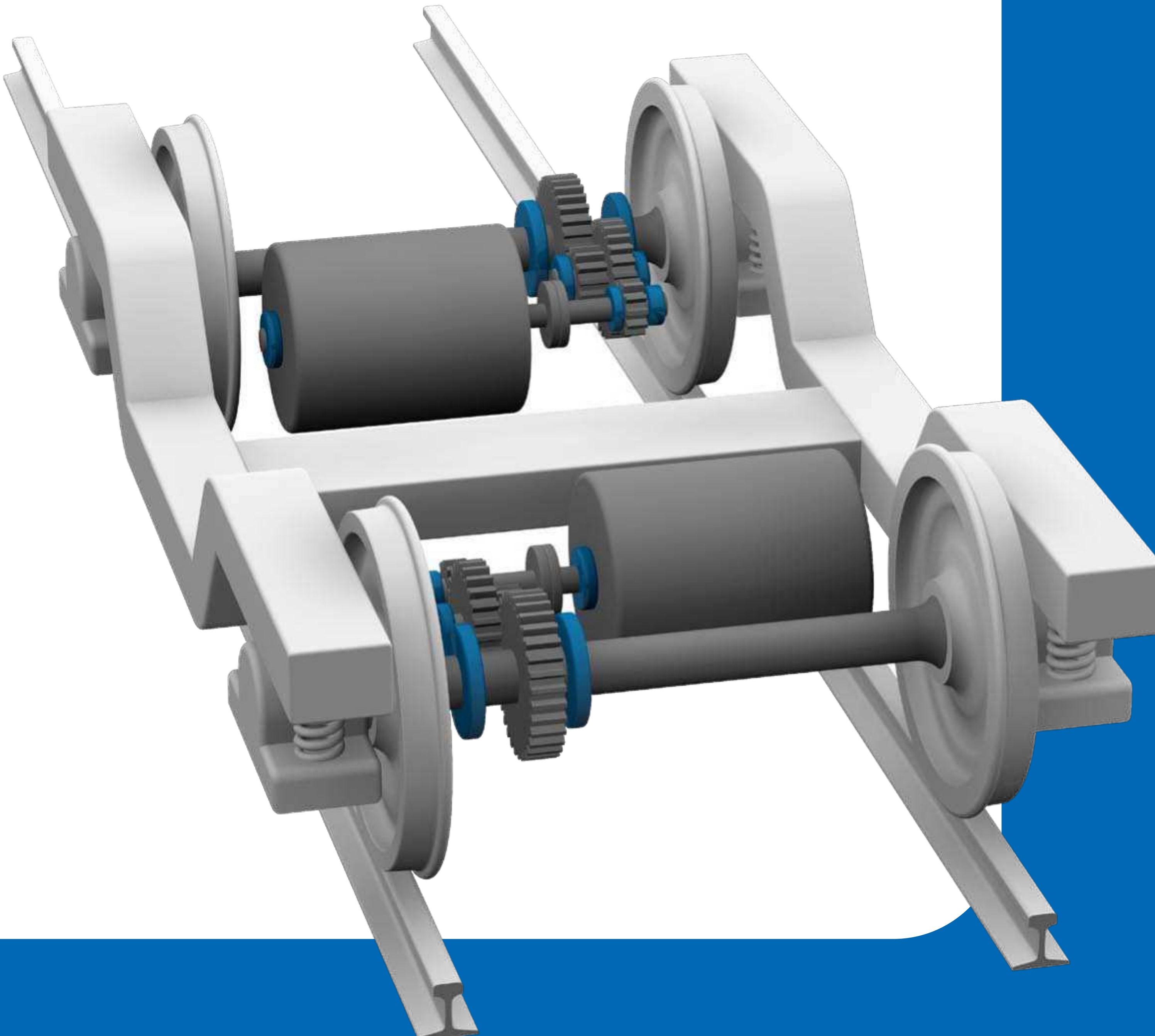
Railway technical handbook

Volume 2

Drive systems: traction motor and gearbox bearings, sensors, condition monitoring and services



Market value of the book 40 EUR

PUB 42/P7 13085 EN · September 2012

ISBN 978-91-978966-6-5

Railway technical handbook

Volume 2

Drive systems: traction motor and gearbox bearings, sensors, condition monitoring and services

A handbook for the industrial designer and operator

This Railway technical handbook, Volume 1, is available as hardcopy or for iPad usage in the App Store / Productivity / SKF

Foreword

This SKF Railway technical handbook – volume 2 – covers drive system solutions such as traction motor and gearbox bearings and bearing units, sensors, condition monitoring and services. The handbook has been developed with various industry specialists in mind.

For designers, this handbook provides the information needed to optimize a variety of design features.

For railway operators, there are recommendations on how to maximize bearing service life through appropriate mounting, maintenance and condition monitoring.

The recommendations are based on experience gained by SKF during decades of close cooperation with the railway industry all over the world. This experience, along with customer input, strongly influences product development within SKF, leading to the introduction of new products and enhanced variants.

General information about the selection and life calculations of ball and roller bearings is provided in SKF catalogues or online at skf.com/bearings. This technical handbook deals with questions arising from the use of special solutions for traction motors and gearbox bearings. Data from SKF catalogues are only repeated here when it is necessary for the sake of clarity.

Additional railway related topics are mentioned in the Railway technical handbook – volume 1 – published in 2010, which focuses on axleboxes, wheelset bearings, sensors, condition monitoring, subsystems and services.

Further information can be found at www.railways.skf.com

Gottfried Kuře and team

The SKF brand now stands for more than ever before, and means more to you as a valued customer.

While SKF maintains its leadership as a high-quality bearing manufacturer throughout the world, new dimensions in technical advances, product support and services have evolved SKF into a truly solutions-oriented supplier, creating greater value for customers.

These solutions enable customers to improve productivity, not only with breakthrough application-specific products, but also through leading-edge design simulation tools and consultancy services, plant asset efficiency maintenance programmes, and the industry's most advanced supply management techniques.

The SKF brand still stands for the very best in rolling bearings, but it now stands for much more.

SKF – the knowledge engineering company

Contents

4 INSOCOAT and hybrid bearings

5 Traction motor bearing units

6 Bearing calculation

7 Bearing investigation

8 Sensors

9 Condition monitoring

10 Services

11 Applications

Index

SKF – the knowledge engineering company

From the company that invented the self-aligning ball bearing more than 100 years ago, SKF has evolved into a knowledge engineering company that is able to draw on five technology platforms to create unique solutions for its customers. These platforms include bearings, bearing units and seals, of course, but extend to other areas including: lubricants and lubrication systems, critical for long bearing life in many applications; mechatronics that combine mechanical and electronics knowledge into systems for more effective linear motion and sensorized solutions; and a full range of services, from design and logistics support to condition monitoring and reliability systems.

Though the scope has broadened, SKF continues to maintain the world's leadership in the design, manufacture and marketing of rolling bearings, as well as complementary products such as radial seals. SKF also holds an increasingly important position in the market for linear motion products, high-precision aerospace bearings, machine tool spindles and plant maintenance services.

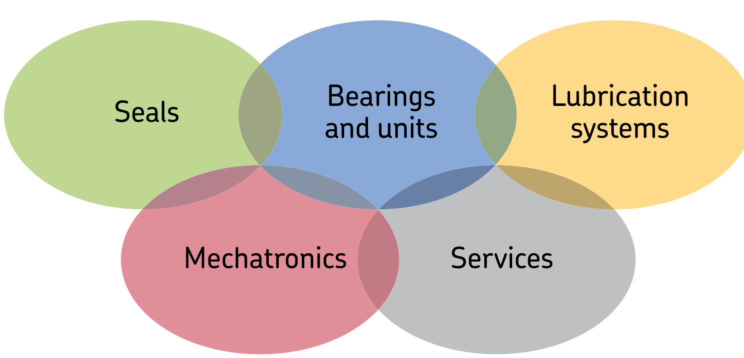
The SKF Group is globally certified to ISO 14001, the international standard for environmental management, as well as OHSAS 18001, the health and safety management standard. Individual divisions have been approved for quality certification in accordance with ISO 9001 and other customer specific requirements.

