SCHAEFFLER

Higher Performance Capacity Through the Use of Coatings

Functional coatings for automotive and industrial applications

Introduction

Functional coatings for automotive and industrial applications

Surface technology is one of the most important key technologies in industrialized countries. The Schaeffler Surface Technology Department brings together three important competences: coating technology, basics of tribology and nanotechnology.

Schaeffler is a world leader in functional surfaces and coatings. Accordingly, precision components and systems from Schaeffler offer high performance capacity with extended maintenance intervals as well as a long lifetime.

Through the use of suitable coating systems, it is possible to fulfil higher requirements in terms of corrosion or wear protection as well as reductions in friction. As a result, coating systems from Schaeffler contribute to the conservation of resources, since the operating life of components is extended and energy losses are reduced as a result of lower friction.

Coating systems and their areas of application

Selection of the appropriate coating system is based on the modular coating tool box from Schaeffler, *Figure 1*. The modular coating tool box offers individual solutions for the customer. The coating systems are applied to the surface by completely different methods. They should always be individually matched to the mounting situation. In many cases, it is sufficient to coat only one component or one of the rolling contact partners.

This Technical Information gives an overview of the coatings used at Schaeffler, arranged according to the main areas of use. The features, advantages and benefits are given for each type of coating. Specific examples and references are shown.

This technology will become increasingly important in the future, not only for existing products but also in particular for new types of products. Examples that can be cited in this respect include energy systems and wind energy. Furthermore, a future contribution to the digitalized networking of our components and systems will be made possible by the surfaces of our parts as a result of their multifunctional characteristics. In particular, there will be increasing emphasis on tribological and sensor-related functions.

Further information

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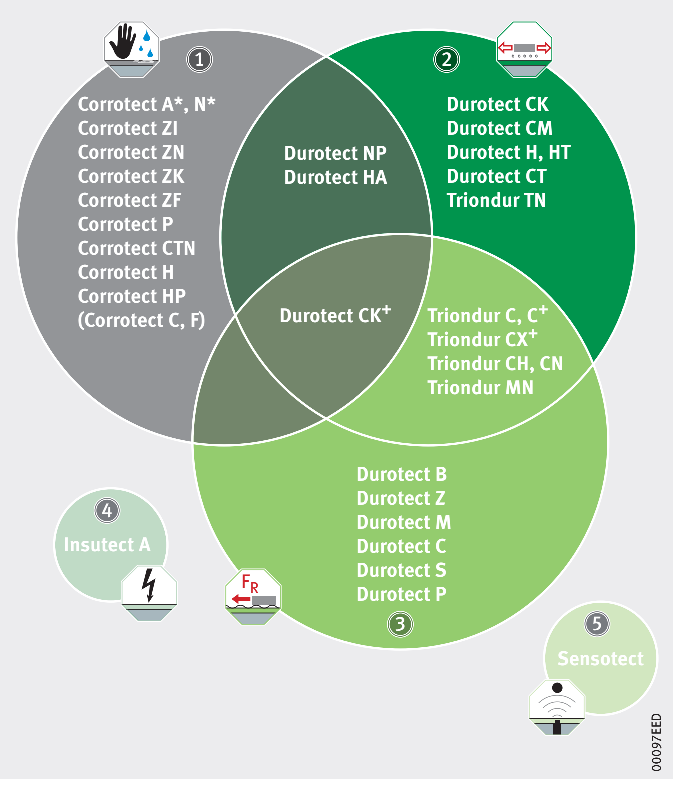
Modular Coating Tool Box

The following coating systems are currently available, *Figure 1*.



① Corrosion protection
② Wear protection
③ Friction reduction
④ Current insulation
⑤ Sensor technology

Figure 1
Coating systems and their areas of application

Corrotect Corrotect covers all coating systems that are used primarily to give protection against corrosion (film and base metal corrosion). Depending on the coating system, they are applied by means of electrochemical methods (electroplating), as a paint or by thermal spraying.

Durotect These coating systems are used primarily in applications that require protection against wear, reduction in friction or both. Depending on the coating system, they are applied by means of chemical or electrochemical methods, as a paint or by thermal spraying.

Triondur Triondur coating systems offer the best combination of wear protection and friction reduction for components subjected to very high tribomechanical stress.

They are applied under vacuum by means of PVD or plasma-assisted CVD methods.

Insutect Insutect covers coating systems that are used primarily to achieve insulation against current. They are applied by means of thermal spraying.

Sensotect Sensotect is a sensory coating that facilitates expansion in the functions of components. This is of particular significance in conjunction with the subjects of Industry 4.0 and digitalization.

This coating system is used for the continuous measurement of force and torque on two-dimensional and three-dimensional component geometries. The particular feature in this case is that the sensor technology can be applied by means of PVD technology and subsequent laser structuring directly to the component surface.

Contents

Corrotect coating systems free from Cr(VI), corrosion protection

Coating system	Composition	Principal function	
		Corrosion protection	Wear protection
Corrotect A*	Zinc-iron Thin film	■	–
Corrotect N*	Zinc-iron Thin film	■	–
Corrotect ZI	Zinc-iron	■	–
Corrotect ZN	Zinc-nickel	■	–
Corrotect ZK	Zinc	■	–
Corrotect ZF	Zinc flakes	■	–
Corrotect P	Paint systems	■	–
Corrotect CTN	Copper-tin-nickel combination	■	–
Corrotect H	Zinc or zinc-aluminium	■	–
Corrotect HP	Zinc or zinc-aluminium with topcoat	■	–

Corrotect coating systems containing Cr(VI), corrosion protection

Coating system	Composition	Principal function	
		Corrosion protection	Wear protection
Corrotect C[1)]	Zinc-iron Thin film	■	–
Corrotect F[1)]	Zinc-iron Thin film	■	–

1) Attention!
Information on REACh:

With the End of Life Vehicles Directive (EU Directive 2000/53/EC), the use of hexavalent chromium compounds was regulated for the first time. In the automotive sector, this means that the use of types of post-treatment containing Cr(VI) in coating methods, so-called yellow chromate passivation (Corrotect C) and black chromate passivation (Corrotect F) is no longer permissible.

In April 2013, hexavalent chromium compounds were included in Appendix XIV of the REACh directive by the European Chemicals Agency on account of their mutagenic and carcinogenic effects. The background to this directive is the improvement of the protection of human health and the environment against risks that may arise from the use of chemicals. The REACh directive is only valid within the entire European Union (in addition to Liechtenstein, Iceland and Norway). Switzerland has laws that are harmonized with REACh.

Without authorization approved by the ECHA, the use of hexavalent chromium compounds in the coating process is prohibited with effect from September 2017 for all sectors within the scope of REACh. As a result, this also affects the industrial sector.

At Schaeffler, all affected materials are being progressively changed over to post-treatments free from Cr(VI). For all new parts, the coating variants Corrotect C and Corrotect F are therefore no longer recommended or used.

	Additional function	Main area of application, special feature	Description
Friction reduction			Page
–	–	Belt drives, selector shafts, bearings, bearing components	19
–	–	Belt drives, detent systems	19
–	–	Belt drives, bearing components, screws with moderate corrosion protection requirements	20
–	–	Belt drives, bearing components, screws with high corrosion protection requirements	22
–	–	Simple corrosion protection applications	24
–	–	Chassis engineering, components, screws and safety components with high tensile strength	26
–	Current-insulating according to coating variant	Housings, flanges, slewing rings, connectors, main bearings	28
–	Wear protection based on hardness of coating	Corrosion protection in maritime applications	30
–	–	Corrosion protection for inner and outer rings of large size bearings, slewing rings, main bearings, generator bearings	32
–	–	Corrosion protection for inner and outer rings of large size bearings, slewing rings, main bearings, generator bearings	32

	Additional function	Main area of application, special feature
Friction reduction		
–	–	Bearings, bearing components
–	–	Linear components, individual bearing components

Durotect coating systems, wear protection and friction reduction

Coating system	Composition	Principal function	
		Corrosion protection	Wear protection
Durotect B	Mixed iron oxide	–	–
Durotect Z	Zinc phosphate	–	–
Durotect M	Manganese phosphate	–	–
Durotect CK	Columnar thin dense chromium coating	–	■
Durotect CK+	Columnar thin dense chromium coating and mixed chromium oxide	■	■
Durotect CM, Durotect CMT	Microcracked thin dense chromium coating	–	■
Durotect NP	Nickel-phosphorus	■	■
Durotect C	Copper	–	–
Durotect S	Silver	–	–
Durotect H	Chromium steel or manganese steel	–	■
Durotect HT	Range of variants	–	■
Durotect HA	Hard anodizing (Al)	■	■
Durotect CT	Copper-tin(-bronze) combination	■	■
Durotect P	Polymer-based coating	–	–

	Additional function	Main area of application, special feature	Description
Friction reduction			Page
■	Improved running-in behaviour Reduced slippage damage Short term corrosion protection (for example for transport) Reduced failures as a result of WEC	Belt drives, selector shafts, bearings, bearing components	36
■	Short term corrosion protection (for example for transport) Protection against fretting corrosion Suitable for sliding seats Bonding layer for paint, soaps, oils, vulcanization	Aerospace, linear guidance systems, bearings, bearing components	38
■	Improved running-in behaviour Short term corrosion protection (for example for transport) Emergency running lubrication Retention layer for dry lubricants	Aerospace, bearing components	40
–	Corrosion protection possible, depending on the application Slightly reduced friction Reduced fretting corrosion	Linear technology, aerospace, vibratory screen bearings, spindle bearings	42
■	Reduced fretting corrosion	Bearing components, linear technology	44
–	Corrosion protection possible, depending on the application Slightly reduced friction	Needle roller bearings, bearing and engine components	46
–	Friction reduction by means of PTFE additives	Drawn cups, guide ring segments	48
■	Emergency running lubrication Dissipation of frictional heat	Cages in bearings running at high speeds	50
■	Emergency running lubrication Dissipation of frictional heat	Aerospace, linear guidance systems, bearing components, cages in bearings running at high speeds	52
–	–	For dimensional correction of rolling bearing rings	54
–	Increase in adhesive friction (static or dynamic)	Synchronizer rings, inner rings, intermediate rings	55
–	Current insulation	Sliding sleeves, bearing cages, housing components	56
–	Corrosion protection Security against smearing and fretting Emergency running characteristics under lubricant starvation	Linear guidance systems	58
■	Protection against fretting corrosion Current insulation	Bearing rings, guide sleeves, cages	59

Triondur coating systems, wear protection and friction reduction in components subjected to high tribomechanical stresses

Coating system	Composition	Principal function	
		Corrosion protection	Wear protection
Triondur C	a-C:H:Me (metal-containing hydrogenated amorphous carbon coating)	–	■
Triondur C^+	a-C:H (hydrogenated amorphous carbon coating)	–	■
Triondur CX^+	a-C:H:X (modified hydrogenated amorphous carbon coating)	–	■
Triondur CH	ta-C (tetrahedral hydrogen-free amorphous carbon coating)	–	■
Triondur CN	Cr_xN	–	■
Triondur TN	Titanium nitride TiN	–	■
Triondur MN	CuMoN (nitridic hard material layer)	–	■

Insutect coating systems, current insulation

Coating system	Composition	Principal function
Insutect A	Aluminium oxide	Current insulation

Sensotect coating systems, sensor technology

Coating system	Composition	Principal function
Sensotect	Multi-layer system comprising insulation coating and strain-sensitive PVD coating	Measurement of force and torque

Friction reduction	Additional function	Main area of application, special feature	Description Page
■	□ Reduction in slippage damage	Bearing components, engine components	64
■	–	Engine components, bearing components	66
■	–	Engine components, bearing components, nanostructured, ideal combination of friction reduction and wear protection	67
■	–	Engine components, friction reduction with appropriate lubricant, highest wear resistance of all coating systems	68
■	–	Valve train components	69
–	–	Bearing components, rib surfaces	70
■	□ Increase in temperature resistance	Engine components, bearing components, nanostructured, wear protection and friction reduction under tribomechanical load	71

Additional function	Main area of application, special feature	Description Page
–	Rail vehicles, electric motors, generators	74

Additional function	Main area of application, special feature	Description Page
–	Rolling bearings, bottom bracket bearings, wheel bearings, shafts, bending beams	78

Coating systems and their areas of application

Features

The use of specifically formulated coatings improves the potential usage of components in the automotive and industrial sectors. Coating systems are therefore regarded as an independent design element.

