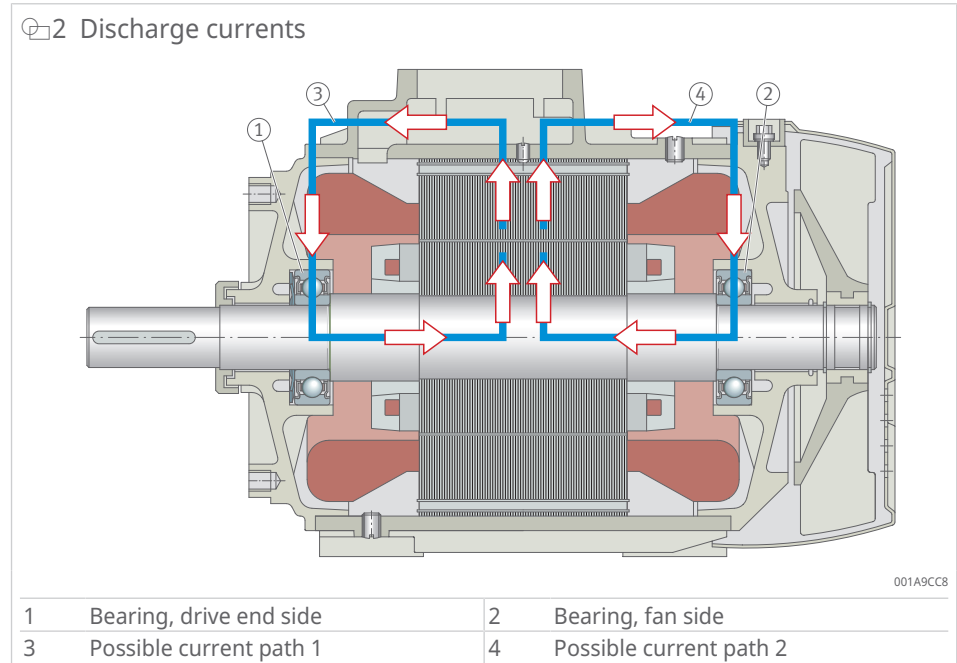
1 Induced voltage along a shaft



#### Discharge currents

Common mode voltage is an unwanted occurrence in electric motors that are operated with frequency converters. This voltage, which is present between the shaft and housing, can lead to discharge currents, particularly in small electric motors with frame sizes of up to 315 mm, that can flow separately through each of the two bearings.

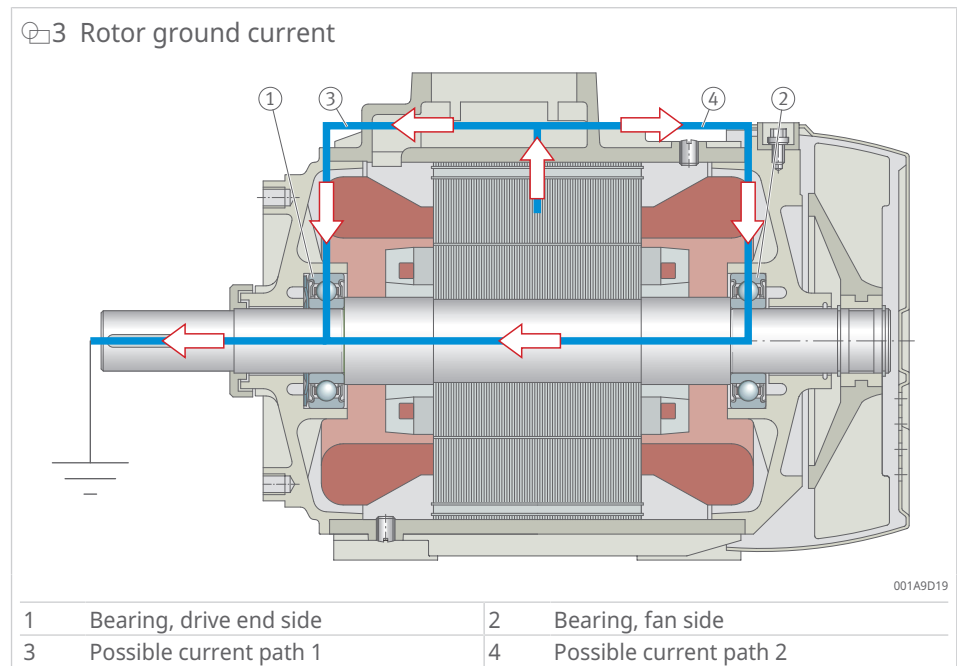
Two hybrid bearings with ceramic rolling elements and/or current conductive solutions have proven to be effective remedies against discharge currents. Alternatively, a solution is also available in the form of an Insutect A coating, which must be selected in a suitable layer thickness. The motor and adjacent parts determine which is the better solution for the respective application.



### Rotor ground currents

Particularly in larger stationary electrical machines, poor grounding conditions can result in a current that flows from the housing, via the bearings, to the shaft and through the driven or driving unit.

Suitable remedies for such currents include grounding that is suitable for high-frequency currents, an insulated coupling or insulation of the rolling bearings on the drive and fan sides.



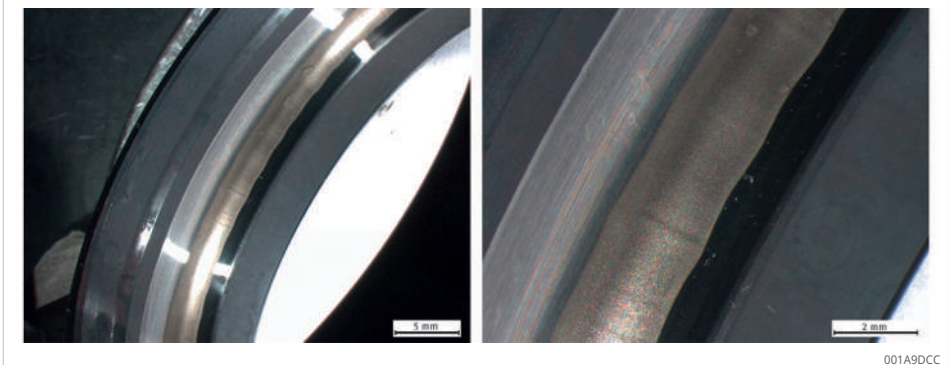
## 2.2 Typical bearing damage in current passage

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

### 2.2.1 Marks on raceways and rolling elements

In many cases, uniformly matt grey marks are created by current passage on the raceways and rolling element surfaces. These marks can also be caused by other influences, for example by abrasive substances in contaminated lubricant.