With over 120 manufacturing sites worldwide and sales companies in 70 countries, SKF is a truly international corporation. In addition, our distributors and dealers in some 15 000 locations around the world, an e-business marketplace and a global distribution system put SKF close to customers for the supply of both products and services. In essence, SKF solutions are available wherever and whenever customers need them. Overall, the SKF brand and the corporation are stronger than ever. As the knowledge engineering company, we stand ready to serve you with world-class product competencies, intellectual resources, and the vision to help you succeed.

© Airbus – photo: e^{x}m company, H. Goussé

Evolving by-wire technology
SKF has a unique expertise in the fast-growing by-wire technology, from fly-by-wire, to drive-by-wire, to work-by-wire. SKF pioneered practical fly-by-wire technology and is a close working partner with all aerospace industry leaders. As an example, virtually all aircraft of the Airbus design use SKF by-wire systems for cockpit flight control.

SKF is also a leader in automotive by-wire technology, and has partnered with automotive engineers to develop two concept cars, which employ SKF mechatronics for steering and braking. Further by-wire development has led SKF to produce an all-electric forklift truck, which uses mechatronics rather than hydraulics for all controls.



Harnessing wind power
The growing industry of wind-generated electric power provides a source of clean, green electricity. SKF is working closely with global industry leaders to develop efficient and trouble-free turbines, providing a wide range of large, highly specialized bearings and condition monitoring systems to extend equipment life of wind farms located in even the most remote and inhospitable environments.

Working in extreme environments
In frigid winters, especially in northern countries, extreme sub-zero temperatures can cause bearings in railway axleboxes to seize due to lubrication starvation. SKF created a new family of synthetic lubricants formulated to retain their lubrication viscosity even at these extreme temperatures. SKF knowledge enables manufacturers and end user customers to overcome the performance issues resulting from extreme temperatures, whether hot or cold. For example, SKF products are at work in diverse environments such as baking ovens and instant freezing in food processing plants.

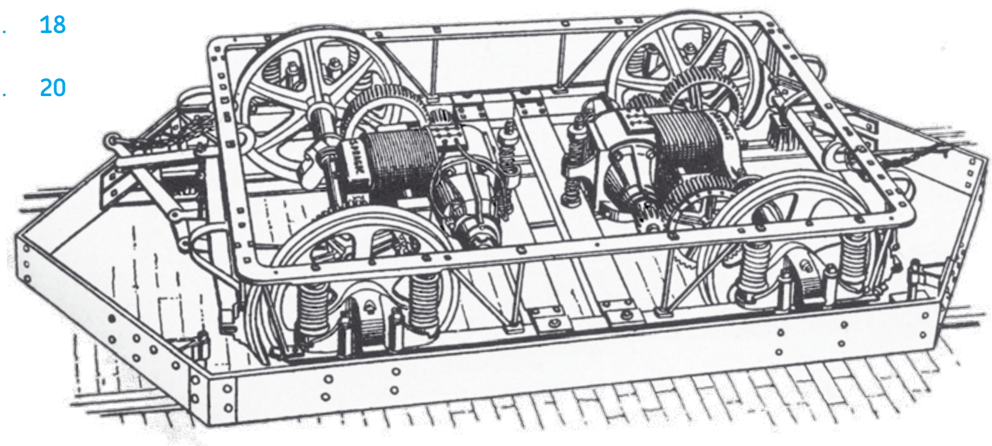
Developing a cleaner cleaner
The electric motor and its bearings are the heart of many household appliances. SKF works closely with appliance manufacturers to improve their products' performance, cut costs, reduce weight, and reduce energy consumption. A recent example of this cooperation is a new generation of vacuum cleaners with substantially more suction. SKF knowledge in the area of small bearing technology is also applied to manufacturers of power tools and office equipment.

Maintaining a 350 km/h R&D lab
In addition to SKF's renowned research and development facilities in Europe and the United States, Formula One car racing provides a unique environment for SKF to push the limits of bearing technology. For over 60 years, SKF products, engineering and knowledge have helped make Scuderia Ferrari a formidable force in F1 racing. (The average racing Ferrari utilizes around 150 SKF components.) Lessons learned here are applied to the products we provide to automakers and the aftermarket worldwide.

Delivering Asset Efficiency Optimization
Through SKF Reliability Systems, SKF provides a comprehensive range of asset efficiency products and services, from condition monitoring hardware and software to maintenance strategies, engineering assistance and machine reliability programmes. To optimize efficiency and boost productivity, some industrial facilities opt for an Integrated Maintenance Solution, in which SKF delivers all services under one fixed-fee, performance-based contract.

Planning for sustainable growth
By their very nature, bearings make a positive contribution to the natural environment, enabling machinery to operate more efficiently, consume less power, and require less lubrication. By raising the performance bar for our own products, SKF is enabling a new generation of high-efficiency products and equipment. With an eye to the future and the world we will leave to our children, the SKF Group policy on environment, health and safety, as well as the manufacturing techniques, are planned and implemented to help protect and preserve the earth's limited natural resources. We remain committed to sustainable, environmentally responsible growth.

1 Past and present



First nose suspension drive design invented by Frank J. Sprague (1857 – 1934), used for the Richmond (Virginia) tramway system, which opened in 1887

High-speed quill drive design with integrated disc brake shaft
Source: Siemens

Past and present

Drive systems, such as gearboxes and traction motors for railway applications, have to be powerful, meet environmental regulations, be very reliable, be cost-effective and have a low need for maintenance. The requirements for these applications are much more stringent than those found in many other industries, because of the heavy weight of railway vehicles and the need for long service intervals.

SKF, as a leading global supplier, offers a broad range of customer solutions that includes bearings, seals, lubrication, mechatronics and services for the railway industry. This includes a wide assortment of rolling bearings and services to meet the demanding needs of railway applications.

SKF has a broad and deep railway application knowledge and over the years has developed a unique range of products and solutions for drive systems.

The railway industry never stands still and new designs and performance enhancements are developed frequently. SKF's customers are always aware of the latest trends in the market place and SKF's research and development efforts are committed to integrating the very latest innovations into new solutions.

Drive systems development

The very early development steps in railways starting with the invention of the wheel, the energy saving capabilities of a railway system and the first axlebox bearings are already described in the SKF *Railway technical handbook, Volume 1*. This publication is focused on axleboxes, wheelset bearings, sensors, condition monitoring, subsystems and services [1].

The main historical features include:

- The wheel principle enables the saving of up to 99% of tractive effort.
- Freight carried on railways saves up to 90% tractive effort.
- The introduction of ball bearings saved 86% and roller bearings 52% tractive efforts.

- Development of bearings is very much focused on sealing solutions, lubrication and macro/micro geometry to further reduce friction and to save energy. Lower friction reduces bearing operating temperature and has a positive influence on grease life. This determines in many cases the service life and maintenance intervals.