Coating is a proven method for increasing the performance capability of the base material by functional expansion and thus providing components with additional characteristics for specific applications. For many years, Schaeffler has coated rolling bearings and precision components in order to improve corrosion protection as well as the tribological and electrical insulation characteristics.

Corroded bearing parts can lead to functional problems, lower efficiency and premature failure of bearings. Appropriate coatings can be an alternative to expensive, corrosion-resistant bearing steels, see page 14.

The quality of a rolling bearing is determined to a significant extent by its smooth running and wear resistance. These factors influence not only the basic function but also the requirement for energy and process materials. A low friction coefficient reduces not only energy consumption but also the requirement for lubricant.
This is associated with less mechanical wear. In turn, this secures the function of the bearing for the long term and its operating life is extended.

For the improvement of tribological behaviour, the Durotect and Triondur coating systems are suitable, see page 34 and page 60. Through selection of the correct coating, performance under poor lubrication conditions (lubricant starvation) can also be significantly improved in these cases.

In order to prevent rolling bearing failures as a result of current passage, the cylindrical surfaces and end faces of the bearing rings can be provided with ceramic insulating coatings, see page 72.

The following tables give a general overview of the performance strengths of coatings in relation to corrosion protection, wear protection and friction reduction, see tables, page 13.

! The actual performance is dependent on the specific application and may vary in some cases. In such cases, please consult Schaeffler.

Characteristics of coatings with primary corrosion protection function

Coating system	Principal function		
	Corrosion protection	Wear protection	Friction reduction
Corrotect ZK	+	––	––
Corrotect ZI	++	––	––
Corrotect ZN	+++	––	––
Corrotect ZF	+++	––	––
Corrotect P	++	––	––
Corrotect CTN	+++	++	––
Corrotect H	++	––	––
Corrotect HP	+++	––	––

Characteristics of coatings with primary wear protection function

Coating system	Principal function		
	Corrosion protection	Wear protection	Friction reduction
Durotect NP	++	++	––
Durotect HA	+	+	––
Durotect CM, Durotect CMT	+	++	+
Durotect CK	+	+++	+
Durotect CK^{+}	++	+++	++
Durotect CT	++	++	+
Durotect HT	––	++	––

Characteristics of coatings with primary friction reduction function

Coating system	Principal function		
	Corrosion protection	Wear protection	Friction reduction
Durotect B	–	+	+
Durotect M	–	+	+
Durotect Z	–	+	+
Durotect C	––	––	+
Durotect S	––	––	+
Durotect P	+	+	++
Triondur systems	––	+++	+++

+++ = high
++ = moderate
+ = low
– = short term (for example for transport with oiling)
–– = not ensured

Corrosion protection

Corrotect coating systems

Rolling bearing components are normally manufactured from martensitic, bainitic or case hardened rolling bearing steels 100Cr6. If standard rolling bearing steels come into contact with water or humidity, however, they can undergo corrosion, which can cause a permanent impairment of the intended function. Corrosion-resistant rolling bearing steels provide a remedy here but are expensive. The most economical variant for optimising the characteristics under moderate corrosion conditions is therefore the combination of a standard rolling bearing steel with an appropriate coating; see tables, page 13. For particularly high corrosion loads, coatings resistant to seawater are available.

A wide selection of Corrotect coatings of differing performance capability ensures corrosion protection (for film and base metal corrosion) individually matched to the customer application, *Figure 1*. The anti-corrosion coatings from Schaeffler are explained in detail below and application examples are given.

Corrotect covers all coating systems that are used primarily to give protection against corrosion. The coating systems available for this purpose give protection in different ways. Depending on the coating system, the action is based on cathodic corrosion protection (as in the case of zinc alloys), anodic corrosion protection (as in the case of chemical nickel coatings) or a barrier effect (for example in paint systems).

1 Layer thickness
2 Corrosion resistance to red rust in accordance with DIN EN ISO 9227

In the neutral salt spray test (NSS test) in accordance with DIN EN ISO 9227, the components are exposed to a defined sodium chloride climate, in order to compare the corrosion protection performance of the coating systems.

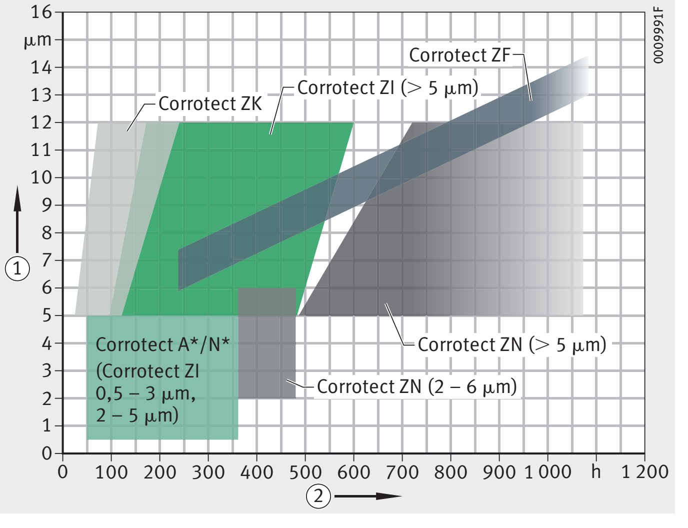


Figure 1
Comparison of Corrotect coating systems (cathodic corrosion protection) in the salt spray test

Coating methods

Depending on the coating system, it is applied by means of an electrochemical (electroplating) process (for zinc alloys) or a spraying or dipping method (paint systems).

Electroplated corrosion protection coatings

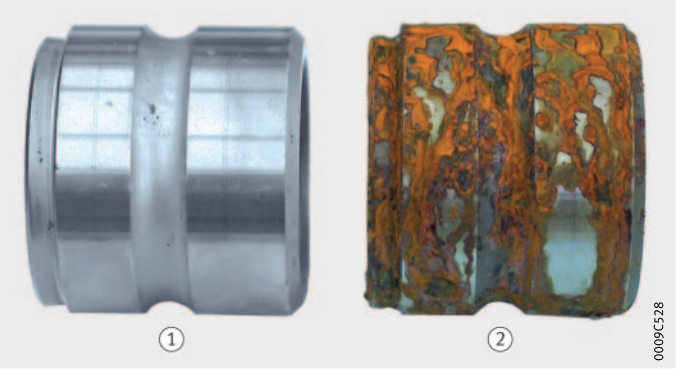
Zinc and zinc alloys have been used in industry for many years as an anti-corrosion coating, *Figure 2*. In rolling bearing applications, the soft layers on the overrolled area of the bearing raceway are worn away during operation, thus increasing the bearing clearance. Layer thicknesses of $> 5\ \mu m$ are therefore not generally suitable in these fields. In the thin layer variants Corrotect A* and Corrotect N*, film thicknesses in the range from 0,5 μm to 5 μm are applied, making their use possible in the case of standard rolling bearings.

Due to their amphoteric character, zinc-based anti-corrosion coatings are suitable only under certain conditions or not at all for application and contact in aggressive environments. In contact with acid or alkaline agents (pH value < 6 or pH value > 8), it must be expected that the coated surface will be attacked or accelerated film and base metal corrosion will occur.

!

During the coating process, the component is located in an electrical circuit. As a result, an electrical field of varying intensity is formed over the whole component geometry, leading to increased film formation at edges (bone effect).

Due to these physical effects, however, film deposition will be reduced or not present at all in holes, in undercuts and on inner edges. Through the use of optimized coating fixtures specially matched to the component, these effects can in certain cases be reduced or eliminated.



Test time 24 h in salt spray

1 With zinc-iron coating
2 Uncoated

Figure 2
Coated and uncoated part after salt spray test

Passivation and sealing of zinc and zinc alloy coatings

In order to increase the corrosion protection effect, passivation is additionally carried out on zinc and zinc alloy coatings. In this case, a conversion coating free from Cr(VI) is achieved by dipping the components in passivation solutions. This conversion coating protects the zinc-based coating against corrosion and thus extends the resistance of the complete system to white and red rust.

In special applications, additional sealing is possible. In this case, organic or inorganic substances are applied to the passivation as a cover layer. This gives a further increase in corrosion resistance.

Combination of different metal contact surfaces

The protective performance of coatings with cathodic corrosion protection is sharply reduced by contact with precious or semi-precious metals such as copper sealing rings as a result of the electrochemical potential generated. Combination of different metal contact surfaces should therefore be avoided wherever possible.

Transport and handling tasks

If there are only slight requirements for corrosion resistance, for example in transport and handling tasks, economical zinc phosphating (Durotect Z) or black oxide coating (Durotect B) is possible, in each case with application of oil. In this case, however, the expectations placed on the protection system must be compared with the possible system performance levels and carefully weighed up. In general, these simple protection systems only give acceptable corrosion protection levels if oil is applied to the parts.

Paint-based anti-corrosion coatings

In the case of large component dimensions or components with special requirements, the dipping of components in electrolytes for an electroplating process is often not possible. As an alternative, paints (Corrotect P) or a high-resistance, paint-based coating system (Corrotect ZF) are therefore used for corrosion protection.

Corrosion protection

Multi-layer corrosion protection systems

Multi-layer corrosion protection systems such as Corrotect CTN are used in challenging areas and climates.

This coating option offers interesting alternatives to cost-intensive sprayed coatings or multiple layer coatings (such as zinc primer, base paint, cover paint, topcoat).

Corrotect CTN

The particular characteristics of the impermeable bronze intermediate layer (barrier layer of a defined composition) provide the coating with corrosion resistance to seawater, mineral acids and corrosive chemicals such as iron (III) chloride, sulphuric acid, hydrochloric acid, nitric acid and phosphoric acid. Due to the good wear resistance of the cover layer, applications under high stress levels, for example in offshore and mining operation, have also proved effective.

Other coatings for corrosion protection

In contact with highly corrosive media such as acids or alkalis, nickel-phosphorus coatings (NiP coatings) deposited by electroless methods have proved effective. However, a tolerance must be included for the coating of the order of magnitude of the layer thickness.

Columnar thin dense chromium coating

As an anti-corrosion coating resistant to wear and overrolling, a columnar thin dense chromium coating Durotect CK and Durotect CK$^+$ can be used, see page 42 and page 44.

Corrotect A*, Corrotect N*

Zinc-iron coating (layer thickness $< 5\ \mu m$) with thick film passivation A* or nanoparticle-backed thick film passivation N*.

Coating process

- Electroplating method
- Subsequent heat treatment necessary for high strength materials (against hydrogen embrittlement).

Advantages, benefits

- Protection against base metal corrosion (red rust formation)
- Economical, cathodic corrosion protection
- Thin film coating technology allows complete bearing coating without taking account of deviations and tolerance specifications.

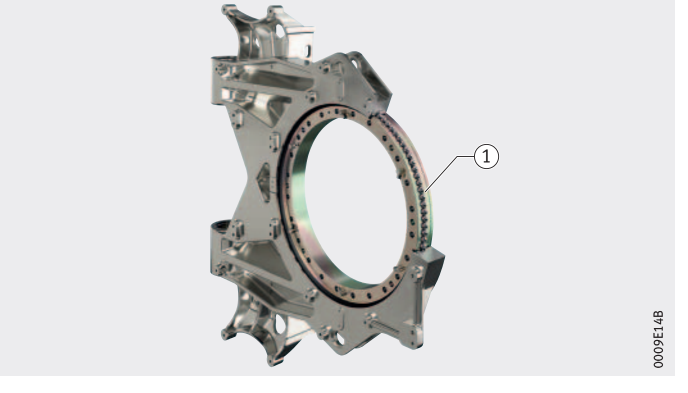
Common applications

Various bearings, bearing components and bearing adjacent parts with requirement for increased corrosion resistance:

- bearing inner rings, outer rings
- drawn cup needle roller bearings and thin-walled components in large quantities, such as detent sleeves.