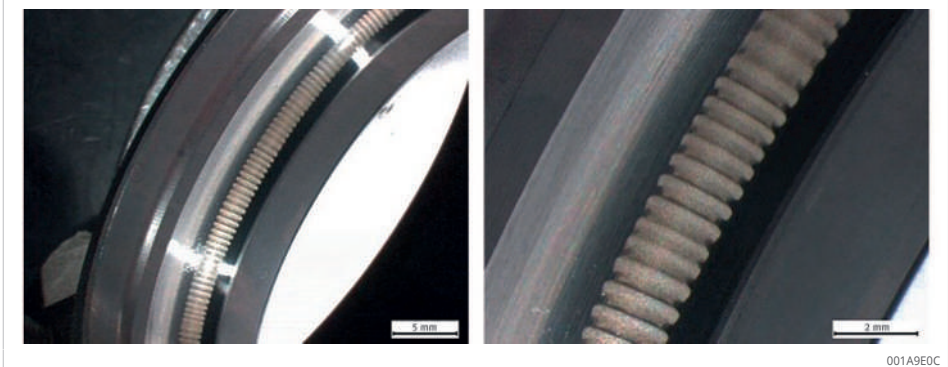
4 Marks on raceways



### 2.2.2 Fluting

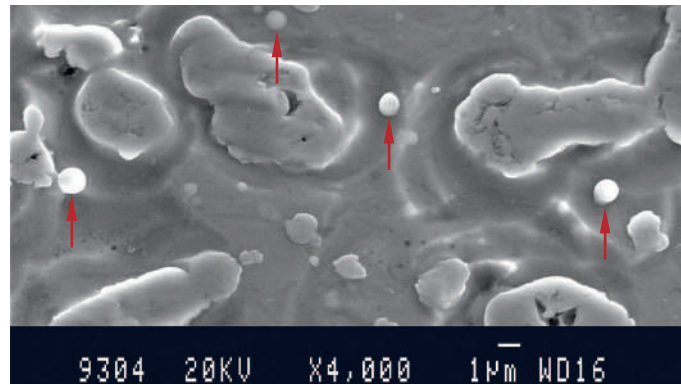
Fluting consists of periodic patterns running in the direction of rolling on areas of the surface of different depth. Current passage is often the cause of fluting.

5 Fluting



The use of a scanning electron microscope (SEM) reveals that both structures are composed of melt craters and welding beads in the  $\mu\text{m}$  range. The damage structures overlap the overrolled raceway in a tightly packed form. This demonstrates current passage through the bearing.

6 Damage structures under the scanning electron microscope (SEM)



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### 2.2.3 Development of bearing damage

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

With metal-to-metal contact in the mixed friction range, the surfaces involved become fused together. This fusion is then immediately broken apart again by the rotation of the bearing, during which material becomes detached from the surfaces and immediately solidifies to form welding beads. Some of the welding beads are mixed with the lubricant and are deposited on the metal surfaces. As overrolling continues, the craters and welding beads can be flattened and smoothed. Under a continuing flow of current, the surface layers involved repeatedly melt in this way over time.

Fluting is responsible for most bearing failures ▶7|5.

The commonly applied theory behind its formation is as follows: When a rolling element rolls over any sufficiently large melt crater it undergoes radial motion. The parameters for this radial motion are dependent on the internal geometry, speed and load of the bearing. When the rolling element swings back, the lubricant film thickness is reduced. New sparkovers increasingly occur in this area and a self-sustaining process is initiated, which produces the periodic structures on the raceway. After a time, fluting can cover the raceway of the ring in the load zone or the entire circumference of the raceway. This fluting leads to further increases in bearing vibration and ultimately to failure of the bearing.

### 2.2.4 Influence on the lubricant

Current passage also has a negative effect on the lubricant. The base oil and additives are damaged. Premature ageing and an increased concentration of iron particles cause a marked deterioration in the lubrication characteristics and noise behaviour of the bearing.



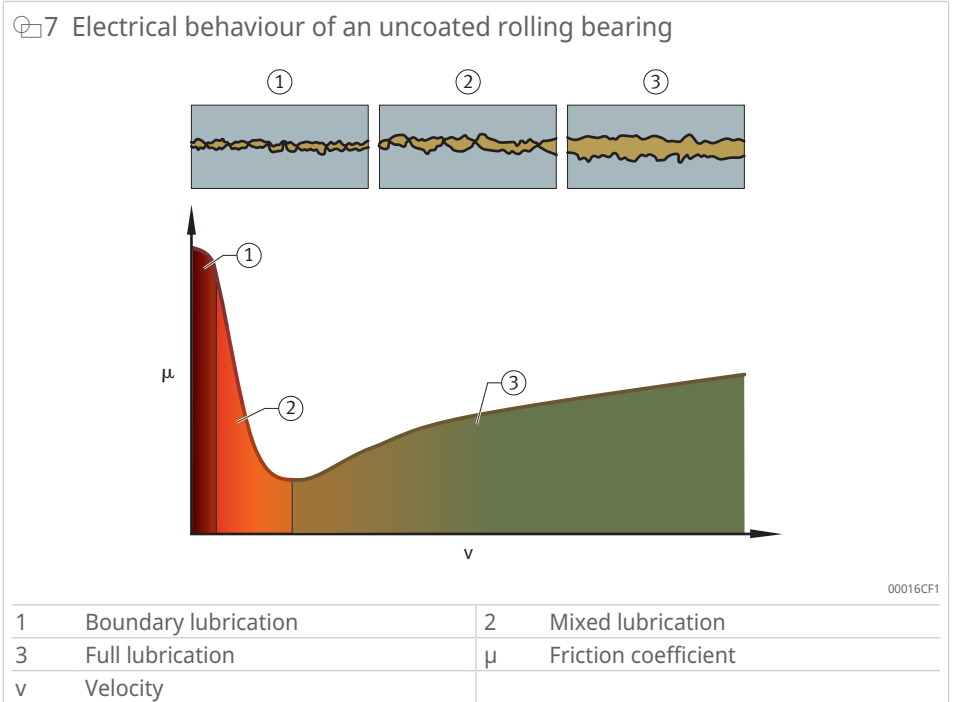
### 3 Current-insulated rolling bearings

Rolling bearings, in which either the inner ring or outer ring has a ceramic coating, are current-insulated bearings. This ceramic coating has the task of reducing or eliminating current passage through the bearing.