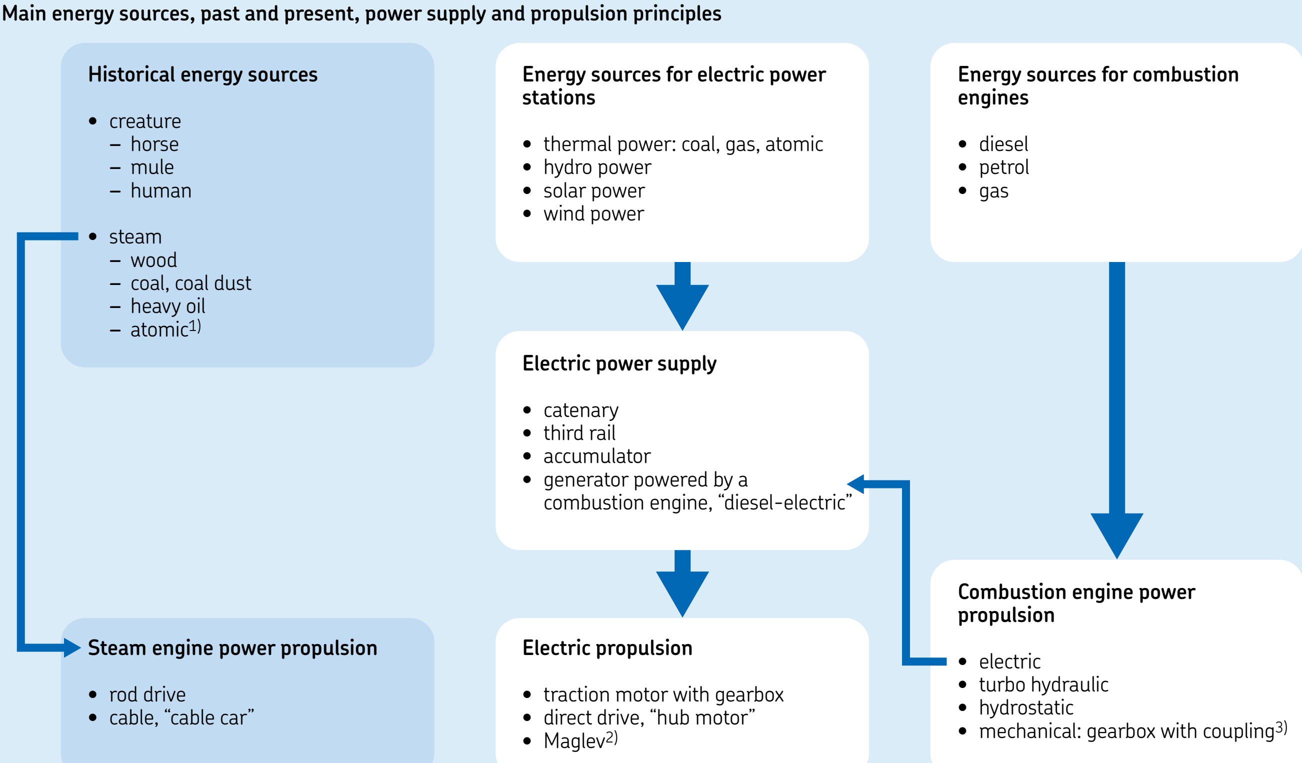
Energy for hauling railways was always limited. Early rail vehicles were horse or even human powered. At a later stage, steam locomotives were introduced with a goal to optimize the design to save coal and subsequently coal dust and oil. Ideas about atomic powered steam turbo-locomotives were published in the 1950s but never realised. The table below explains main energy sources, transmissions and propulsion principles.

The first electric powered rail vehicles were tramcars because of the limited traction motor size. The change from horse powered tramways to electric traction started in the 1880s. This had a dramatic impact on reducing the operational cost. In the literature [2], savings in the range of 30% were mentioned. This change occurred quickly around 1900. At this time, many new electric tram and metro operations were put into service. The introduction of electric propulsion for railway operations started at the same time and even in 1903 a top speed of 210 km/h was achieved with electric test train vehicles on the test railway line Marienfelde-Zossen (close to Berlin, Germany).

Because of required higher traction motor power rating of locomotives and longer distances between the power stations, the introduction of electric propulsion for railways took much more time than for tramways.

After 1900, combustion engines were used first very rarely for smaller locomotives powered with petrol, diesel and gas. The main introduction of diesel powered locomotives and multiple units started in the 1930s. Both propulsion modes, electric and hydraulic transmission, are applied. Diesel-electric transmission is based on a diesel motor driven generator which powers electric traction motors, a very similar design such as for electric locomotives, but in many cases with much lower power rating. For limited powered vehicles, mechanical propulsion is applied.

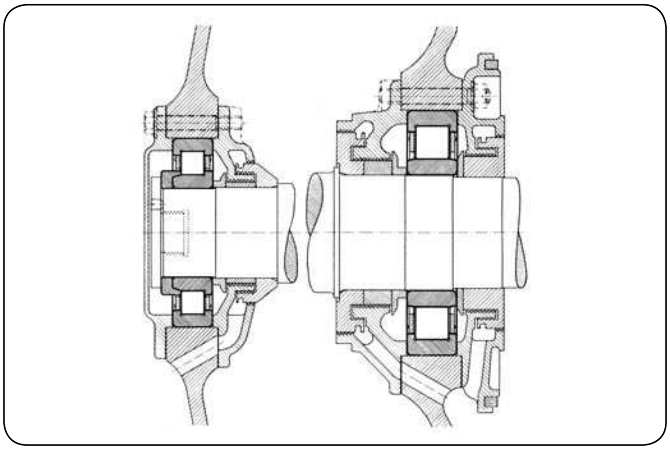
Main energy sources, past and present, power supply and propulsion principles



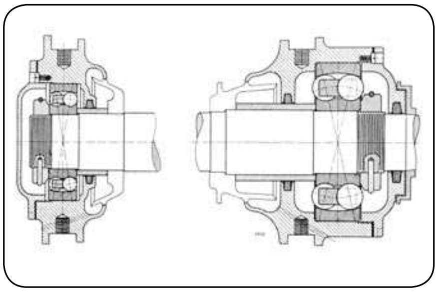
1) Ideas from the 1950s
2) Not considered in this publication
3) For limited power only

Historical applications

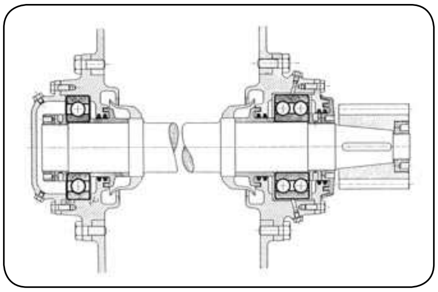
Reduced maintenance cost, space requirements and increased reliability have always been a key driver for implementing new bearing solutions for gearbox and traction motors. Very early designs were equipped with oil lubricated plain bearings. These bearings required the daily check of oil level and to refill oil. In 1918 SKF stated that tramway bearing maintenance cost can be reduced by 25 up to 70% by using self-aligning ball bearings instead of plain bearings.



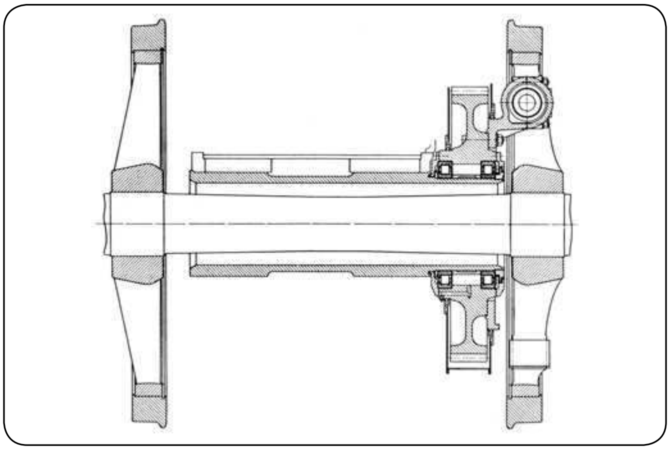
American Pennsylvania Railroad's class GG1 electric locomotives had a total power of 3 442 kW and obtained a max. speed of 160 km/h. They were introduced in 1934. The traction motors were equipped with two SKF cylindrical roller bearings, NJ design + HJ angle ring and NU design.
Source: Das Kugellager (SKF) 1939 – 2, page 19