Characteristics

Feature	Coating	
	Corrotect A*	Corrotect N*
Composition	Zinc-iron	
Post-treatment	Thick film passivation	Nanoparticle-backed thick film passivation
Corrosion resistance	Depending on the layer thickness and passivation, between 48 h and 360 h against base metal corrosion (salt spray test in accordance with DIN EN ISO 9227)	
Colour	Silver, iridescent	Silver, slightly iridescent
Layer thickness	$0{,}5\ \mu m - 3\ \mu m$ $2\ \mu m - 5\ \mu m$	
Coating resistance	Coating is amphoteric in character and therefore has reduced corrosion resistance for pH value < 6 and pH value > 8	



① Four point contact bearing with Corrotect A*-coated inner ring

Figure 3
Application example
Swivel system

Corrosion protection

Corrotect ZI

Zinc-iron coating (layer thickness $> 5\ \mu m$) with thick film passivation A* or nanoparticle-backed thick film passivation N*.

Coating process

- Electroplating method
- Subsequent heat treatment necessary for high strength materials (against hydrogen embrittlement).

Advantages, benefits

- Protection against base metal corrosion (red rust formation)
- Economical, cathodic corrosion protection.

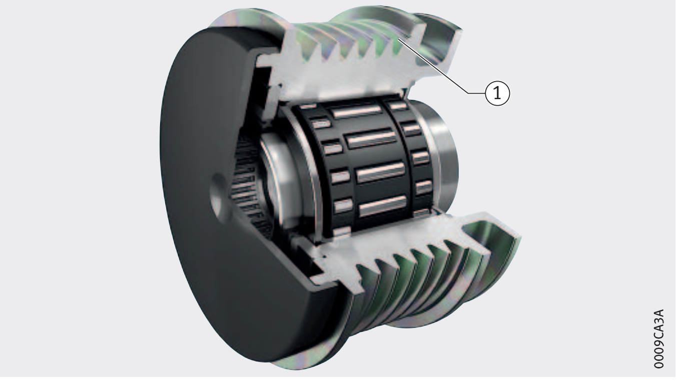
Common applications

Components with requirement for increased corrosion resistance, such as:

- adjacent bearing parts
- housings
- belt pulleys
- levers.

Characteristics

Feature	Coating	
	Corrotect ZI A*	Corrotect ZI N*
Composition	Zinc-iron	
Post-treatment	Thick film passivation	Nanoparticle-backed thick film passivation
Corrosion resistance	Depending on the layer thickness and passivation, between 120 h and 600 h against base metal corrosion (salt spray test in accordance with DIN EN ISO 9227)	
Colour	Silver, iridescent	Silver, slightly iridescent
Layer thickness	$> 5\ \mu m$	
Coating resistance	Coating is amphoteric in character and therefore has reduced corrosion resistance for pH value < 6 and pH value > 8	



① Outer ring with Corrotect ZI A* coating

Figure 4
Overrunning alternator pulley
from belt drive

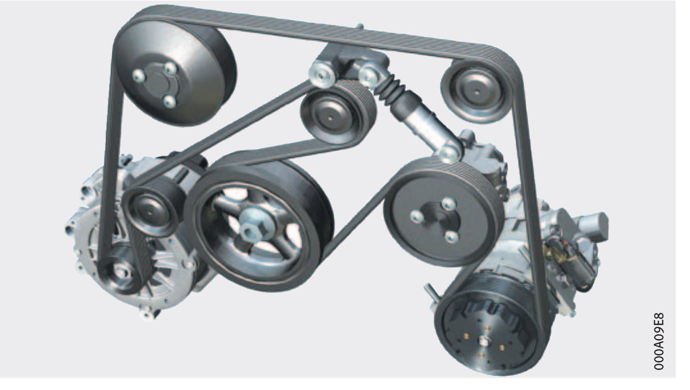


Figure 5
Application example
Belt drive

Corrosion protection

Corrotect ZN

Zinc-nickel coating with thick film passivation A*.

Coating process

- Electroplating method
- Subsequent heat treatment necessary for high strength materials (against hydrogen embrittlement).

Advantages, benefits

- Protection against base metal corrosion (red rust formation)
- High quality, cathodic corrosion protection
- Best ratio between layer thickness and corrosion protection effect.

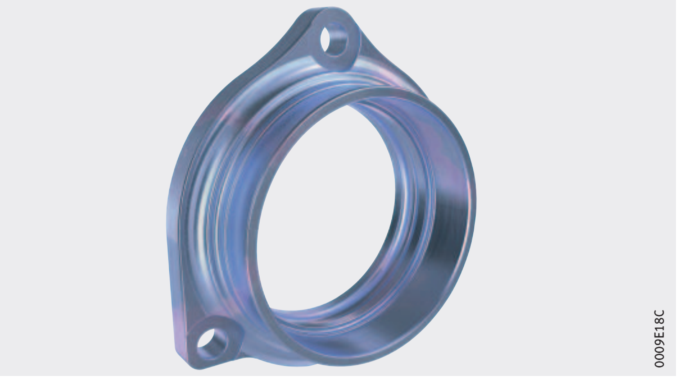
Common applications

Components with requirement for very high corrosion resistance, such as:

- steering and detent bushes
- bearing pins
- mechanical levers.

Characteristics

Feature	Coating
Composition	Zinc-nickel
Post-treatment	Thick film passivation
Corrosion resistance	Depending on the layer thickness and passivation, between 360 h and 720 h against base metal corrosion (salt spray test in accordance with DIN EN ISO 9227); in combination with a performance-enhancing post-treatment, corrosion protection of more than 720 h against red rust may be possible
Colour	Silver-blue, in some cases with coloured iridescence
Layer thickness	$> 2\ \mu m$
Coating resistance	Coating is amphoteric in character and therefore has reduced corrosion resistance for pH value < 6 and pH value > 8



Corrotect ZN A* coating

Figure 6
Outer ring from ball screw drive

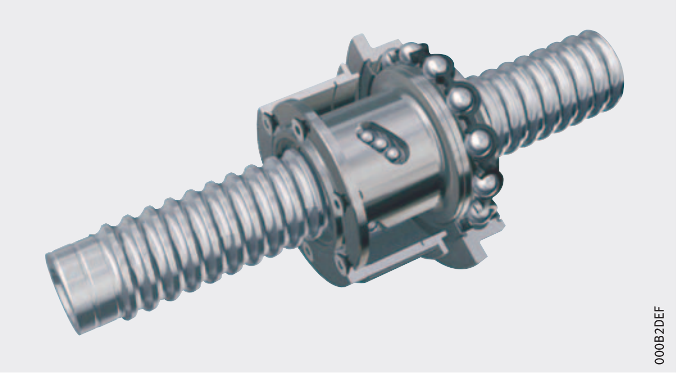


Figure 7
Application example
Ball screw drive

Corrosion protection

Corrotect ZK Electroplated zinc coating with thick film passivation A* or thin film passivation A or B.

Coating process
- Electroplating method
- Subsequent heat treatment necessary for high strength materials (against hydrogen embrittlement).

Advantages, benefits
- Protection against base metal corrosion (red rust formation).

Common applications

Components with requirement for slight corrosion resistance:
- simple blanked and bent parts
- small mounting parts such as impact sleeves
- screws.

Characteristics

Feature	Coating		
	Corrotect ZK A*	Corrotect ZK A	Corrotect ZK B
Composition	Zinc		
Post-treatment	Thick film passivation	Thin film passivation	Thin film passivation
Corrosion resistance	Depending on the layer thickness and passivation, between 24 h and 240 h against base metal corrosion (salt spray test in accordance with DIN EN ISO 9227)		
Colour	Silver, iridescent	Colourless, silver	Silver-blue
Layer thickness	$> 5\ \mu m$		
Coating resistance	Coating is amphoteric in character and therefore has reduced corrosion resistance for pH value < 6 and pH value > 8		

① Drawn cup with Corrotect ZK coating

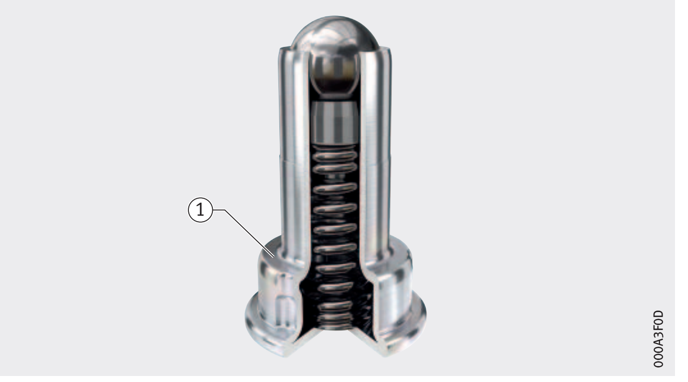


Figure 8
Selector rod detent pin
from manual gearbox

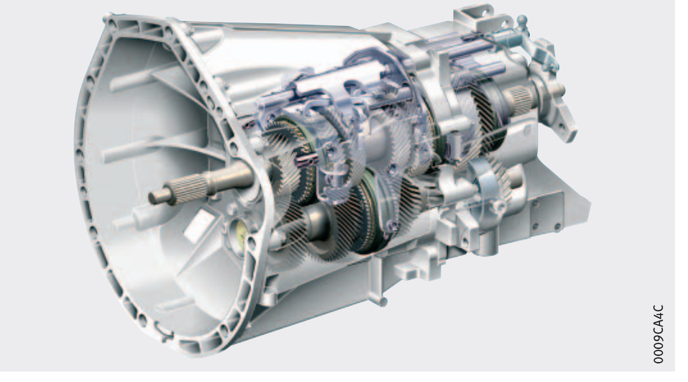


Figure 9
Application example
Manual gearbox

Corrosion protection

Corrotect ZF

Zinc flake coating.

Coating process

- Dipping, centrifugal or spraying methods.

Advantages, benefits

- Protection against base metal corrosion (red rust formation)
- Partially cathodic corrosion protection similar to paint
- Increased temperature resistance in comparison with normal anti-corrosion paints
- Corrosion protection without subsequent heat treatment of high strength materials. No risk of hydrogen embrittlement due to coating process.

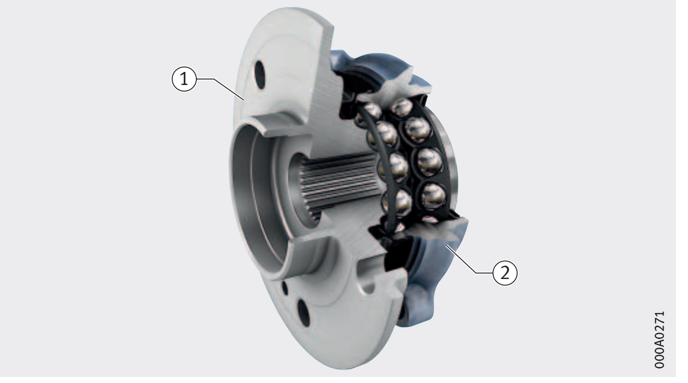
Common applications

In automotive engineering:

- axle and wheel bearing components
- impulse and intermediate rings
- high strength screws (of or larger than thread M5).