There are also hybrid bearings which contain rolling elements made from ceramic. In these bearings, the rolling elements prevent current passage.

#### 3.1 Electrical behaviour of rolling bearings

##### 3.1.1 Electrical behaviour of an uncoated rolling bearing



The electrical behaviour of a rolling bearing is dependent on the lubrication condition. The lubrication condition in which solid body contact is predominantly present with only partial fluid friction is described as boundary lubrication (area 1). In this condition, the bearing can be viewed as having ohmic resistance.

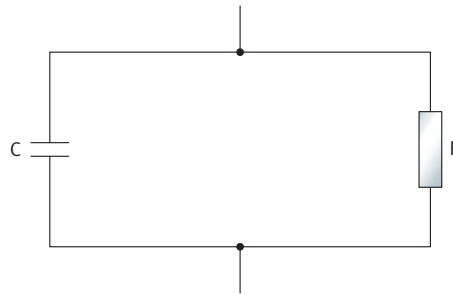
If the rolling contact surfaces moving relative to each are separated almost completely by a lubricant film, the term full lubrication is used (area 3). With full lubrication, the rolling bearing exhibits capacitance behaviour.

In the case of mixed friction or partial lubrication (area 2), a thin lubricant film is present, but the rolling contact surfaces continue to come into contact. In such cases, the rolling bearing exhibits both ohmic and capacitive resistance.

##### 3.1.2 Electrical behaviour of a current-insulated rolling bearing

A current-insulated bearing can be viewed as a parallel connection of ohmic resistance and capacitance.

8 Parallel circuit, resistance and capacitance



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C	F	Electrical capacitance
R	Ω	Ohmic resistance

For good insulation, the ohmic resistance should be as high as possible and the capacitance as low as possible.

The decisive factor in the selection of current insulation is the type of voltages present. In the case of direct current voltage and alternating current voltage at 50 Hz or 60 Hz, the ohmic resistance is decisive. In the case of higher-frequency alternating current, the capacitive resistance of the bearing is decisive. These high-frequency alternating currents are often found in electric motors that are operated using frequency converters, where frequencies ranging from several 100 kHz to several MHz are typically encountered.

2 types of electrical resistance are important:

- Direct current voltage resistance  
The direct current voltage resistance of bearings with an Insutect A coating is at least 50 MΩ at room temperature, based on the coating J20AB. Thus, according to Ohm's Law  $I = V/R$ , only currents significantly below 20 μA are possible with voltages up to 1000 V. Currents below 20 μA are not critical to bearings.
- Alternating current voltage resistance  
Frequency converters that generate unwanted and high-frequency currents in the range of several 100 kHz to several MHz are being used in an increasing number of applications. In this frequency range, ohmic resistance plays a minor role. The decisive factor here is the capacitive impedance of the bearing insulation, which should be as high as possible, and is largely determined by the frequency of the bearing current and the capacitance of the bearing.

11 Impedance dependent on frequency and capacitance

$$Z = \frac{1}{2 \cdot \pi \cdot f \cdot C}$$

C	F	Electrical capacitance
f	Hz	Frequency
Z	Ω	Impedance

The capacitance of a rolling bearing with an Insutect A coating can be calculated using the following formula:

f12 Capacitance from area and layer thickness

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

$\epsilon_0$	As/Vm	Electric field constant
$\epsilon_r$	-	Relative permittivity, dependent on material
A	mm <sup>2</sup>	Area coated
C	F	Electrical capacitance
s	mm	Layer thickness

A large coating thickness and a small coated surface will nevertheless lead to a low capacitance and thus to a high impedance.

In practice, a reliable criterion for assessing the level of hazard presented by current passage has been found to be the calculated current density  $J_S$ , in other words the effective amperage divided by the total contact area between the rolling elements and the inner or outer ring of the bearing. The calculated current density is dependent on the bearing type and the operating conditions. At current densities with effective amperages above around 0,1 A/mm<sup>2</sup>, there is the risk of current damage ▶ 7 | 2.2. In addition, white etching cracks (WECs) can also occur at lower current densities. White etching cracks are the result of interactions between certain lubrications and an additional load, e.g. current passage.

f13 Current density

$$J_S = \frac{I}{A_{\text{eff}}} \left[ \text{A/mm}^2 \right]$$

$A_{\text{eff}}$	mm <sup>2</sup>	Effective contact area
I	A	Amperage
$J_S$	A/mm <sup>2</sup>	Effective current density

## 3.2 Ceramic-coated bearings

Ceramic-coated bearings are standard bearings in which either the inner ring or outer ring has the ceramic coating Insutect A.

### 3.2.1 Types of coatings

9 Deep groove ball bearing with ceramic coating on the outer ring



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10 Cylindrical roller bearing with ceramic coating on the outer ring



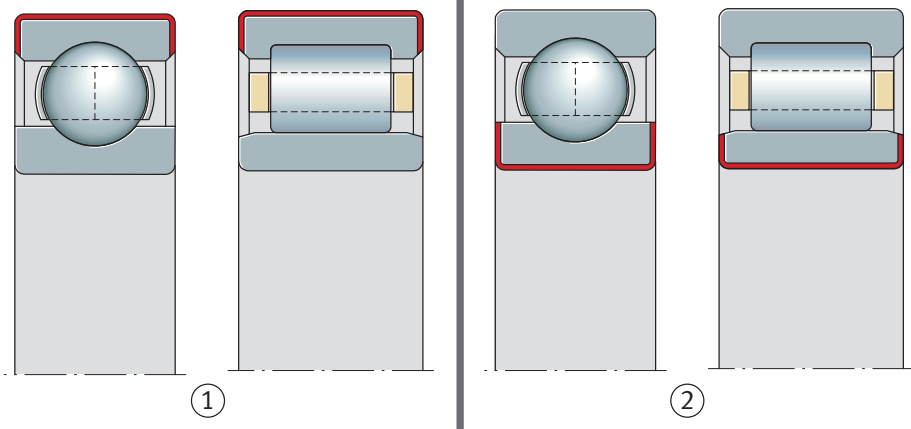
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Bearings coated with Insutect A have a high degree of electrical insulation protection. Bearings with an oxide ceramic coating are identified by the suffix J20 and an additional letter combination of GA, GB or GI. Previously, the suffixes AB, AA or C were used. The oxide ceramic layer is very hard, resistant to wear and has good thermal conductivity.

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.

The various type of coatings for bearings are shown in cross-section.