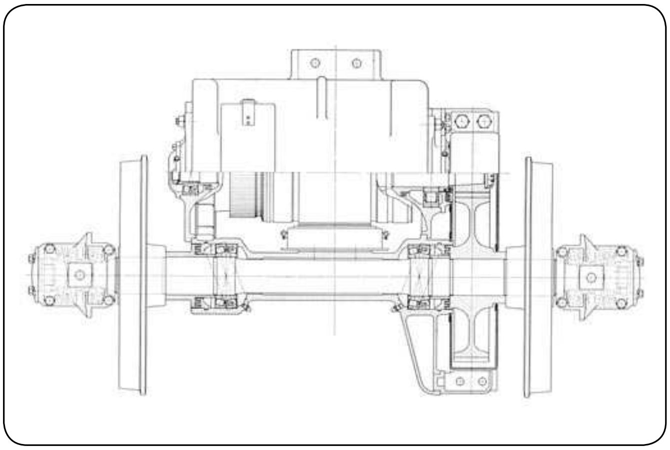
Göteborg tramway traction motor from the 1910s equipped with two SKF self-aligning ball bearings
Source: Hauptkatalog SKF Kugellager-gesellschaft 1918, page 190



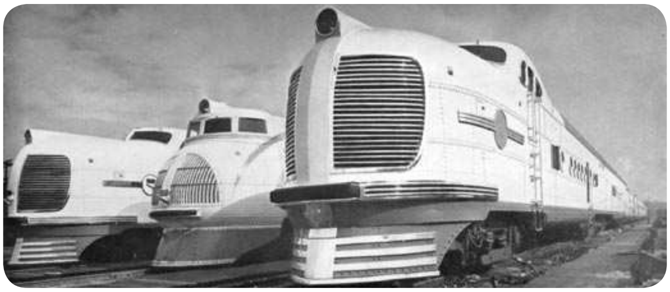
Tramway traction motor from the 1920s equipped with two STEYR deep groove ball bearings
Source: STEYR Hauptkatalog 1926



The American Pennsylvania Railroad's class R1 electric locomotives were equipped with a quill drive design with elastic coupling. They incorporated two SKF NJ type cylindrical roller bearings, special dimension 380 x 530 x 60 mm.
Source: Das Kugellager (SKF) 1939 – 2, page 21



Tramway traction motor and suspension tube from the 1930s equipped with SKF spherical roller bearings, pinion side of the traction motor is equipped with an SKF cylindrical roller bearing.
Source: SKF Bearings for tramway service 1939, page 31



American Union Pacific stream line trains from the 1930s equipped with SKF cylindrical roller traction motor bearings, power rating per traction motor on average 220 kW
Source: Das Kugellager (SKF) 1939 – 2, page 18

Bearing designs, present

Drive system bearings

Ball bearings | Roller bearings




	Deep groove ball bearings	**Angular contact ball bearings**	**Four-point contact ball bearings**	**Cylindrical roller bearings**
Traction motor applications	Applied for locating bearing positions			Applied for locating and non-locating bearing positions
Gearbox applications		Applied for locating bearing positions	Applied for locating positions, mostly in combination with cylindrical roller bearings	
Electrical insulation				
Sealed and factory lubricated				

		Electrically insulated bearings		Bearing unit designs
				
Tapered roller bearings	**Spherical roller bearings**	**INSOCOAT bearings**	**Hybrid bearings**	**Traction motor bearing units**
		Available as deep groove ball, tapered and cylindrical roller bearings	Available as deep groove ball and cylindrical roller bearings	Available as designs based on deep groove ball or cylindrical roller bearings
Universal applications	Universal applications. Today, mainly tapered and cylindrical roller bearings are used			
			Available as deep groove ball and cylindrical roller bearings	Available as designs based on deep groove ball or cylindrical roller bearings

Focus, present and future

Speed

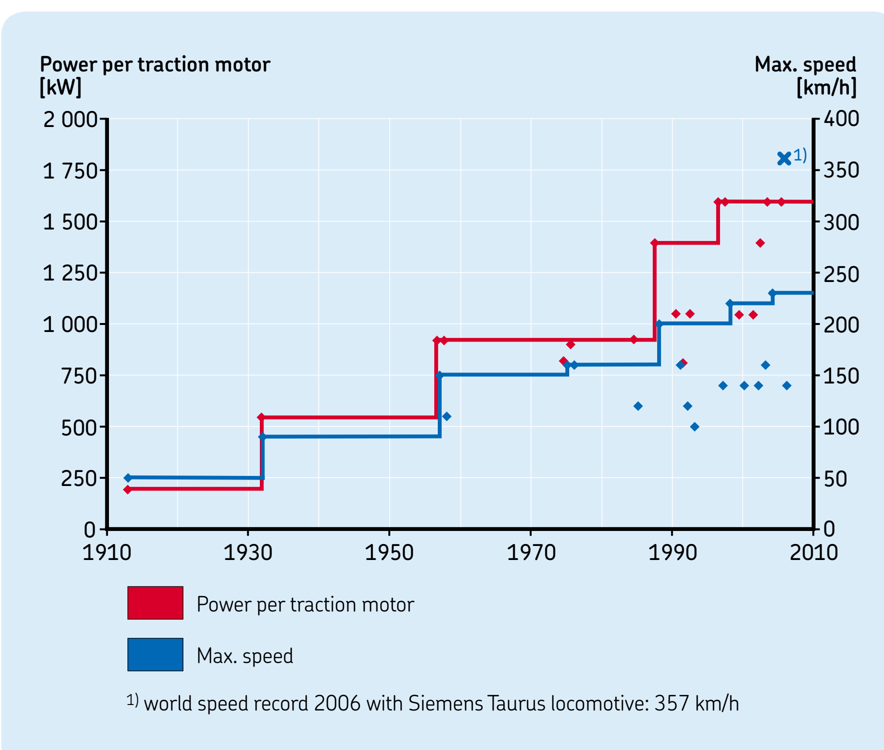
Passenger and freight transportation is very much related to speed. Over time, speed in railways has been increasing. Vehicle speed and a given wheel diameter determine the rotational speed of the gearbox output shaft and the bearings at this location. A multiple of this speed, which is defined by the gear ratio, is the gearbox input and the traction motor speed. The product of the two factors, rotational speed (n) and bearing mean diameter (d_m) is an important parameter for selecting the bearing size and roller set, cage design and lubricant viscosity.

Beyond the vehicle speed, the n d_m value is increasing because of higher traction motor speed caused by downsizing of the traction motor geometry.

On the other hand, high power traction motor designs can only be realized with higher motor speeds. In particular, the distance between the two wheels, which is defined by the rail gauge, is limiting the total horizontal length of the gearbox and traction motor arrangement.

Power

Following up the historical development of traction motor designs over a longer period, the power has been increased step by step. By taking as a common reference a typical 4-axle locomotive design with each one traction motor driving one wheelset (also called Bo' Bo') [1], the traction motor power today is close to 10 times higher when compared to when this design principle was first implemented. The power related to the speed has a direct influence on loads acting on the gearbox input shafts. As described in chapter 2, modern drive designs are focused on reducing bearing loads and applying oil lubrication as much as possible.



Development of total power rating and maximum speed of selected German railways Bo' Bo' locomotives
Bo' Bo': 4-axle vehicle equipped with 2 bogies and all axles driven by a separate motor, see Railway technical handbook, Volume 1, ***page 28****.*

Maintenance intervals

An important trend today, which will continue in the foreseeable future, is to extend maintenance intervals. A benefit of using AC propulsion technology for electric powered vehicles is the reduced maintenance demand, which naturally results in extended maintenance intervals. Today, grease lubricated traction motor bearings have some limitations in service life because an overall midlife of around 15 years is expected without maintenance. Some new designs, calculation models and test results can be the basis of reaching this target step by step (→ chapter 5).