Characteristics

Feature	Coating
Composition	Zinc(-aluminium) flakes
Post-treatment	No passivation, topcoat in some cases
Corrosion resistance	Depending on the layer thickness, up to 1 000 h against base metal corrosion (salt spray test in accordance with DIN EN ISO 9227)
Colour	Silver-grey (topcoat can optionally be coloured as required)
Layer thickness	> 5 µm



① Rim seat with Corrotect ZF coating
② Outer ring with Corrotect ZN coating

Figure 10
Wheel flange

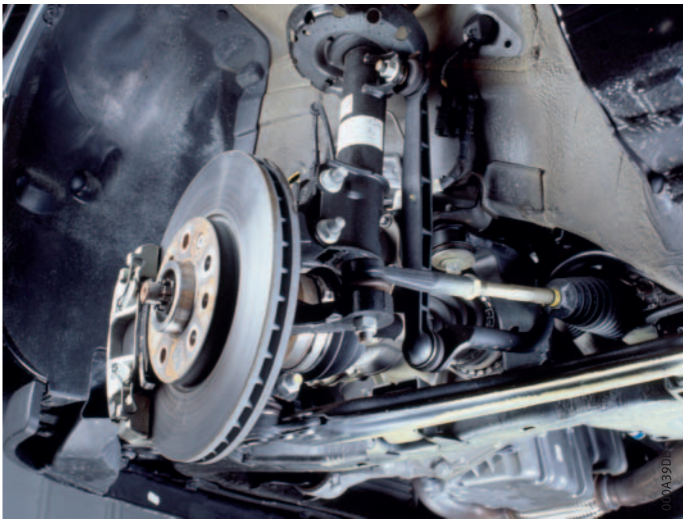


Figure 11
Application example
Wheel suspension

Figure 12
Application example
Spreading vehicle

Corrosion protection

Corrotect P

Polymer-based coating.

Corrotect P includes various paint coating systems used for corrosion protection.

Coating process

- Dipping method:
  - complete coating of individual components
- Spraying method:
  - complete or partial coating
- Curing temperature dependent on paint system, from room temperature to approx. +250 °C.

Advantages, benefits

- Protection against base metal corrosion (red rust formation)
- Corrosion protection for various ambient conditions in accordance with DIN EN ISO 12944-2; corrosivity categories C1 to C5-M
- No white rust formation
- Depending on coating variant, current insulation in low voltage range
- Good chemical resistance
- Colour freely selectable.

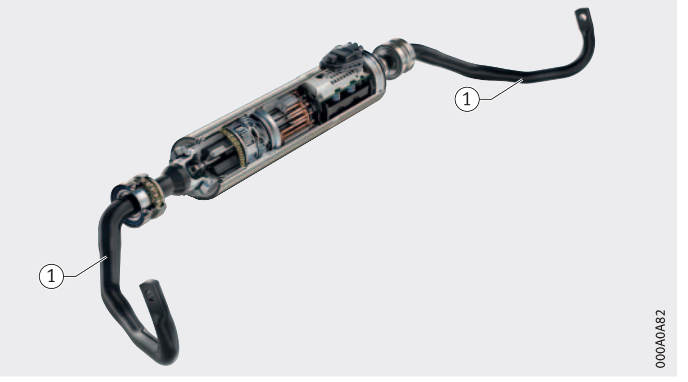
Common applications

Components with low to very high requirements for corrosion protection, such as:

- rotor main bearing arrangements in wind turbines
- active roll control (housing, torsion bar)
- plummer block housings
- wheel bearings.

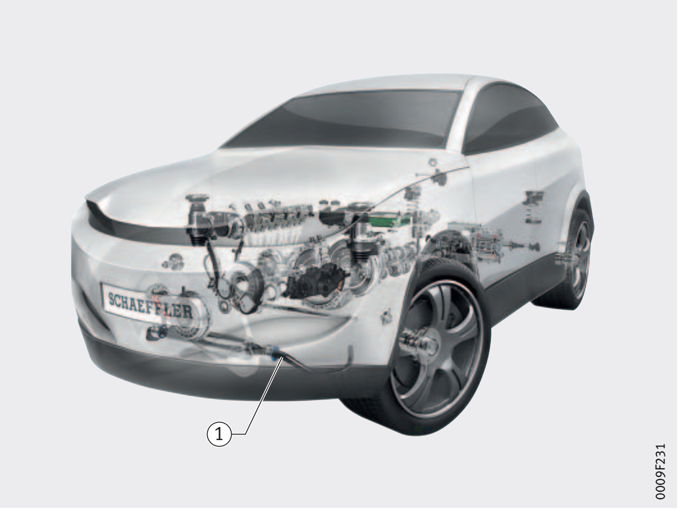
Characteristics

Feature	Coating
Composition	Polymer-based
Post-treatment	No passivation
Corrosion resistance	Corrosion protection in accordance with DIN EN ISO 12944-2; corrosivity categories C1 to C5-M; depending on the layer thickness, up to 720 h against base metal corrosion (salt spray test in accordance with DIN EN ISO 9227)
Colour	Freely selectable
Layer thickness	15 µm – 500 µm



1 Roll arms with Corrotect P coating

Figure 13
Active roll control



Schaeffler glass car

1 Active roll control

Figure 14
Application example
Chassis

Corrotect CTN Copper-bronze-nickel combination.

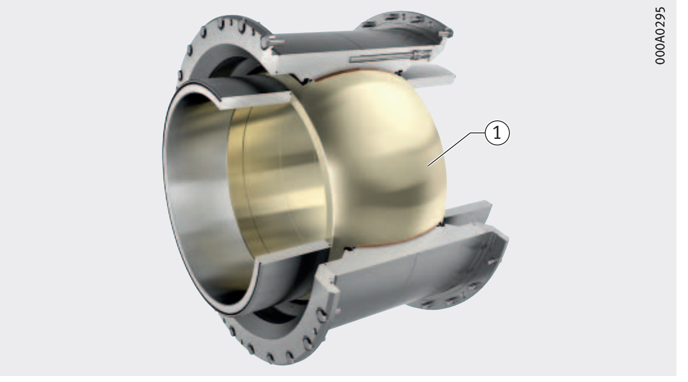
Coating process
- Electroplating method
- Subsequent heat treatment necessary for high strength materials (against hydrogen embrittlement).

Advantages, benefits
- Excellent corrosion resistance in seawater, mineral acids and various chemicals
- Due to the good wear resistance of the cover layer, also for applications under high stress levels in offshore and mining operation
- High temperature resistance up to +600 °C.

Common applications
- Maritime applications
- Spherical plain bearings.

Characteristics

Feature	Coating
Composition	Copper-bronze-nickel combination
Post-treatment	None
Corrosion resistance	Corrosion protection due to barrier effect against base metal corrosion (red rust formation), depending on design and layer thickness: ■ ≧ 1 000 h according to salt spray test in accordance with DIN EN ISO 9227 ■ ≧ 72 h seawater-resistant in accordance with ASTM G48-C
Colour	Silver, in some cases with yellow shimmer
Layer thickness	$>$ 60 μm (preferred)



1 Inner ring with Corrotect CTN coating

Figure 15
Spherical plain bearing
with two-piece outer ring and
ELGOGLIDE-W11 sliding layer

Figure 16
Offshore application
Shipping

Corrosion protection

Corrotect H, Corrotect HP

Thermally sprayed, metallic layers as corrosion protection with zinc or zinc-aluminium (optionally with topcoat).

Coating process

- Thermal spraying (optionally topcoat by painting).

Advantages, benefits

- Corrosion protection for various ambient conditions in accordance with DIN EN ISO 12944-2
- Corrosivity categories C1 to C5-M; possible corrosion protection period 15 years (protection period class H)
- Coating of geometrically difficult and large-dimension components.

Common applications

Very high corrosion protection for the following areas:

- inner and outer rings for large size bearings
- slewing rings, main bearings and generator bearings in wind energy applications.

Characteristics

Feature	Coating	
	Corrotect H	Corrotect HP
Composition	Zinc or zinc-aluminium coating	
Post-treatment	None	Polymer-based topcoat (paint)
Corrosion resistance	> 15 years possible, in accordance with DIN EN ISO 12944	
Colour	Metallic	Topcoat suitable for individual colouring
Layer thickness	50 μm – 400 μm	

Corrotect H coating on all outside surfaces

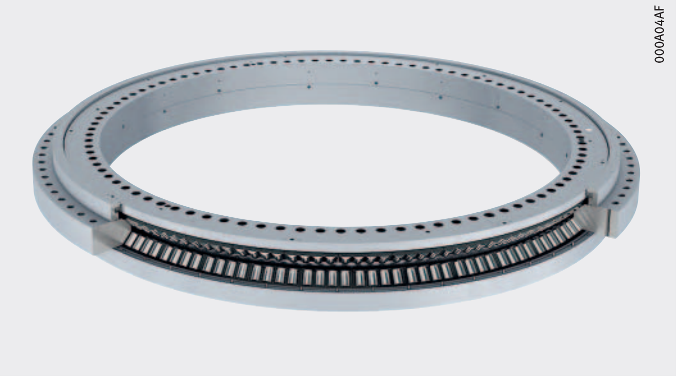
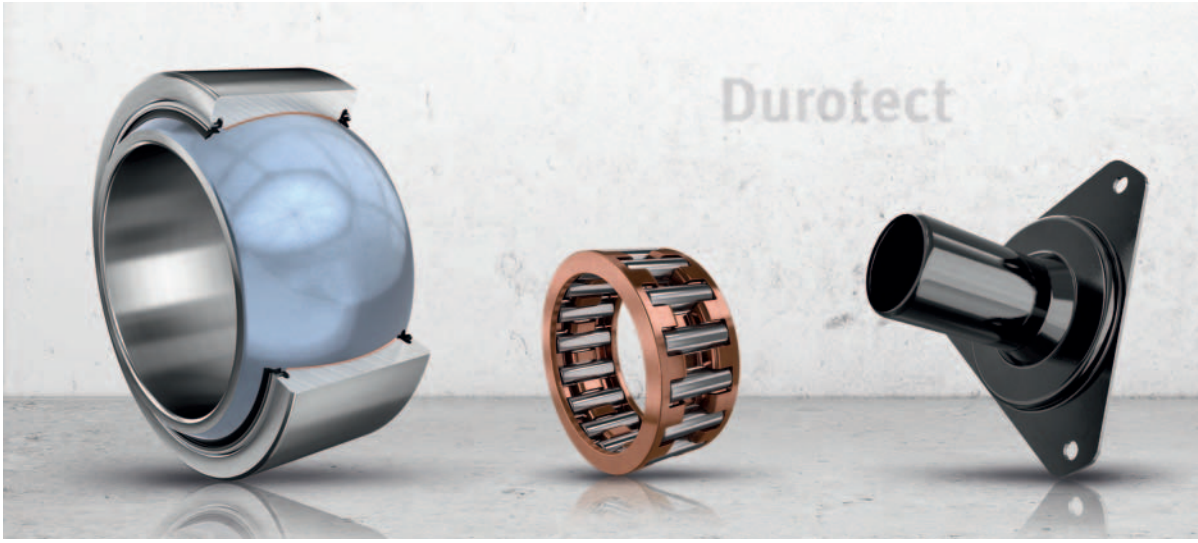


Figure 17
Tapered roller bearing system
for wind turbines

Figure 18
Application example
Offshore wind turbine



Wear protection and friction reduction

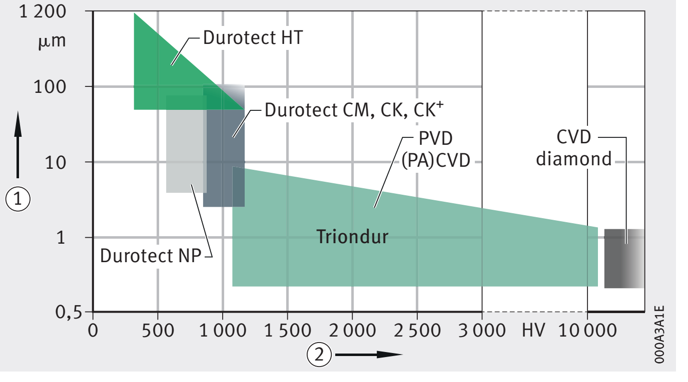
Durotect coating systems

The modular coating tool box from Schaeffler provides coatings matched to the specific application for wear protection and friction reduction of components under high tribological stress.

Furthermore, special Durotect coating systems offer additional functions such as emergency running lubrication, heat dissipation, protection against (tribo)chemical reactions (such as fretting corrosion) or short term corrosion protection (for example for transport).