11 Types of coatings



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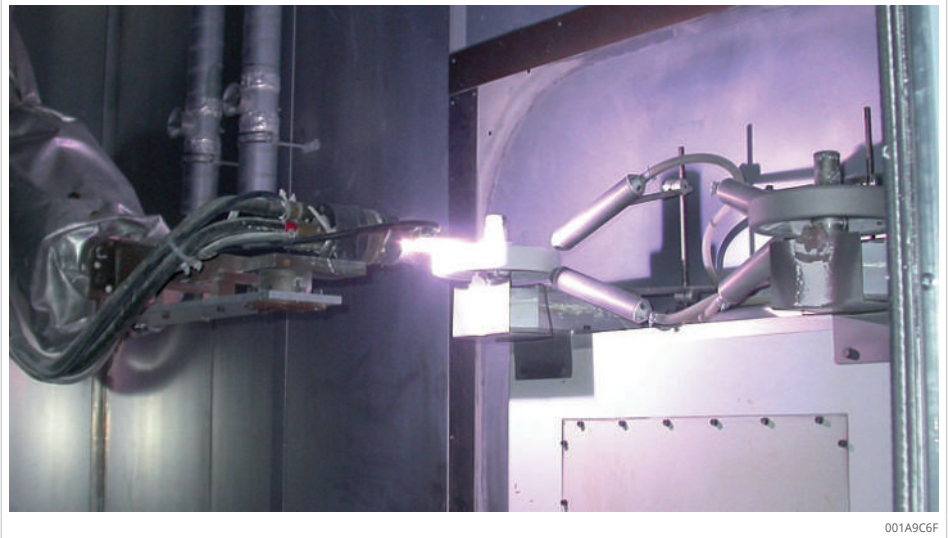
1 Outer ring coating: J20GA, J20GB

2 Inner ring coating: J20GI

### 3.2.2 Coating method

The bearings are coated using the plasma spray method. In the plasma spray method, an electric arc is generated between two electrodes and the inert gas introduced is thus ionised. The resulting plasma jet is then used as a carrier jet for the aluminium oxide powder fed into the device. The aluminium oxide powder is melted and sprayed at high velocity onto the outer or inner ring. The base material is roughened prior to application of the oxide layer. The oxide layer is then sealed.

12 Plasma spray method

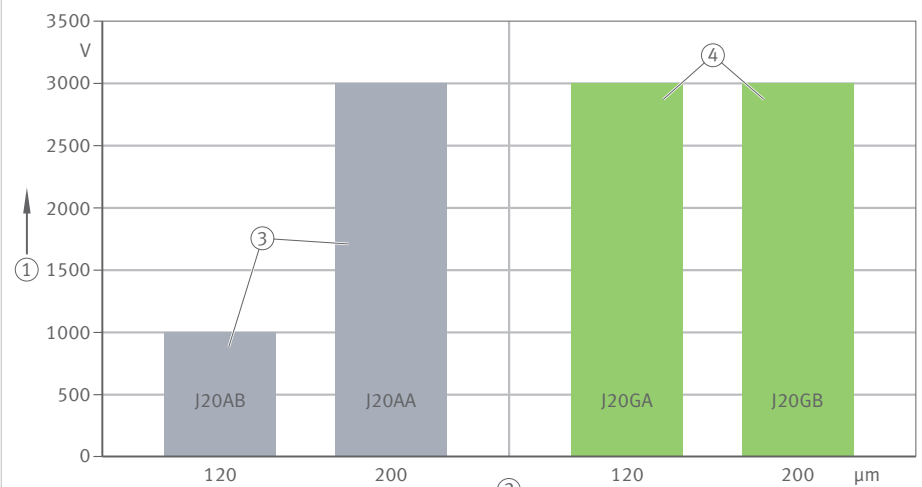


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### 3.2.3 Increased insulation performance with the new J20G coating