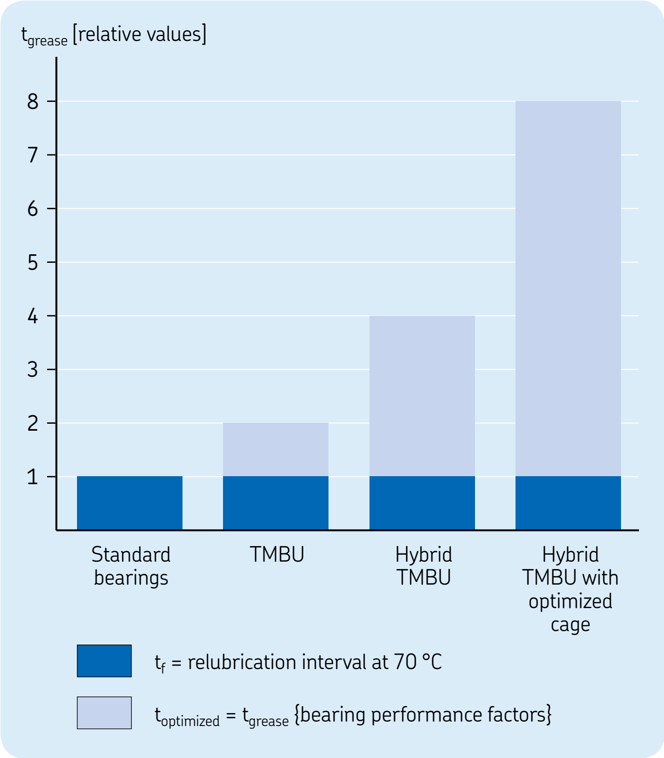
Drives product platforms

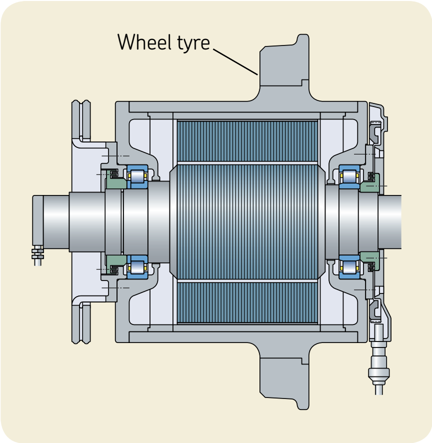
Gearbox designs are becoming more and more standardized and in some applications similar designs are used for very different applications such as high speed, multiple units or even metro cars. It seems that in future railway rolling stock suppliers will continue to focus on selected designs, which are the basis for product platforms that will achieve higher production quantities and save cost.

Low-floor vehicles

Low-floor vehicles such as light rail vehicles and tramways require special designs because of space limitations. Today, there are several very different designs used to meet these individual requirements (→ chapter 2).

Applied SKF optimized grease life guidelines, for further information see *page 132*





Integrated traction motor design for low-floor vehicles (*→ chapter 2*)

SKF solution packages

For over 100 years, SKF has become synonymous with advanced bearing technology and is the world's leading supplier to the railway industry. Adding to this solid knowledge base, SKF is also a leading supplier of products and solutions in mechatronics, lubrication systems, seals and services for various applications.

The bogie application related solutions include:

- axleboxes,
- wheelset bearings,
- sensors,
- condition monitoring,
- subsystems and
- related services

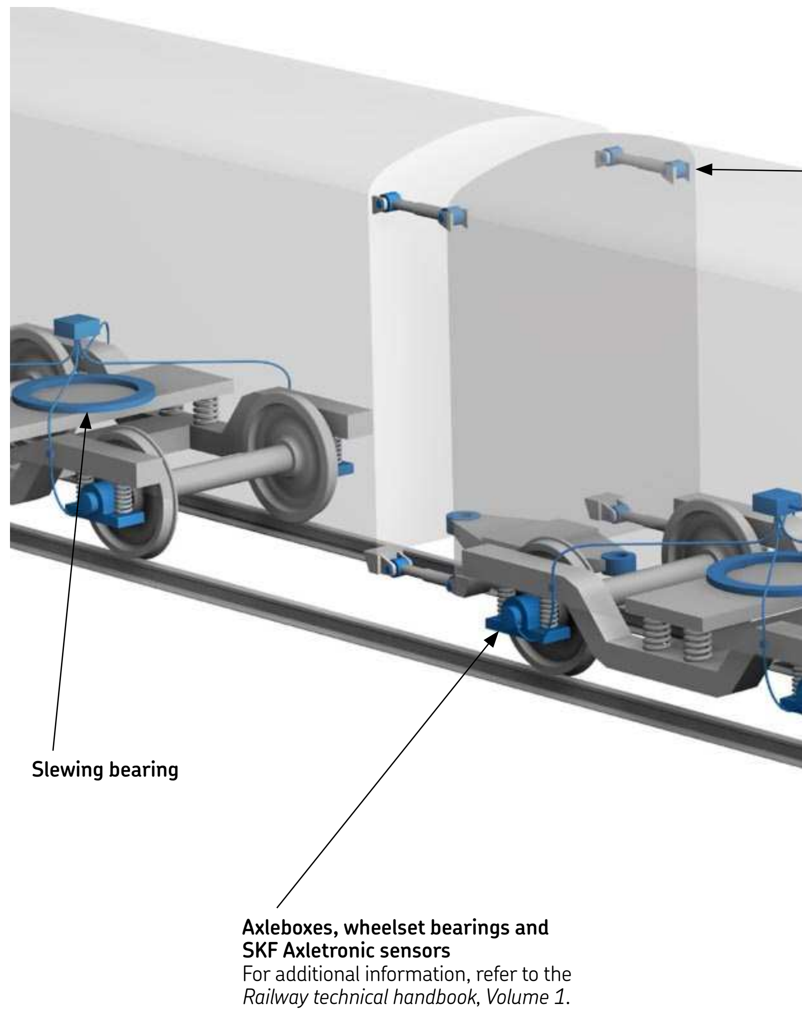
and are already mentioned in the SKF *Railway technical handbook, Volume 1* [1].

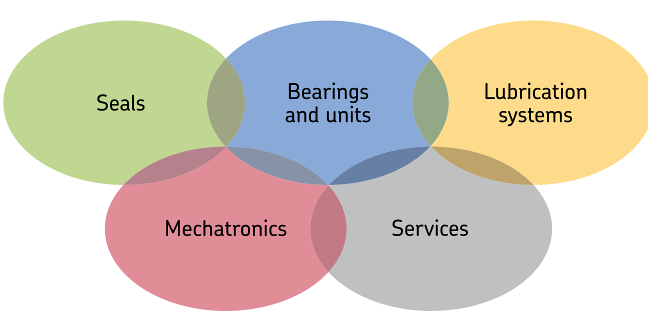
Drive solutions

The delivery scope for the present and future is comprised of:

- bearings for traction motors and gearboxes,
- electrically insulated INSOCOAT and hybrid bearings,
- traction motor bearing units,
- sensors,
- condition monitoring and
- services

SKF offers a unique worldwide network of sales, application and service engineers to work closely with manufacturers and operators on international projects.