Depending on the requirements of the component, the application process is carried out by means of chemical or electrochemical methods, as paint or by means of thermal spraying.

On the following pages, the coating systems are presented and application examples are given, *Figure 1* and starting page 36.



1 Layer thickness
2 Hardness

Figure 1
Comparison of coating systems

Abrasive and adhesive wear

High surface hardness is necessary for protection against abrasive wear. The contact partners can be protected here by particularly hard coatings.

Certain Durotect coating systems such as Durotect CM, Durotect CMT, Durotect CK, Durotect CK+ or Durotect NP can prevent abrasive wear, since their hardnesses are greater than those of the base material.

Adhesive wear occurs principally in contact partners with similar bonding characteristics, such as steel on steel. In order to prevent this wear mechanism, the type of bond can be modified by the suitable coating of a contact partner.

A typical example of adhesive wear is slippage damage.
This wear can be reduced by, for example, the targeted oxidation of the material surface, for example by means of black oxide coating.

In this respect, Schaeffler is setting new standards worldwide with the specially optimized black oxide coating method for the coating system Durotect B.

Durotect B Mixed iron oxide coating with optimized surface structure.

Coating process
- Chemical conversion.

Advantages, benefits
- No change to component geometry necessary
- Geometrically stable coating even under bending and compressive stress on the component
- Improved running-in behaviour
- Reduction in slippage damage
- Reduction in WEC-induced failures
- Improved resistance capability against surface-induced damage SIF (surface initiated fatigue)
- Improvement in friction characteristics in conditions of lubricant starvation.

Common applications
- Full complement cylindrical roller bearings
- Ball bearings
- Rolling elements and rings for bearings in wind turbines and railway drive bearings
- Various components in transmission and belt drive systems.

Characteristics

Characteristic	Coating
Composition	Mixed iron oxide
Colour	Dark brown to black
Layer thickness	≧ 0,5 μm

Figure 2
Single row cylindrical roller bearing
with Durotect B coating

Figure 3
Application example
Wind turbine

Durotect Z

Zinc phosphate coating.

Coating process

- Chemical conversion.

Advantages, benefits

- Temporary corrosion protection in oiled condition
- Prevention of fretting corrosion (tribocorrosion) in bearing seats
- Prevention of adhesive wear
- Reduced damage as a result of standstill marks (false brinelling).

Common applications

- Tapered roller bearings in rail vehicles
- Large size bearings (predominantly in the paper industry)
- Rolling bearing cages and drawn cups
- Retention layer for lubricants such as soaps, oils, greases or waxes
- Primer for paints and zinc flake coating systems
- Aid for cold forming (such as deep drawing).

Characteristics

Feature	Coating
Composition	Zinc phosphate
Corrosion resistance	≦ 24 h (with application of oil), according to salt spray test in accordance with DIN EN ISO 9227
Colour	Light grey to dark grey
Structure	Fine crystalline structure
Layer thickness	1 μm – 10 μm
Temperature resistance	≦ +250 °C

① Inner ring, outer ring and cage
with Durotect Z coating

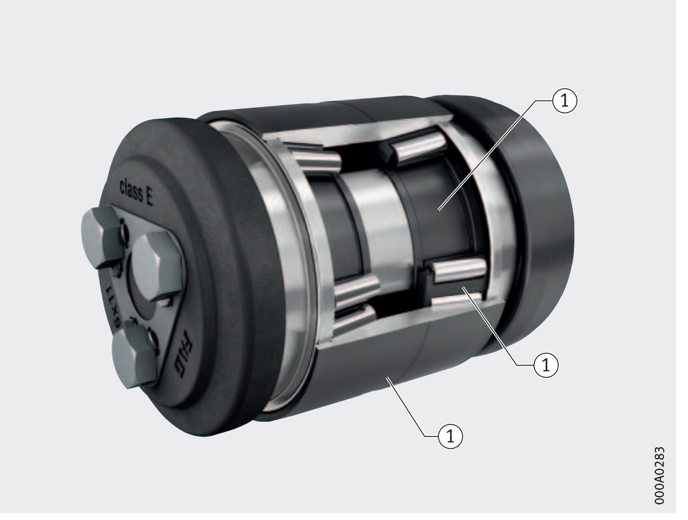


Figure 4
Tapered roller bearing unit
for application
in heavy freight transport

Figure 5
Application example
Rail

Durotect M

Manganese phosphate.

Coating process

- Chemical conversion.

Advantages, benefits

- Improvement in sliding and running-in behaviour
- Emergency running lubrication
- Wear protection of cages
- Prevention of adhesive wear
- Reduced damage as a result of standstill marks (false brinelling).

Common applications

- Sheet steel cages
- Inner ring bores in crankshaft bearings
- Primer for anti-friction paints and dry lubricants
- Running-in aid for tappets.

Characteristics

Feature	Coating
Composition	Manganese phosphate
Corrosion resistance	≦ 24 h (with application of oil), according to salt spray test in accordance with DIN EN ISO 9227
Colour	Dark grey to black
Structure	Fine crystalline structure
Layer thickness	1 μm – 10 μm
Temperature resistance	≦ +350 °C

Durotect M coating of inner and outer ring

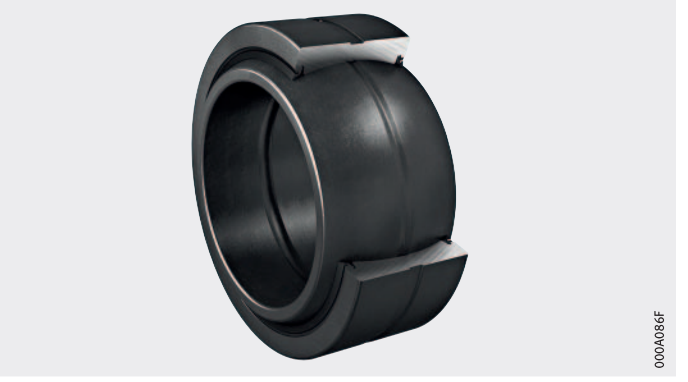


Figure 6
Spherical plain bearing
GE80-DO-2RS

Figure 7
Application example
Straddle truck

Durotect CK Columnar hard chromium coating.

Coating process

- Electroplating method
- Subsequent heat treatment recommended for high strength materials (against hydrogen embrittlement).

Advantages, benefits

- High wear resistance especially at the axial contact running points or on fit surfaces where fretting corrosion is expected
- Effective wear protection under mixed friction for small ball and roller bearings
- Low friction coefficient under mixed friction
- Reduced friction factors allow unconstrained displacements in non-locating bearings
- Higher corrosion resistance compared with rolling bearing steel (salt spray test in accordance with DIN EN ISO 9227).

Common applications

- Raceways in high precision bearings for aerospace applications
- Outside diameter of spindle bearings
- Complete coating of spherical roller bearings (rings, rolling elements) running in corrosive environments
- Protection against fretting corrosion on inside diameter
- Inner and outer rings of ball bearings for swash plates in helicopters
- Linear components in aggressive environments.

Characteristics

Feature	Coating
Composition	Hard chromium coating
Colour	Grey (matt)
Structure	Pearly structure (columnar)
Layer thickness	1 μm – 4 μm
Hardness	900 HV – 1 000 HV

Durotect CK coating on outer surfaces

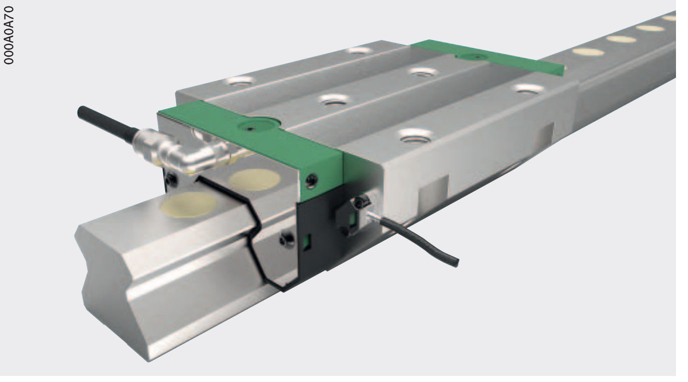
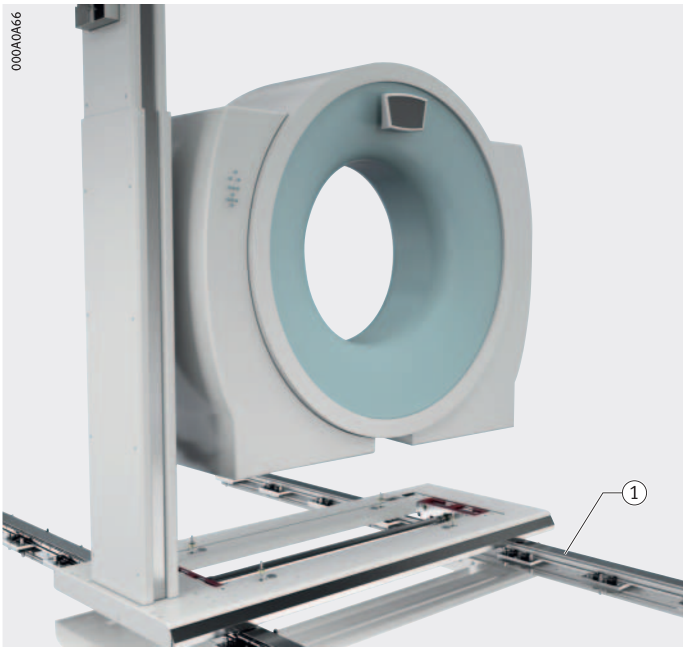


Figure 8
Linear recirculating roller bearing and guideway assembly RUE



1 Linear system with Durotect CK coating

Figure 9
Application example
Movable, rail-guided computer tomograph

Durotect CK+

Columnar thin dense chromium coating with mixed chromium oxide top layer.

Coating process

- Electroplating method
- Subsequent heat treatment recommended for high strength materials (against hydrogen embrittlement).

Advantages, benefits

- Mixed chromium oxide top layer acts as dry lubricant
- Improved running-in behaviour
- Improved friction and wear behaviour under lubricant starvation
- Extension of maintenance intervals in rail transport
- Improved corrosion protection in comparison with Durotect CK.

Common applications

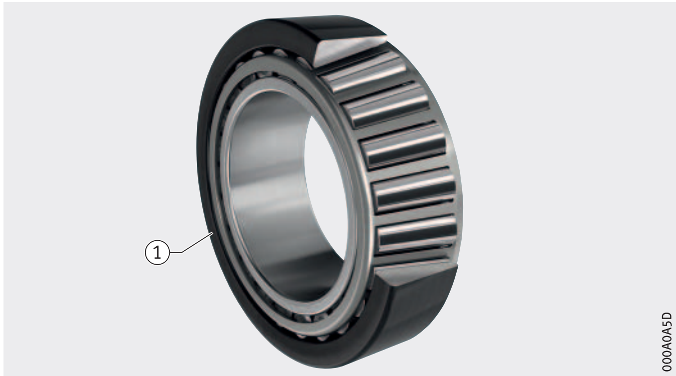
- Bearing components with corrosion protection requirement
- Traction motor bearings in rail vehicles
- Back-up rollers for multi-roll cold rolling mills
- Linear components.

Characteristics

Feature	Coating
Composition	Hard chromium with mixed chromium oxide top layer
Colour	Black
Structure	Smooth top layer made from mixed chromium oxide on columnar chromium layer
Layer thickness	
Columnar chromium layer	1 µm – 4 µm
Mixed chromium oxide	0,5 µm – 3 µm
Hardness	
Columnar chromium layer	900 HV – 1 100 HV
Mixed chromium oxide	150 HV – 200 HV

(1) Outer ring with Durotect CK+ coating

Figure 10
Tapered roller bearing 33112



Durotect CM, Durotect CMT

Microcracked hard chrome plating.

Coating process

- Electroplating method
- Subsequent heat treatment recommended for high strength materials (against hydrogen embrittlement).