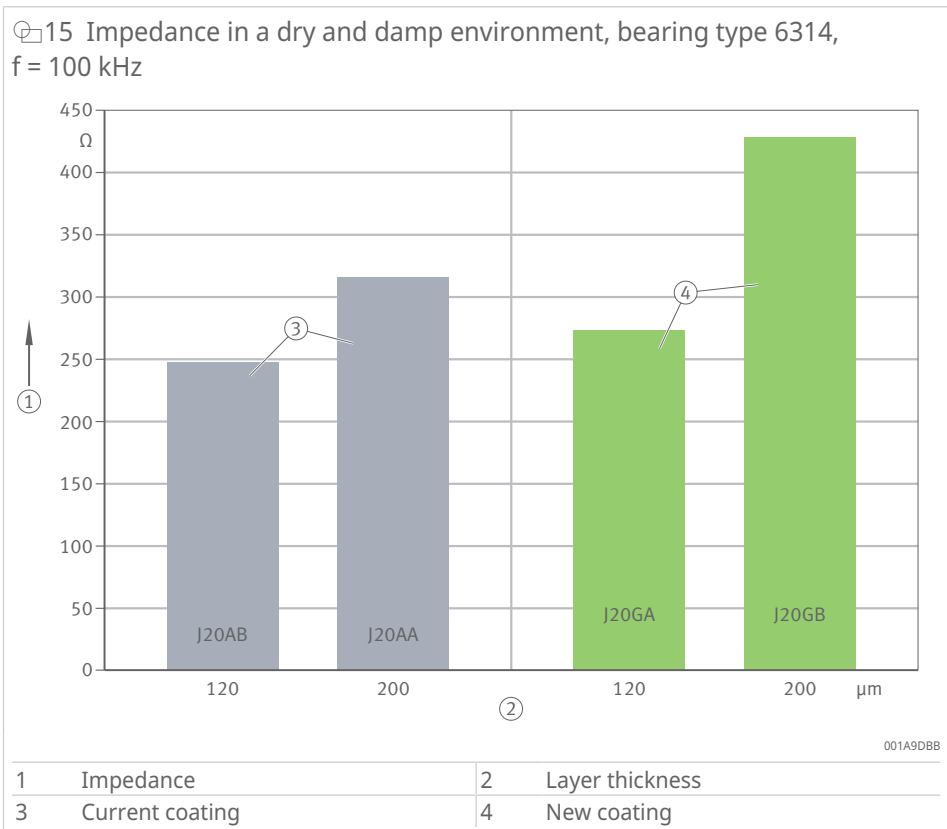
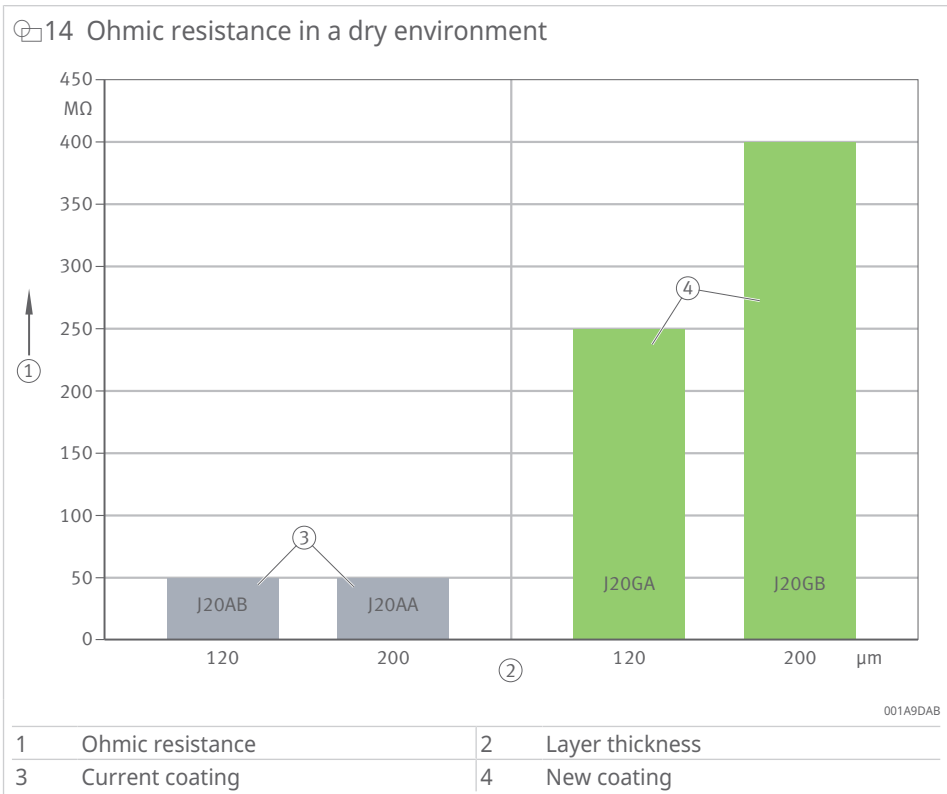
Systematic further developments have led to improvements in the insulation properties of rolling bearings with the Insutect A coating. In addition to improving electrical properties in dry environments, a significant increase in performance has also been achieved in damp operation conditions. A comparison with the values for the previous coating is provided in the following figures.

13 Dielectric strength in a dry and damp environment



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1	Puncture voltage	2	Layer thickness
3	Current coating	4	New coating

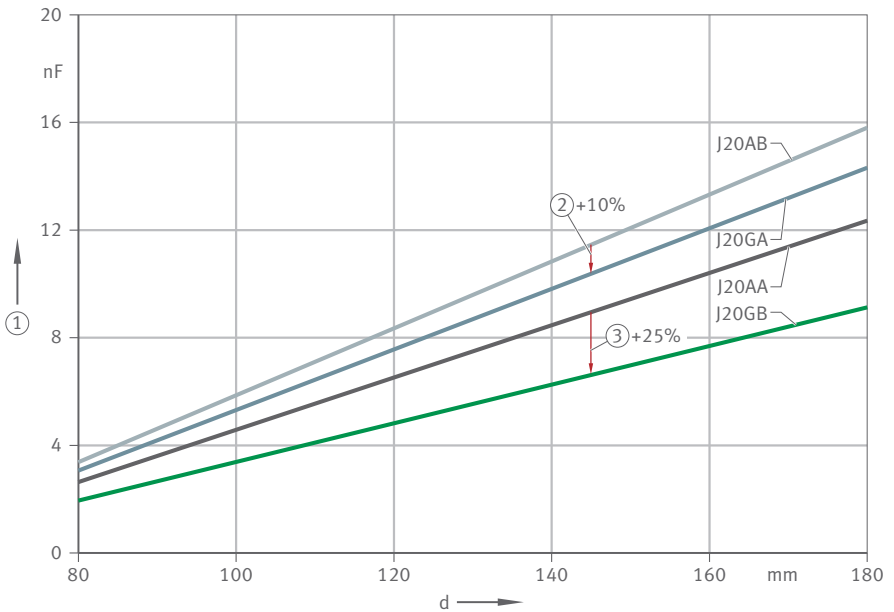


### 3.2.4 Coating parameters

Electrical simulations and calculations are increasingly being used to find the right insulation solution – processes in which the electrical properties of rolling bearings play a key role. The electrical insulating effect of the lubricant film can only be determined if the exact operating parameters are known. Schaeffler of-

fers expert guidance to assist you in this respect. The impedance or capacitance is crucial for the electrical properties of the insulation layer on Insutect A bearings. Guide values for the capacitance of deep groove ball bearings of bearing series 60, 62 and 63 can be found in the following figures. The lowest possible capacitance is necessary in order to reduce the current passage through the bearing to optimum effect. The values shown can also be used as an initial approximation for other designs with the same external dimensions, e.g. for cylindrical roller bearings in the same dimension range. The values for capacitance are also valid for use in damp environments, e.g. 90 % relative humidity.

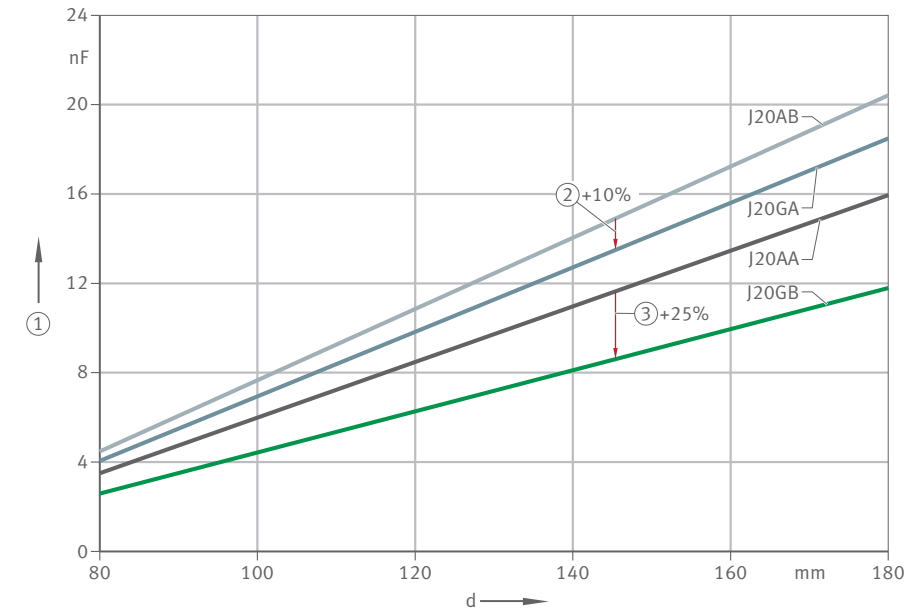
16 Guide values for the rolling bearing capacitance of bearing series 60