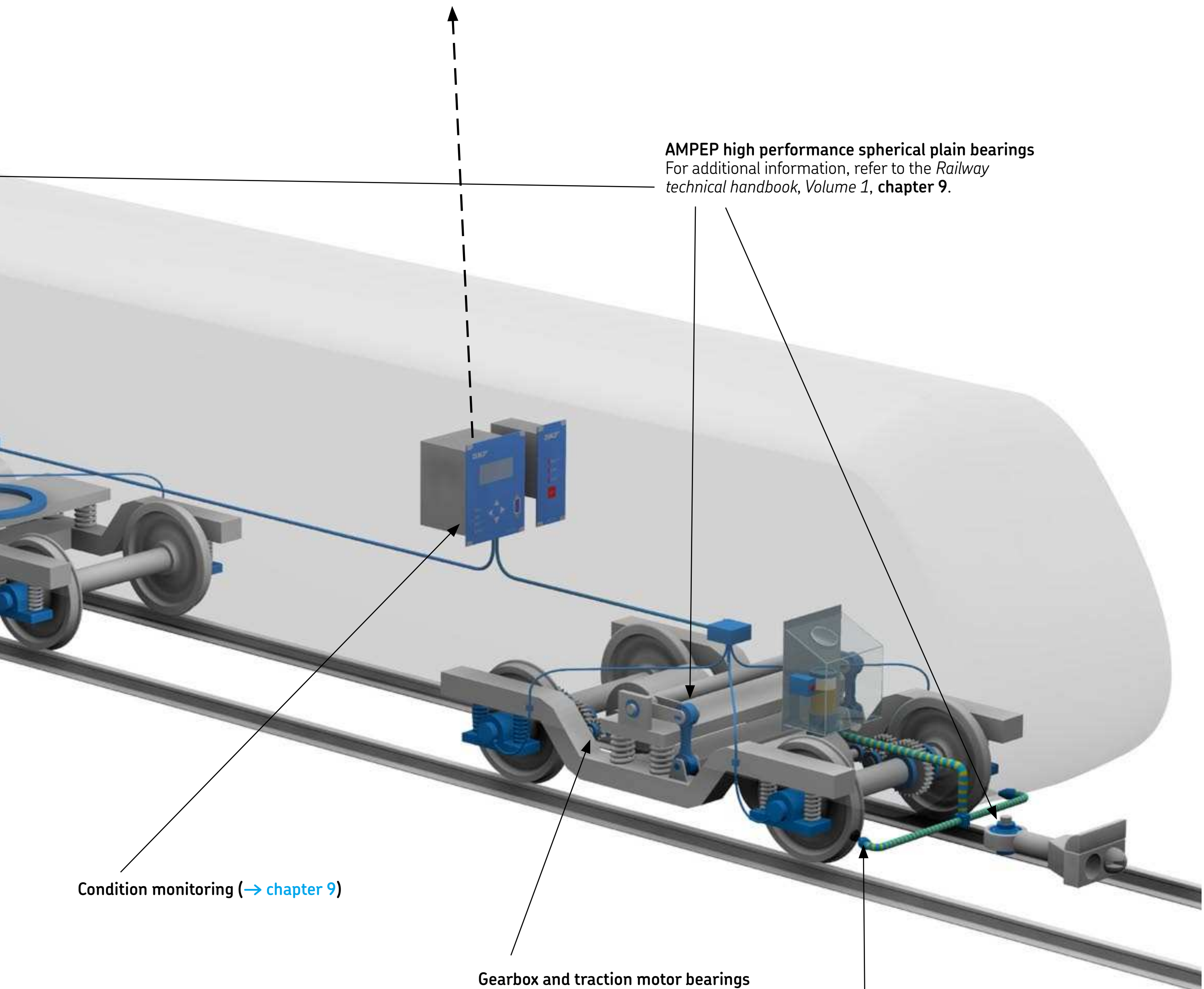




Condition data transmission, monitoring and management
(→ chapter 9)

SKF offers a range of services to the railway industry to meet customer's specific requirements
(→ chapter 10)

AMPEP high performance spherical plain bearings
For additional information, refer to the *Railway technical handbook*, *Volume 1*, **chapter 9**.



Condition monitoring (→ chapter 9)

Gearbox and traction motor bearings
- deep groove ball bearings
- angular contact ball bearings
- four-point contact ball bearings
- cylindrical roller bearings
- tapered roller bearings
- spherical roller bearings

(→ chapter 3)

- INSOCOAT bearings
- hybrid bearings

(→ chapter 4)

- traction motor bearing units

(→ chapter 5)

Wheel flange lubrication
For additional information, refer to the *Railway technical handbook, Volume 1*, **chapter 9**.

Life cycle partnership

With the life cycle partnership concept, SKF combines all its expertise and technologies to help railway customers meet their economical and environmental challenges, such as:

- innovations for profitable and sustainable growth
- development and implementation
- asset management and remanufacturing
- local presence

Specification

As market leader and technology trendsetter, SKF is committed to the special demand in the railway industry and offers customized solutions and products.

Design and develop

SKF knowledge platforms and established practical experience can provide a precise customer needs analysis and a future-oriented solution – based on economic and environmental requirements in railways.

It is more than a partnership that unites SKF with its customers; it is a close and highly involved relationship from the start, driven by joint values such as: safety, quality, profitability and energy saving.

Manufacture and test

SKF has an experienced railway team and manufacturing standards in excellence, accompanied by quality control and quality assurance techniques as well as dedicated railway test centres in China, Russia and Europe.

The decisive key for long term reliability is rigorous performance and endurance testing in modern test rigs as well as in the field, certified by significant qualified authorities.

Install and commission

The SKF installation service offers the best holistic service from homologation to on-site mounting, including manuals and documentation and individual training.

The highly trained local sales and service engineering SKF teams provide railway customers with dedicated application knowledge and personal support, in the local language and for customized requirements.

SKF's strong local resources, around 140 manufacturing and operational sites in 32 countries, offer the best customer service capabilities to the global railway industry.

Operate and monitor

SKF has a deep knowledge of railway reliability that is unmatched in the world. Close working partnerships with customers has given SKF a unique and intimate understanding of the processes and challenges specific to every railway industry. As a result, SKF stands apart as a total solution provider for maximizing reliability, safety and operator productivity.

Using condition detection systems and applying sophisticated algorithms for data processing can detect incipient damage and allow sufficient time for repairs before significant mechanical failures occur, thus lowering life cycle costs.

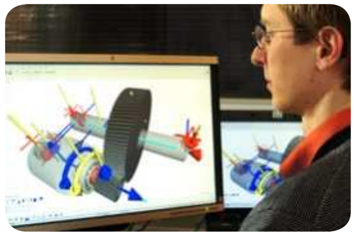
Maintain and repair

Maintenance and repair performed by SKF personnel provides longer product life, reduces unplanned maintenance and increases uptime. SKF offers an individual maintenance strategy and engineering plan.

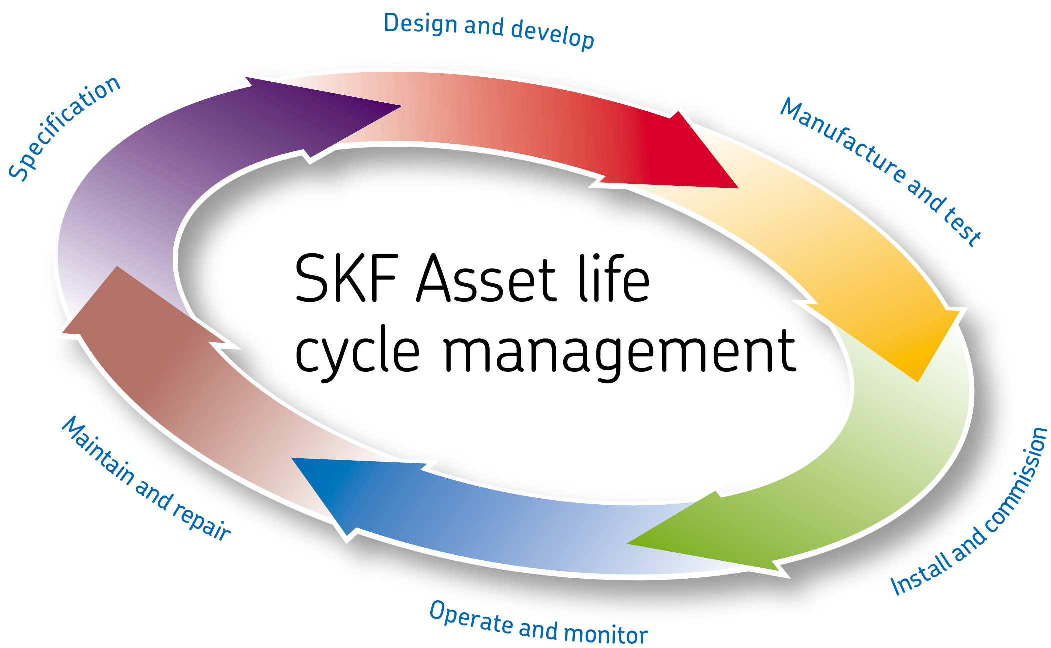
SKF personnel remanufacture bearings and return them as good as new, using state-of the-art technologies, strict reuse guidelines, advanced remanufacturing systems and rigourous quality control.