Advantages, benefits

- Improved friction and wear behaviour under lubricant starvation
- Increased life due to hard surfaces as wear protection
- Good corrosion protection and high resistance to many chemicals with coating thicknesses greater than 30 μm
- Protection against tribocorrosion
- Protection against standstill marks (false brinelling)
- Low friction coefficient, good sliding characteristics
- Anti-adhesive characteristics.

Common applications

Applications with high wear load in automotive and industrial sectors:

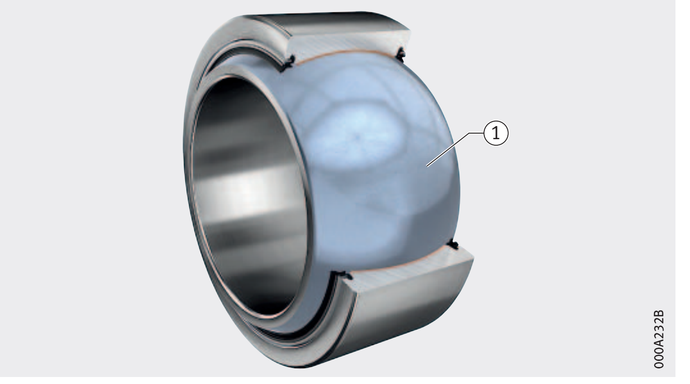
- spherical plain bearings
- shafts
- bearing and engine components.

Characteristics

Feature	Coating
Composition	Hard chrome plating
Colour	Silver (lustrous)
Structure	Microcracked hard chromium layer, initial roughness substantially maintained
Layer thickness	0,1 μm – 500 μm (depending on application)
Hardness	850 HV – 1 100 HV
Temperature resistance	Colour stable up to +300 °C Hardness stable up to +700 °C

1 Durotect CMT-coated inner ring

Figure 11
Radial spherical plain bearing GE60-UK-2TS, maintenance-free



1 Durotect CMT-coated spherical plain bearing

Figure 12
Application example with high wear load: spherical plain bearings in excavator

Durotect NP

Nickel-phosphorus alloy.

Coating process

- Autocatalytic chemical deposition.

Advantages, benefits

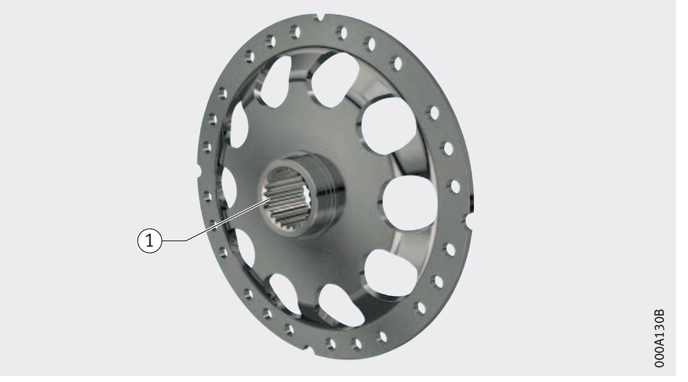
- Almost uniform layer distribution over entire component surface
- Combination of wear and corrosion protection
- Corrosion protection for maritime applications
- High chemical resistance to aggressive media
- Compatible with food under certain conditions
- Through inclusion of PTFE or hard substance particles (diamond, SiC), friction and wear characteristics can be matched
- Increased hardness by means of thermal post-treatment.

Common applications

- Guide rings of spherical roller bearings
- Spherical plain bearings
- Housings for the food industry
- Needle roller and cage assemblies
- Thrust washers.

Characteristics

Characteristic	Coating
Composition	Nickel-phosphorus
Colour	Metallic silver, slight yellow tinge
Layer thickness	
With corrosion protection	5 μm – 75 μm (non-maritime application) > 75 μm (maritime application)
With tribological stress	> 5 μm (depending on requirement)
Phosphorus content	
2% – 5%	Wear protection
6% – 9%	General application for wear and corrosion resistance
10% – 13%	Corrosion protection
Hardness (depending on phosphorus content)	
Standard	500 HV – 600 HV0,1
With heat treatment	750 HV – 1000 HV0,1
Magnetism	Magnetic effect up to 9% phosphorus



(1) Inner tooth set with Durotect NP coating

Figure 13
Clutch hub

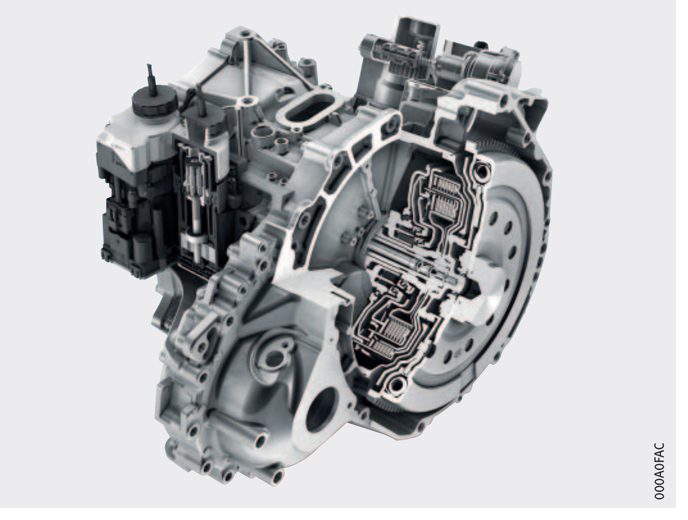


Figure 14
Application example
Clutch system

Durotect C

Copper coating.

Coating process

- Electroplating method
- Subsequent heat treatment necessary for high strength materials (against hydrogen embrittlement).

Advantages, benefits

- Improvement in tribological characteristics
- Improvement in emergency running behaviour in conditions of lubricant starvation
- Temperature dissipation from functional area
- Use at high speeds and velocities
- Increased electrical conductivity.

Common applications

- Sheet steel cages for connecting rod bearing arrangements in two-stroke and four-stroke engines
- Cages for aerospace applications
- Large size bearing cages
- Plug contacts.

Characteristics

Feature	Coating
Composition	Pure copper layer
Colour	Copper coloured
Layer thickness	2 μm – 50 μm (depending on requirement)

① Cage with Durotect C coating

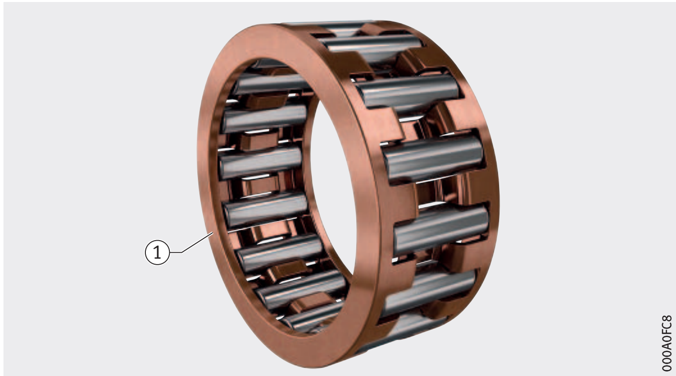


Figure 15
Needle roller and cage assembly for connecting rod bearing arrangements

Figure 16
Application example
Motorcycle

Durotect S

Silver coating.

Coating process

- Electroplating method
- Subsequent heat treatment necessary for high strength materials (against hydrogen embrittlement).

Advantages, benefits

- Improvement in tribological characteristics
- Improvement in emergency running behaviour in conditions of lubricant starvation
- Temperature dissipation from functional area
- Use at high speeds and velocities
- Improved tribological performance in comparison with Durotect C
- Higher electrical conductivity.

Common applications

- Sheet steel cages for connecting rod bearing arrangements in two-stroke and four-stroke engines
- Cages for aerospace applications
- Large size bearing cages.

Characteristics

Characteristic	Coating
Composition	Silver coating on copper bonding layer
Colour	Silver
Layer thickness	$\geqq 2\ \mu m$ (depending on requirement)

FAG three point contact bearing

Figure 17
Engine bearings for aircraft

Figure 18
Application example
Aircraft, engine

Durotect H

Metallic coating for dimensional correction (depending on application).

Coating process
- Thermal spraying.

Advantages, benefits
- Material application for dimensional correction (recreation of damaged or worn surfaces)
- Additional increase in wear resistance.

Common applications
- Large size bearings.

Characteristics

Feature	Coating
Composition	Metallic coating, coating material dependent on specific application
Colour	Metallic
Layer thickness	Selectable, dependent on necessary dimensional correction
Hardness	Selectable, depending on hardness of base material

Durotect HT

Metallic coating.

Coating process

- Thermal spraying.

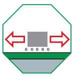
Advantages, benefits

- Increase in wear resistance of surfaces under high stress
- Increase in static friction coefficient
- Setting of dynamic friction coefficient.

Common applications

Engine components:

- Camshaft phasing unit
- Sprockets.



Characteristics

Feature	Coating
Composition	Metallic coating, coating material dependent on specific application (such as CrO_2, WC-Co, SiC)
Colour	Metallic (depending on coating material used)
Layer thickness	50 μm – 500 μm (depending on application)
Hardness	> 650 HV, depending on coating material; hardnesses > 1 000 HV also achievable

Durotect HA

Aluminium oxide layer on aluminium alloys.

Coating process

- Electrolytic oxidation (anodizing).

Advantages, benefits

- Increase in wear resistance of aluminium and aluminium alloys through increase in surface hardness
- Increased chemical resistance
- Improved sliding characteristics as a function of running partner
- Increased corrosion protection
- Very uniform layer thickness distribution (excluding narrow gaps).

Common applications

- Aluminium sliding sleeves in clutch bearings
- Aluminium cages for aerospace applications
- Bonding layer for paints as a result of high surface roughness in uncompressed Durotect HA type
- Housings for hydraulic clutch systems.

Characteristics

Characteristic	Coating
Composition	Aluminium oxide
Structure	Capillary pillar structure
Colour	Silver to mouse grey (matt, depending on alloy); in uncompressed type, entire oxide layer can be coloured as required
Layer thickness	2 μm – 25 μm (of which 50% as volume increase); wear protection at and above 15 μm
Hardness	350 HV – 600 HV (mixed hardness, depending on alloy)
Temperature resistance	$<$ +400 °C

Figure 19
Aluminium cages
with Durotect HA coating

Figure 20
Application example
Brake flap drive on aircraft wing

Wear protection and friction reduction

Durotect CT

Copper-tin layer (bronze).

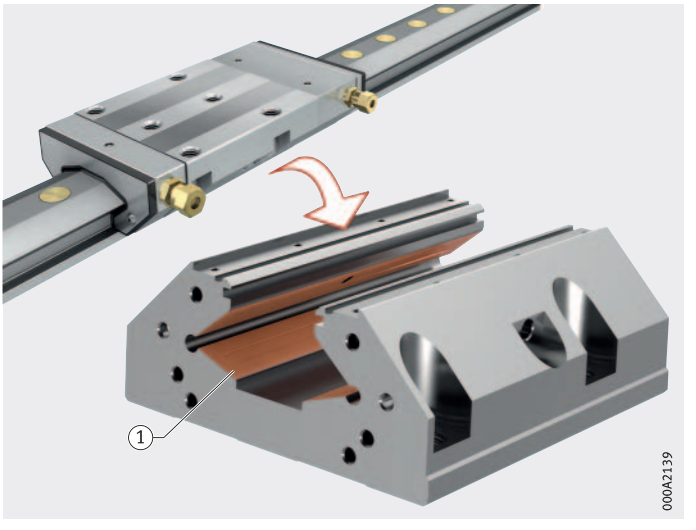
Coating process
- Electroplating method

Advantages, benefits
- Increase in security against smearing and fretting under overload or lubricant starvation (emergency running).

Common applications
- Hydrostatic linear systems.

Characteristics

Feature	Coating
Composition	Copper-tin (bronze)
Colour	Red-yellow (bronze)
Layer thickness	5 µm – 90 µm
Hardness	≈ 300 HV



1 Sliding surface with Durotect CT coating

Figure 21
Hydrostatic compact guidance of linear systems

Durotect P

Polymer-based coating.