001A9E7D

1	Electrical capacitance	2	Improvement in capacitance of J20GA over J20AB of 10%
3	Improvement in capacitance of J20GB over J20AA of 25%		
d	mm	Bore diameter	

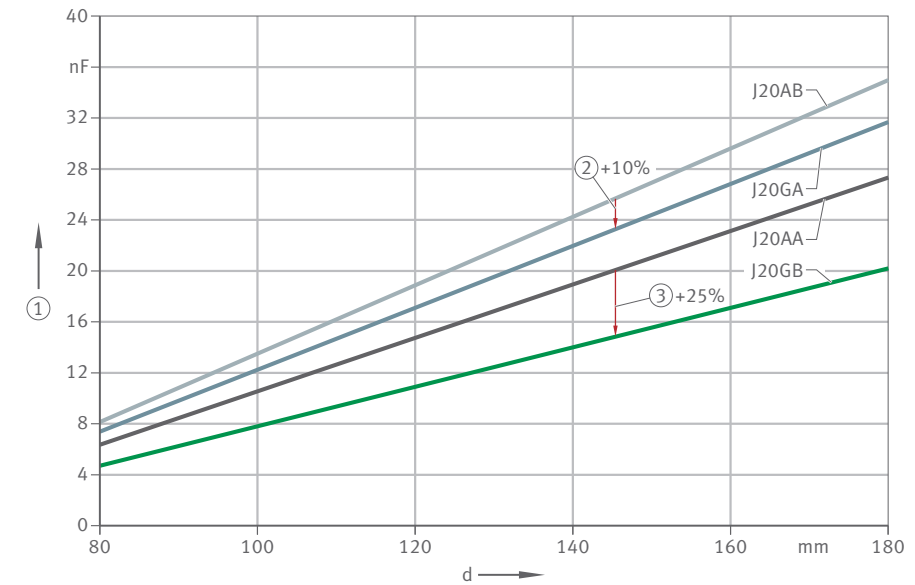
17 Guide values for the rolling bearing capacitance of bearing series 62



001A9E8D

1	Electrical capacitance	2	Improvement in capacitance of J20GA over J20AB of 10%
3	Improvement in capacitance of J20GB over J20AA of 25%		
d	mm	Bore diameter	

18 Guide values for the rolling bearing capacitance of bearing series 63



001A9E9D

1	Electrical capacitance	2	Improvement in capacitance of J20GA over J20AB of 10%
3	Improvement in capacitance of J20GB over J20AA of 25%		
d	mm	Bore diameter	



### 1 Parameters for Insutect A coating types J20G

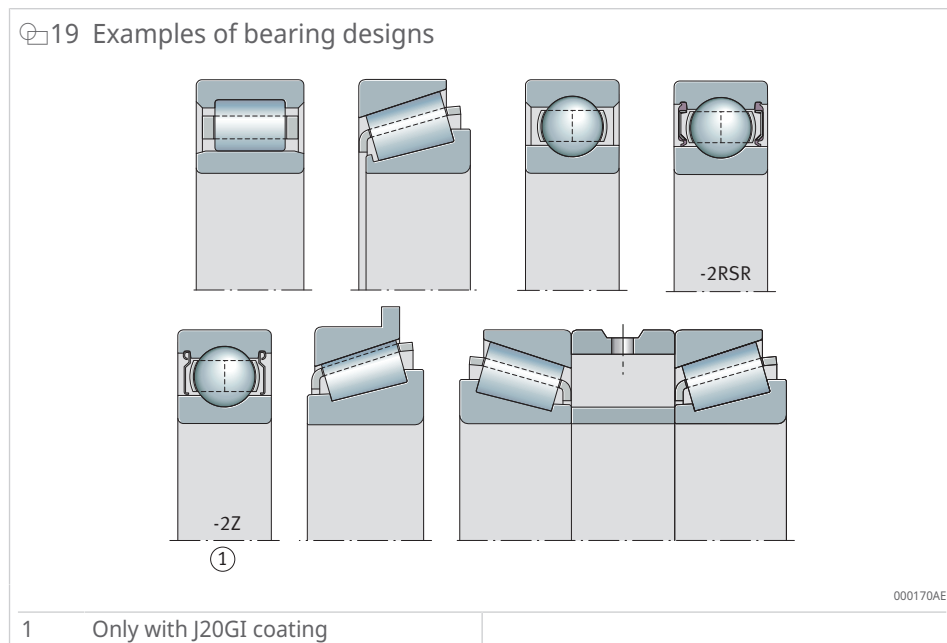
Parameter	Unit	J20GA	J20GB	J20GI
Bearing coating	-	Outer ring	Outer ring	Inner ring
Layer thickness	µm	120	200	120
Operating environment	-	Dry, damp	Dry, damp	Dry, damp
Electric strength	DCV	3000	3000	3000
Ohmic resistance	MΩ	250	400	250
Impedance, 6314, f = 100 kHz	Ω	273	428	583
Possible inside diameters	mm	-	-	≥ 70
Possible outside diameters	mm	70 ... 800	70 ... 800	... 800

The bearing surface of coated rings is cylindrical. If grooves or lubrication holes are present, we recommend that you contact the responsible Application Engineering department at Schaeffler.