Specification

Design and develop



Manufacture and test



Maintain and repair

Operate and monitor

Install and commission

Quality

SKF pursues a systematic and disciplined approach to achieve radical improvements in all business processes with improved customer satisfaction as a primary goal. Continuous improvement is achieved by using Six Sigma methods and toolboxes as well as the SKF Business Excellence programme.

SKF Six Sigma

SKF Six Sigma

SKF Six Sigma is a continuous improvement programme within SKF that targets waste and defects in all business processes. There are a number of tools and methodologies within the SKF Six Sigma programme, ranging from traditional DMAIC and Design for Six Sigma to Lean and other waste reducing methodologies. The foundations for SKF Six Sigma improvements are fact-based and sustainable and contribute to the business objectives.

SKF Business Excellence

SKF Business Excellence delivers value to customers in the most effective and efficient way possible, by utilizing the knowledge of employees, partners and the company's technology. With Business Excellence, SKF is expanding its experience from the manufacturing area into other processes and operations within the SKF Group. Business Excellence is more than just about results – it actively challenges the organization to consider whether it is achieving the right results in the best way possible.

Certification

SKF quality is documented by relevant quality certificates, which are based on international standards and customer approvals. The following is a selection of relevant certificates of the SKF Group and the SKF Railway Business Unit. Other certificates pertaining to SKF railway sales and manufacturing units can be submitted to our customers on request.

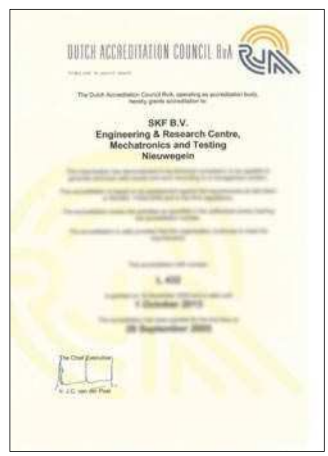

CERTIFICATE OF APPROVAL

SKF Railway Business Unit
Gothenburg
Sweden

ISO 9001:2008

Development, design and manufacturing/procurement of Railway Tapered Bearing Units (TBU's), Axleboxes, Axlebridges, Sensors and Cables/Connectors and other wheelset assemblies. Refurbishment of wheelset bearings.

ISO 9001 quality management system certificate awarded to the SKF Railway Business Unit.


DUTCH ACCREDITATION COUNCIL RvA

SKF B.V.
Engineering & Research Centre,
Mechatronics and Testing
Nieuwegein

ISO/IEC 17025 certificate awarded to the SKF Engineering & Research Centre, Nieuwegein, The Netherlands, confirming its capability to generate technically valid results.


CERTIFICATE

IRIS International Railway Industry Standard certificate awarded to the SKF Railway Business Unit.

ISO 14001, OHSAS 18001 management system standards certificate awarded to the SKF Group.

German DB Q1 certificate for quality capability.

French SNCF AQF2 unconditional quality certificate.

Awards

Customer awards can be seen as a recognition for SKFs outstanding efforts to meet and exceed customer requirements.

This is achieved through the operation of reliable and efficient processes and a programme for continuous improvement with a goal of zero-defects. These customer awards confirm SKF's commitment to continue to strive to make ongoing quality improvements.

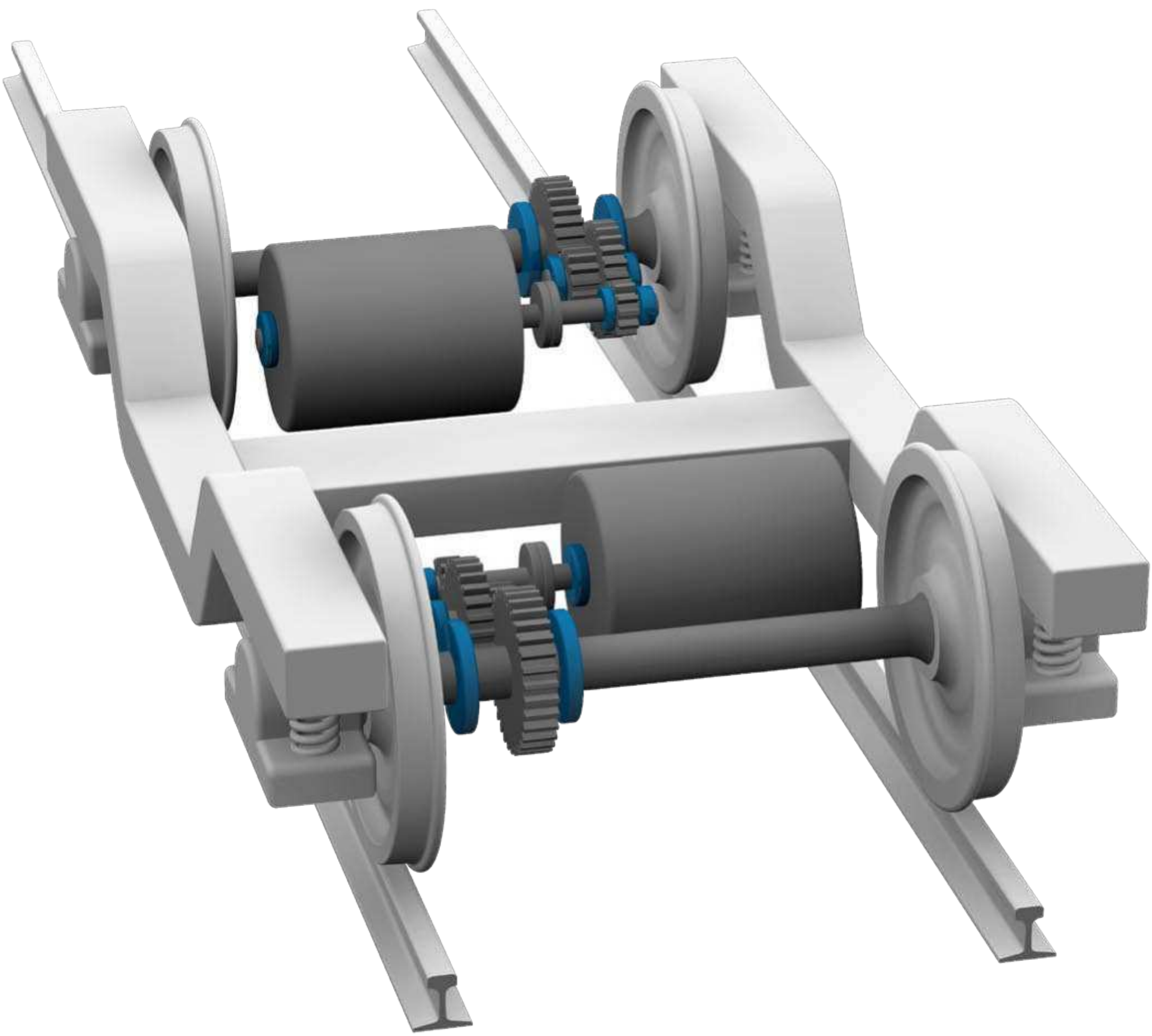
Bombardier Supplier Sustainability Award 2012.