Coating process

- Dipping method:
  – complete coating of individual components
- Spraying method:
  – complete or partial coating
- Curing temperature dependent on paint system,
  from room temperature to approx. +250 °C.

Advantages, benefits

- Increase in sliding capability by means of solid lubricants (MoS_2, graphite, PTFE) in unlubricated state.
  Solid lubricants are released when layer is subjected to load
- Reduction in friction coefficient to $\mu < 0{,}1$ under axial displacement of bearing rings
- Current insulation in low voltage range
- Sliding aid for pressing-in
- Additional function:
  – corrosion protection.

Common applications

- Spherical roller bearing outer ring outside surface
- Cages
- Guide sleeves.

Characteristics

Feature	Coating
Composition	Polymer-based coating
Colour	Black
Layer thickness	15 μm – 100 μm

Full surface Durotect P coating

Figure 22
Guide tube
for the concentric guidance
of a clutch release bearing

Coating systems for surfaces subjected to high tribomechanical stresses

Coating systems for surfaces subjected to high tribomechanical stresses

Wear protection and friction reduction by Triondur coating systems

With the continuing increases in energy efficiency not only in modern combustion engines but also in the entire energy chain (from a wind turbine gear to any moving part in a vehicle), there are increasing demands on the tribological load carrying capacity of components.

With the aid of modern PVD and PACVD coating processes as used for the Triondur coatings from Schaeffler, it is possible to achieve significant increases in the performance capability of components subjected to high tribological stresses. This gives potential for increased life, minimized friction and lightweight design. Triondur coating systems thus make an active contribution to conservation of the environment and resources as well as sustainability.

Triondur coating systems are created under vacuum by means of physical gas phase deposition (PVD = Physical Vapor Deposition) and plasma-assisted chemical gas phase deposition (PACVD = Plasma assisted Chemical Vapor Deposition). Through selection of the coating composition and the deposition process, Triondur coating systems can be ideally matched to the specific application. From elastic coating systems for rolling contacts to extremely hard wear protection coatings, as well as chemical resistance through to targeted reactions for lubricant film formation with selected oil additives, there are many possibilities for optimization.

Triondur coating systems are more than just a coating: they are coating systems that, on the basis of individually matched coating processes and components of optimized design, take account of all necessary aspects from manufacture to application.

Coating systems for surfaces subjected to high tribomechanical stresses

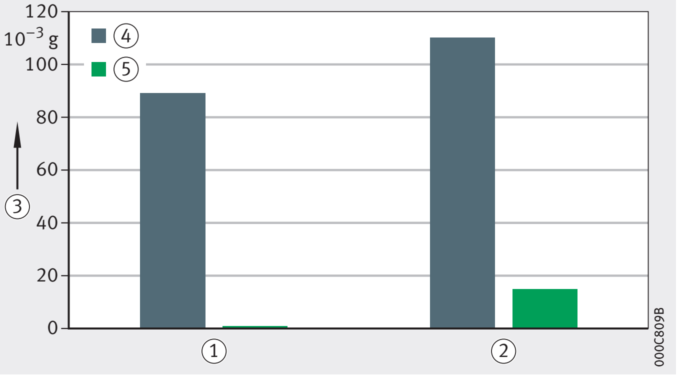
Triondur coating systems for rolling bearings

In rolling bearings, the use of coated rolling elements can achieve a significant increase in operating life, especially if the bearing is subjected in the application to slippage and lubricant starvation.

Coated cylindrical rollers that have been tested under extreme lubricant starvation in a test rig run, exhibit significantly improved results in comparison with uncoated reference parts, *Figure 1*. Gravimetric evaluation of the wear shows that the use of Triondur C has almost eliminated wear of the rolling element, *Figure 2*. At the same time, wear of the uncoated axial washers has been significantly reduced.

A further application for Triondur coating systems in rolling bearings is the coating of large end faces of tapered rollers in order to reduce friction and wear in contact with the rib of the inner ring.

Coating of the outer ring of stud type track rollers, *Figure 3*, page 63, increases not only the operating life of the track roller but also that of the running partner, which is often much more costly. As a result, the additional costs incurred by coating can be amortised within a very short space of time.

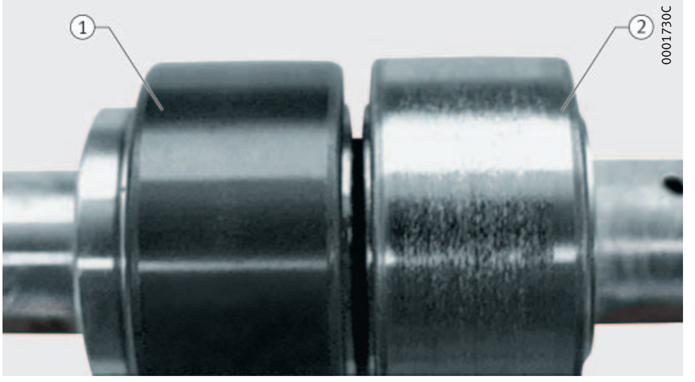


1 Rolling elements
2 Axial washers
3 Wear
4 Uncoated
5 Coated

Figure 1
Test rig run
with extreme lubricant starvation

1 Uncoated
2 Triondur C coated

Figure 2
Rolling element after test rig run



① DLC (Triondur C) coating, no wear

② Without coating, adhesive wear

Figure 3
Stud type track rollers, with and without coating

Triondur coating systems for engine components

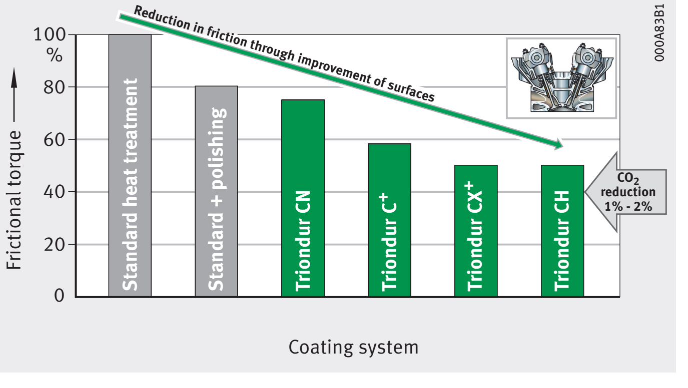
Through the use of Triondur coating systems, it has been possible to continuously reduce friction at the tappet/cam contact in the valve train, *Figure 4*.

Until about 15 years ago, the use of purely heat treated tappets was the state of the art. Through the use and continuous development of Triondur coating systems, it has been possible to reduce frictional torque using Triondur CH by up to 50%. This corresponds to a reduction in CO_2 emissions of between 1% and 2%.

Triondur coating systems are used not only on mechanical tappets but also on other contacts subjected to strong loads.

Examples:

- cam rollers and valve contact surfaces for roller type finger followers
- plain bearing components
- pistons in the high pressure area of fuel pumps.



Example:
engine speed n = 2 000 min^{-1} and oil temperature +80 °C

Figure 4
Friction reduction in valve train by means of Triondur coating systems

Coating systems for surfaces subjected to high tribomechanical stresses

Triondur C

Metal-containing hydrogenated amorphous carbon coating.

Coating process

- PVD method.

Advantages, benefits

- High level of protection against abrasive and adhesive wear together with preservation of the friction partner
- Dry friction against steel is reduced by up to 80%
- If only one friction surface is coated, the operating life of the entire tribological system is increased considerably
- Due to its highly ductile coating structure, Triondur C can withstand the high contact pressures that occur in rolling bearing applications.

Common applications

- Bearing components such as rolling elements, inner rings, outer rings and axial bearing washers
- Yoke and stud type track rollers.

Characteristics

Feature	Coating
Composition	a-C:H:Me (functional layer)
Colour	Anthracite
Layer thickness	0,5 μm – 4 μm
Friction reduction	Up to 80% with DLC/steel in comparison with steel/steel (in dry state)
Hardness	$>$ 1 200 HV

Barrel roller with Triondur C coating

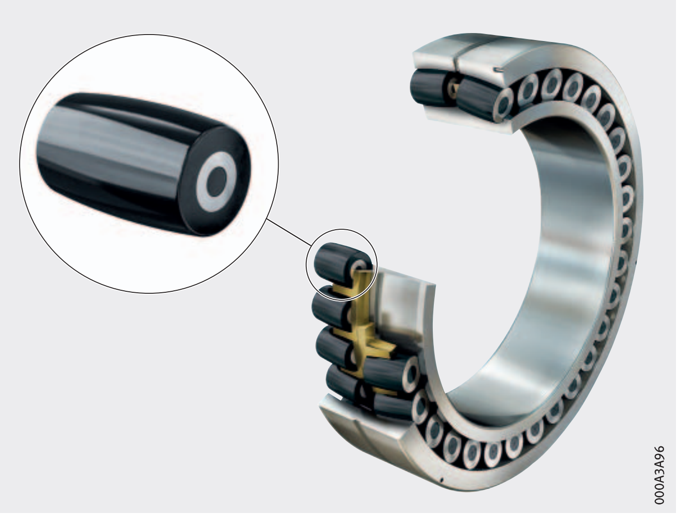


Figure 5
Asymmetrical spherical roller bearing for the bearing arrangement of the rotor shaft in a wind turbine

Figure 6
Application example
Spherical roller bearings in wind turbines

Coating systems for surfaces subjected to high tribomechanical stresses

Triondur C+

Hydrogenated amorphous carbon coating.

Coating process

- PVD and PACVD methods.

Advantages, benefits

- Coating systems for very high tribomechanical stresses
- High resistance to abrasive wear and high level of protection against adhesive wear
- Very high mechanical strength
- Highly suitable for components subjected to high tribological stresses with lubricant starvation.

Common applications

- Engine components such as tappets or finger followers
- Injection components such as pump and control pistons, nozzle needles.

Characteristics

Feature	Coating
Composition	a-C:H (functional layer)
Colour	Black
Layer thickness	2 μm – 4 μm
Friction reduction	Up to 85% with DLC/steel in comparison with steel/steel (in dry state)
Hardness	> 2 000 HV

Figure 7
Switching hydraulic tappet

Triondur CX+

Modified hydrogenated amorphous carbon coating.
Triondur CX+ is a modified and nanostructured coating system.

Coating process

- PVD and PACVD methods.

Advantages, benefits

- Very precise adaptation possible to the tribological requirements present
- Best combination of friction minimization, tribochemical resistance and wear protection of all coating systems.

Common applications

Engine components:

- finger followers
- tappets
- finger follower lever stud
- cages in piston drive.

Characteristics

Feature	Coating
Composition	a-C:H:X (functional layer)
Colour	Black
Layer thickness	2 μm – 4 μm
Friction reduction	Up to 85% with DLC/steel in comparison with steel/steel (in dry state)
Hardness	> 2 000 HV

(1) Sliding surfaces with Triondur CX+ coating

Figure 8
Tappet TSTM

(1) Outer lever with Triondur CX+ coating

Figure 9
Switchable finger follower

Coating systems for surfaces subjected to high tribomechanical stresses

Triondur CH

Tetrahedral hydrogen-free amorphous carbon coating.

Coating process

- PVD method.

Advantages, benefits

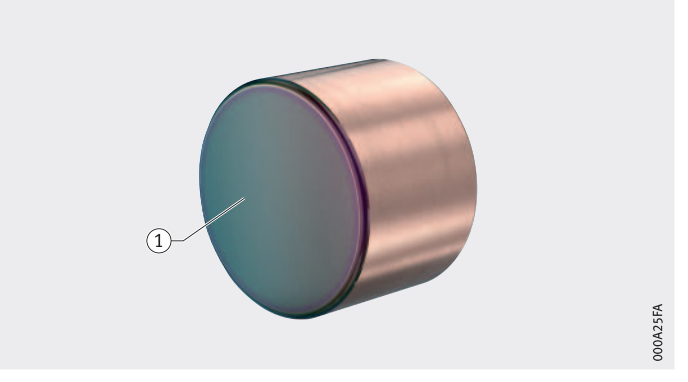
- Due to its high hardness, Triondur CH has the highest wear resistance of all Triondur coatings
- In dedicated tribological systems with appropriately matched lubricants, Triondur CH gives the most effective action and provides the maximum reduction in friction as well as maximum protection against wear.