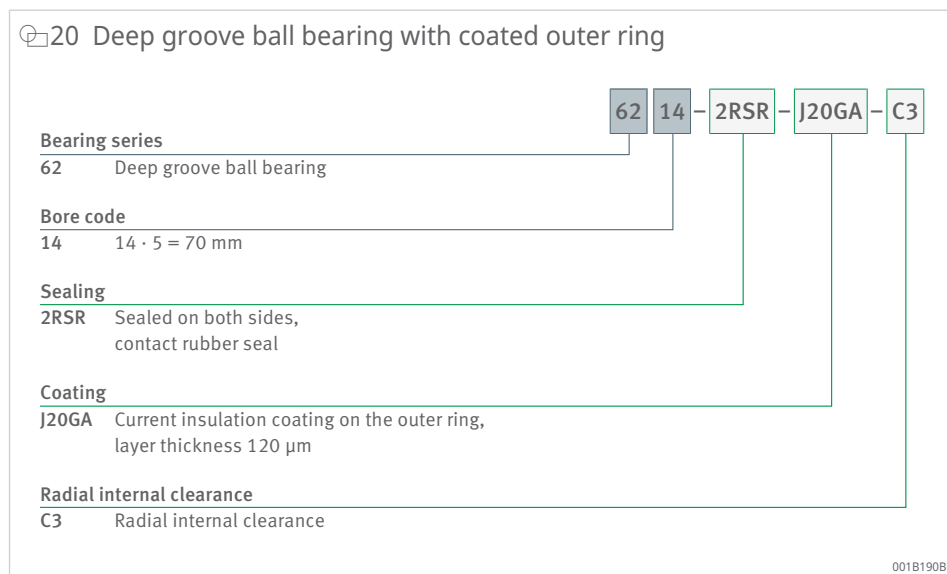
The coated rings are subjected to a 100 % insulation inspection.

### 3.2.5 Bearing designs with ceramic coatings

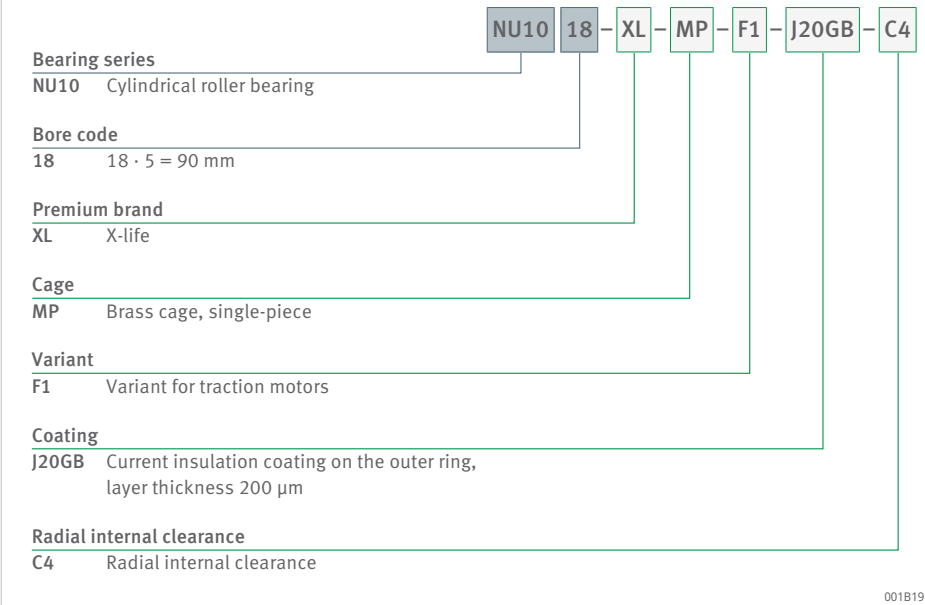
The available bearing designs with ceramic coatings are shown in cross-section.



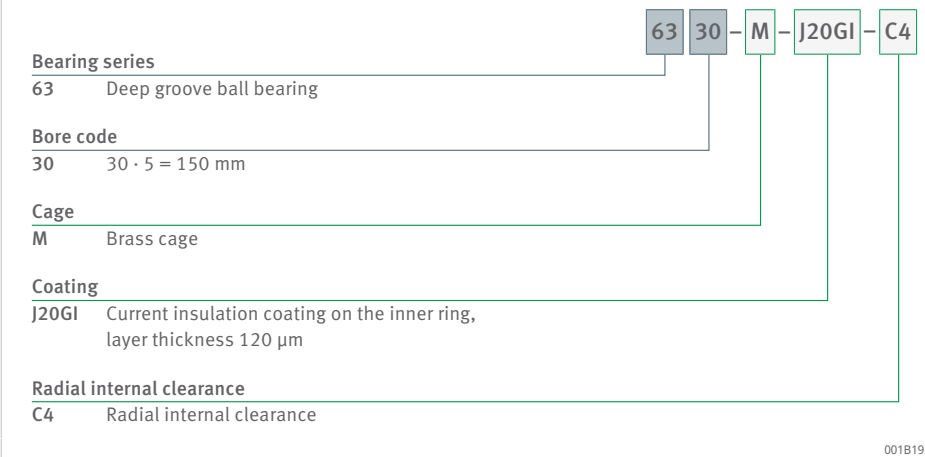
### 3.2.6 Ordering examples



21 Cylindrical roller bearing with coated outer ring



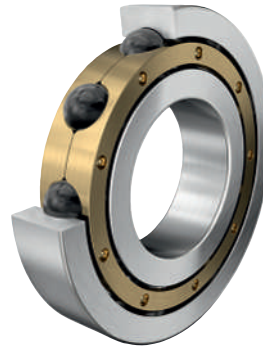
22 Deep groove ball bearing with coated inner ring



### 3.3 Hybrid bearing

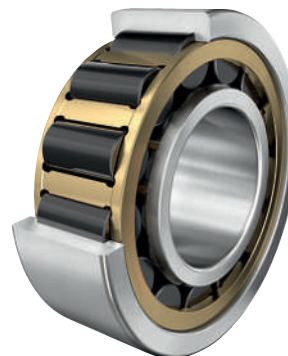
An alternative to Insutect A bearings is FAG hybrid bearings. The rings of the hybrid bearings are made from rolling bearing steel and the rolling elements are made from ceramic. The hybrid bearings are identified by the prefix HC. The rolling elements are highly resistant to wear and perform the function of current insulation. Hybrid bearings are available as ball bearings and as cylindrical roller bearings.

23 Hybrid ball bearing



0019D336

24 Hybrid cylindrical roller bearing



001A9EE3

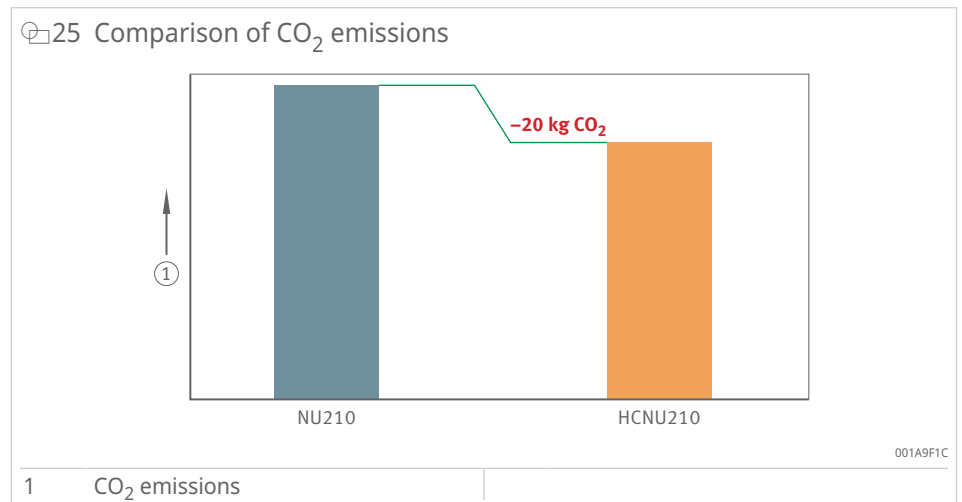
#### Advantages of hybrid bearings

Hybrid bearings have advantages over ceramic-coated bearings:

Hybrid bearings offer very high resistance to current passage. Their direct current resistance, even at high temperatures, is in the GHz range. A typical value for capacitance is 40 pF and is thus lower by a factor of 100 than for bearings with a ceramic coating.

Hybrid bearings allow higher speeds at lower friction and thus lower temperatures in operation. The low weight of the rolling elements leads to lower friction. Less friction reduces CO<sub>2</sub> emissions in the application. A comparison between the CO<sub>2</sub> emissions of a standard cylindrical roller bearing and a hybrid cylindrical roller bearing operating in the drive of a high-speed train over a period of one year and an approximate distance of 600,000 km shows a CO<sub>2</sub> reduction of 20 kg.

Hybrid bearings have better emergency running characteristics than standard bearings.



### Other characteristics

In comparison with standard bearings, hybrid bearings have the following characteristics:

- comparable basic dynamic load ratings  $C_r$  in accordance with ISO 20056-1
- comparable basic static load ratings  $C_{0r}$  in accordance with ISO 20056-2
- 20 % higher limiting speeds  $n_G$

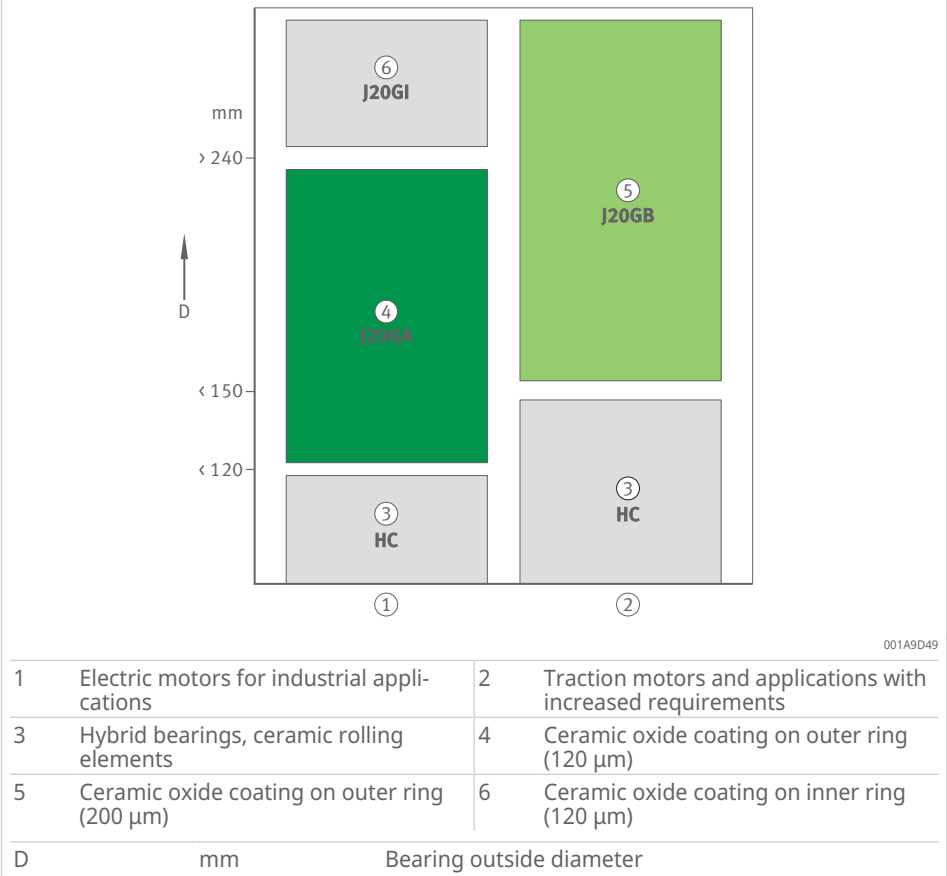
Hybrid bearings have the same dimensions and are therefore suitable for retrofitting. In addition, hybrid bearings offer twice the grease operating life of standard bearings. Hybrid bearings also offer advantages over standard bearings in terms of lifetime costs. The use of hybrid bearings can optimise product-specific life cycle costs by up to 20 %.

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

### 3.4 Standard recommendation for use

Remedial measures that optimally prevent current passage damage in a specific electric motor or generator are dependent on a variety of influencing factors such as operating conditions, motor type or frequency converter type. An initial recommendation for the use of current-insulated bearings is only possible on the basis of empirical values.

26 Recommendation for the use of current-insulated bearings



Fast-switching frequency converters are being used to an ever increasing degree in various applications, thus subjecting rolling bearings to higher electrical loads. For these applications, Schaeffler recommends either hybrid bearings or coatings with a greater layer thickness. Rolling bearings with a current insulating layer of up to 700 µm thick have already been developed by Schaeffler and are available by agreement.



**Schaeffler Technologies**  
**AG & Co. KG**  
Georg-Schäfer-Straße 30  
97421 Schweinfurt  
Germany  
[www.schaeffler.de/en](http://www.schaeffler.de/en)  
[info.de@schaeffler.com](mailto:info.de@schaeffler.com)

In Germany:  
Phone 0180 5003872  
From other countries:  
Phone +49 9721 91-0

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