Common applications

- Tappets.

Characteristics

Feature	Coating
Composition	ta-C (functional layer)
Colour	Greenish
Layer thickness	0,5 μm – 1 μm
Friction reduction	Up to 85% with DLC/steel in comparison with steel/steel (in dry state)
Hardness	> 4 000 HV



1 Sliding surfaces with Triondur CH coating

Figure 10
Tappet with Triondur CH coating

Triondur CN

Chromium nitride coating.

Coating process

- PVD method.

Advantages, benefits

- Due to its nanocrystalline structure, the chromium nitride coating has particularly high hardness and ductility
- The adaptive, very smooth surface is maintained even during operation due to its high wear resistance and very good oil wetting behaviour
- Significant reduction in friction between the contact partners
- Triondur CN is the right choice for parts subjected to high stresses with adequate oil provision.

Common applications

- Engine components.

Characteristics

Feature	Coating
Composition	Chromium nitride (functional layer)
Colour	Silver
Layer thickness	1 μm – 4 μm
Friction reduction	Up to 20% with Triondur CN/steel in comparison with steel/steel (in dry state)
Hardness	> 2 200 HV

Figure 11
Tappet with Triondur CN coating

Coating systems for surfaces subjected to high tribomechanical stresses

Triondur TN

Titanium nitride coating.

Coating process

- PVD method.

Advantages, benefits

- High protection against abrasive wear
- Wear protection of components in sliding contact.

Common applications

- Wear protection of ribs in engine bearings, especially due to the cage running in contact with the rib.

Characteristics

Feature	Coating
Composition	TiN (functional layer)
Colour	Gold coloured
Layer thickness	2 μm – 5 μm
Friction reduction	Up to 20% with Triondur TN/steel in comparison with steel/steel (in dry state)
Hardness	> 2 000 HV

Figure 12
Contact running surfaces of inner ring with Triondur TN coating

Figure 13
Application example Aerospace

Triondur MN

Nano-structured molybdenum nitride coating with metal doping.

Coating process

- PVD method.

Advantages, benefits

- Wear protection and minimization of friction under challenging lubrication conditions
- High hardness and very low friction coefficient in comparison with other nitridic coatings
- Very high temperature resistance up to +600 °C
- High tribochemical wear resistance.

Common applications

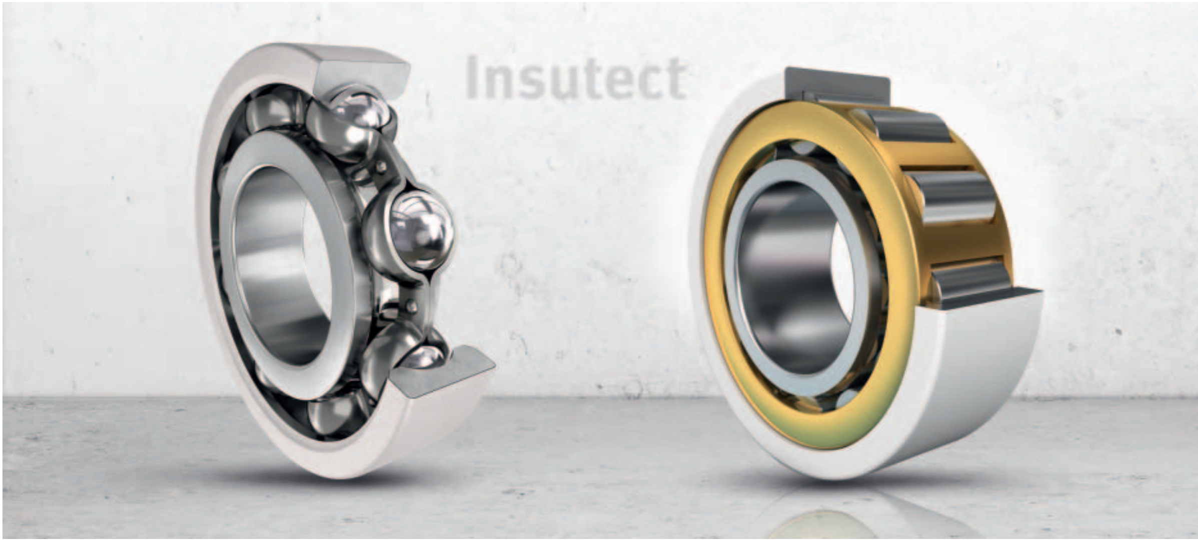
- Rolling bearing components
- Plain bearing components
- Engine components.

Characteristics

Feature	Coating
Composition	CuMoN (functional layer)
Colour	Silver
Layer thickness	1 μm – 4 μm
Friction reduction	Up to 85% with Triondur MN/steel in comparison with steel/steel (in dry state)
Hardness	> 2 200 HV

1 Triondur MN coated cam roller

Figure 14
Cam roller in finger follower



Current insulation

Current insulation

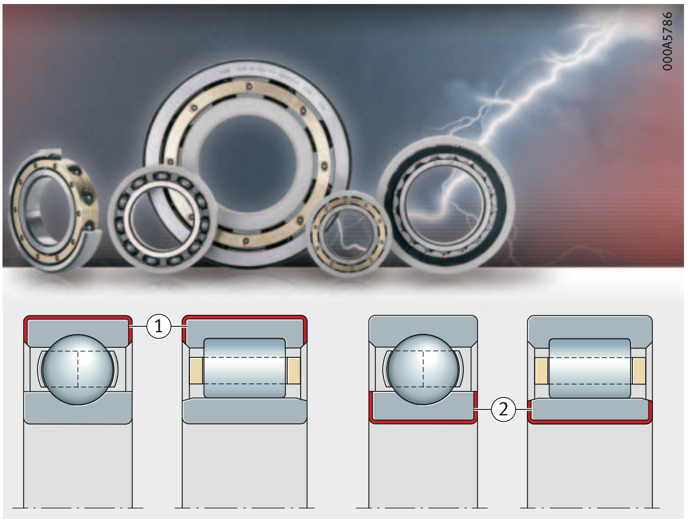
Insutect coating systems

When rolling bearings are used in wheelsets and traction motors for rail vehicles, direct current and alternating current motors as well as generators, current passage may occur. Under unfavourable conditions, this leads to damage to the raceways and rolling elements.

Protection against current passage

In order to prevent failure of the bearing, current-insulating bearings are used, *Figure 1*. This interrupts the passage of current between the housing and shaft. Electrical insulation is possible by, for example, an insulation coating on components (outer or inner ring).

! In selection of the coating, the electrical and mechanical load profile of the application must be taken into consideration.



① Outer ring with coating
② Inner ring with coating

Figure 1
Current-insulating example bearings

Insulation coatings

Depending on the requirements of the application, various Insutect A coating variants can be offered from the modular coating concept. The essential coating characteristics and areas of application of the Insutect A coating system are described below.

Benefits of insulation coating

The advantages include the following:

- A high level of insulation is provided, even in a damp environment
- The external dimensions of the bearing correspond to DIN 616. Coated bearings are therefore interchangeable with standard bearings
- Different coating thicknesses, matched to the planned application, can be applied. The puncture strength of thin layers is up to DC 500 V, while the puncture strength of thick layers is up to at least DC 3000 V.

Insutect A

Ceramic coating made from aluminium oxide Al_2O_3 with sealing.

Coating process

- Plasma spray method
- The insulation coating comprises aluminium oxide which is applied using the plasma spray method. The porous coating is sealed by a resin to give protection against the ingress of moisture. In the case of the outer ring, it is applied to the outer face and the lateral faces, while in the case of the inner ring it is applied to the lateral faces and the bore, *Figure 1*, page 73.

Advantages, benefits

- Current insulation dependent on the layer thickness, including in the case of damp environments
- Direct current resistance $> 50\ M\Omega$, no current puncture up to DC 3 000 V
- Alternating current resistance at f = 50 Hz is in the range between 0,15 $M\Omega$ and 1,5 $M\Omega$
- Additional corrosion protection
- The external dimensions of the bearing correspond to DIN 616. Coated bearings are therefore interchangeable with standard bearings.

Common applications

- Bearings for electric motors
- Traction motor bearings
- Wheelset bearing arrangements
- Bearings in generators
- Marine propulsion systems.

Characteristics

Feature	Coating
Composition	Ceramic coating made from aluminium oxide Al_2O_3 with sealing
Colour	Light grey to beige (matt)
Layer thickness	120 μm – 200 μm (higher upon customer request)

Outer ring with Insutect A coating

① Cylindrical roller bearing
② Deep groove ball bearing

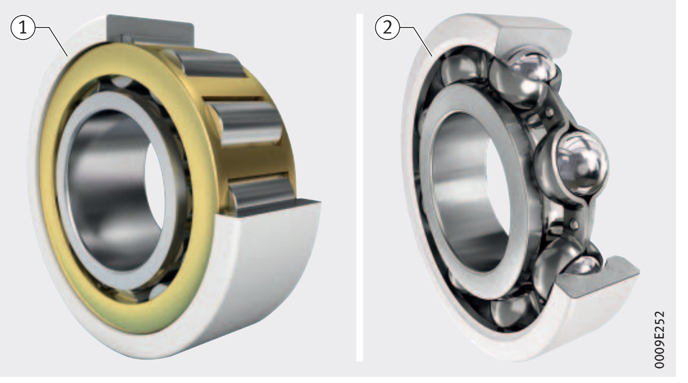


Figure 2
Current-insulating bearings

Figure 3
Application example
Rail

Further information

- TPI 206, Current-insulating Bearings
- PDB 53, Coating System for Current Insulation: Insutect A
- Download and ordering at http://medien.schaeffler.com.

Sensor technology, measurement of force and torque

Sensor technology, measurement of force and torque

Sensotect coating system

With the innovative thin film sensor technology Sensotect, Schaeffler is introducing intelligent coating systems into the automotive and industrial sectors.

Sensotect allows, with neutral effect on design envelope and in real time, measurement of the load condition at locations where classic sensors such as adhesive bonded strain gauges cannot be used.

The functionality is achieved by means of a strain-sensitive metal coating with a thickness measured in the submicrometre range that is structured by microprocessing. This measurement structure allows the continuous measurement of force and torque during operation.

With the aid of modern thin film technology, the component becomes a sensor and the sensor becomes a component. Due to this measurement technology, it is possible for example to determine the torque of drive shafts or in vehicle gearboxes very quickly and precisely. Engine power can then be set exactly to the load occurring. In this way, Sensotect makes an important contribution to saving energy and fuel and ultimately helps to reduce CO_2 emissions.

Both the automotive and industrial sectors offer numerous areas of application in which the integrated sensor coating can make a contribution to digitalization.

Sensor technology, measurement of force and torque

Sensotect

Multi-layer system comprising insulation layer and strain-sensitive metal coating.

Coating process

- PVD method and microstructure processing.

Advantages, benefits

- Very precise measurement of force and torque on functional components where the possibilities associated with conventional methods are limited
- Sensor layer is deposited directly on the substrate surface
- Measurement possible on 2D and 3D geometries
- Sensor technology with neutral effect on design envelope
- No use of adhesives or transfer polymers
- Continuous measurement of force and torque during operation
- High sensitivity with very little deviation in hysteresis and linearity
- No temperature deviations
- No ageing effects
- Wireless transfer of data and energy (telemetry).

Common applications

- Bearings
- Axles
- Shafts
- Individual bending beams.

Characteristics

Feature	Coating
Composition	Multi-layer system comprising insulation coating and strain-sensitive metal coating
Structure	Meander structure
Colour	Light grey to beige (matt)
Layer thickness	approx. 10 μm

Figure 1
Wheel bearing
with Sensotect coating

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