GE Transportation 2010 Supplier of the year award.

Siemens large drives quality award.

CSR Zhuzhou Electric Locomotive “Excellent Supplier” 2009 award.

2 Drive designs



Drive designs

Drive systems, such as gearboxes and traction motors for railway applications, have to be powerful, environmentally friendly, very reliable, cost-effective and have a low need for maintenance. These requirements for such applications are much more stringent than those in many other industries because of the rather heavy weight of railway vehicles and the need for long service intervals.

Drive systems in railways are used to transmit the torque from the traction motor or the combustion engine, usually operating with higher speeds, to the wheelset via a one, two or more shift gearbox.

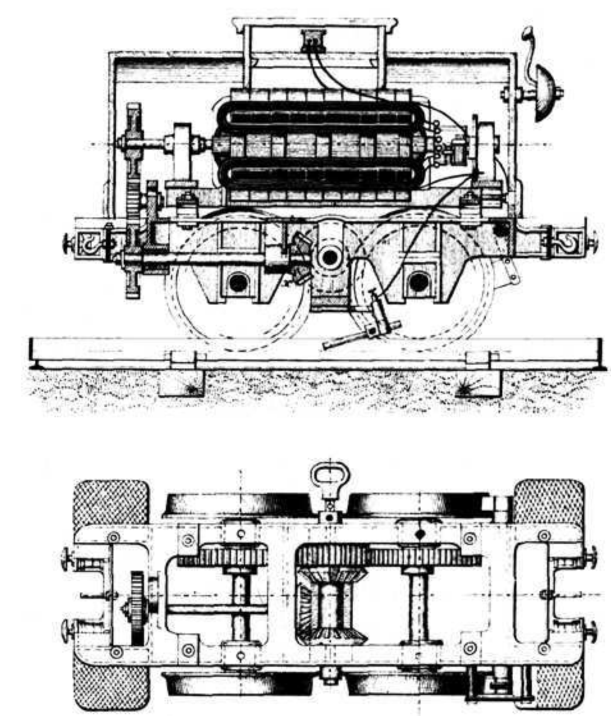
Drive systems have to be powerful, environmentally friendly, very reliable, cost-effective and have a low need for maintenance. The requirement for such maintenance is much more stringent than those required of cars, for example, because the intervals between servicing need to be much longer. New main line locomotives are maintained frequently, but major service is done after the locomotive has logged between 1 million and 1,5 million km. These locomotives operate, on average, more than 1 000 km a day. Very high speed trains operate with speeds up to 350 km/h and reach much higher mileages.

Two major developments such as the AC propulsion systems (→ **page 37**) and low-floor mass transit vehicle designs (→ **pages 51** to **57**), caused fundamental changes in drive design.

Design principles

The overall trend from the early beginning of the drive design development was to apply increasing speeds of motors and engines to achieve a lower mass and to save space. This results in a higher gear ratio at a given train speed. In addition, drive designs have to be capable to accommodate relative movements between the bogie/vehicle frame and the wheelset. The number of gear steps depends on the maximum speed of the traction motor and the vehicle. Normally, locomotives equipped with air-cooled traction motors with a power rating of 500 up to 1 700 kW use a one-step gearbox with a ratio from 3 up to 5.

There are always increasing ambitions to fulfil all design requirements by applying very different designs. In the table (→ **pages 28** to **29**), drive design principles and their variations are listed.



First Siemens electric locomotive[1] from 1879 was equipped with a very complex drive system, including a traction motor with a two step spur gear, a helical gear with reverse step and a further spur gear driving the two wheelsets
Photo: Siemens Corporate Archives

Drive design requirements [3]

- mass and space saving
- damping of dynamic shocks
- correct rotating transmission during relative vertical movements of the wheelset/traction motor. Incorrect rotating transmission would cause additional torques acting on the traction motor during vertical wheelset movements.
- continuous power transmission without causing heterodyne vibrations
- free movement of wheelsets and traction motor
- does not cause reactive energy
- capability to operate in both directions in acceleration and braking modes
- modular design capable for different application requirements
- reduced wear
- low need for maintenance
- designed for production cost optimization

[1] Earlier electric railway milestones:
1835: Thomas Davenport built a model of an electric powered railway in USA.
1837 or 1838: Robert Davidson made a further model and later the full scale test locomotive Galvani in the UK.
1840: Johann Philipp Wagner produced a further model and tried to build a full size loco in Germany, which was not finished.
1850: Charles Grafton Page made an electric locomotive in USA, which failed during testing.
1875: Fjodor Pirozki started operation with an electric tramway in Russia, which was used for field testing.

Design variations

There are three main considerations:

- There are many different drive arrangement designs which can be classified in three main categories:
  - different arrangements of wheelsets and independent wheels, as those used for low floor designs.
  - the applied direction of transmission
  - the suspension principle

  Both transmission and suspension principles have a direct impact on additional dynamic loads that need to be considered.
- There is a large number of gearbox designs. These depend on the arrangement, gear shift, gear teeth, number of bearings per gearbox, or special designs. One particular design is a non-gearbox design, also known as hub motor drive system, which is used for direct drive systems, such as typically applied for low floor vehicles [4].
- The traction motor design depends mainly on three possibilities
  - a coupling (applied or not)
  - overhanging pinion driving directly the gearbox
  - gearwheel mounted on the motor axle shaft

  This has a direct impact on eventual additional dynamic loads that need to be considered. Additionally, there are also special designs (→ **pages 55** to **57**). Finally, the number of bearings on the motor shaft can also vary.

The drive system can be designed to accommodate different attachments such as sensors, a compressor, a generator to feed a battery, brakes, earth brushes and condition monitoring systems.

The table on **pages 28** to **29** lists the selected main designs and variants, as far as they are considered in this handbook. Considering all theoretically possible combinations listed in the table, some 1,1 million variants (without attachment variants) are possible. The aim of the table is to give a general overview. In fact, there are even more variants possible than those listed. More information about gearbox and traction motor designs can be obtained from the manufacturers [5]. In the footnotes to the table, some of the main applications are mentioned. Further details about selected current designs are explained with drawings. Exceptional, older designs are described enabling comparison with current designs [6, 7, 8].

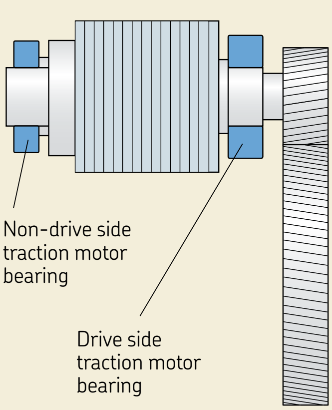
Present and future

The present and possible future focus on the applied drive designs is to increase reliability, extend the maintenance intervals and to apply more module based design principles that can achieve larger volumes and reduce cost. An important tool to achieve these targets is to apply condition monitoring for gearbox, cardan shafts and traction motors (→ **chapter 9**).

Relative service life [9], customer experience

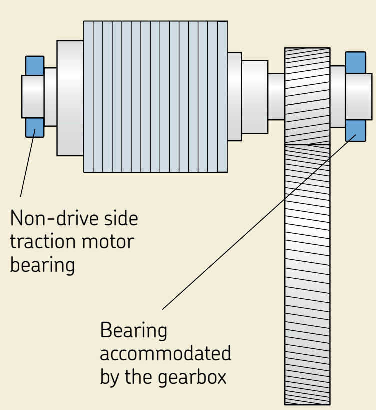
Overhanging traction motor pinion

Relative service life: 100



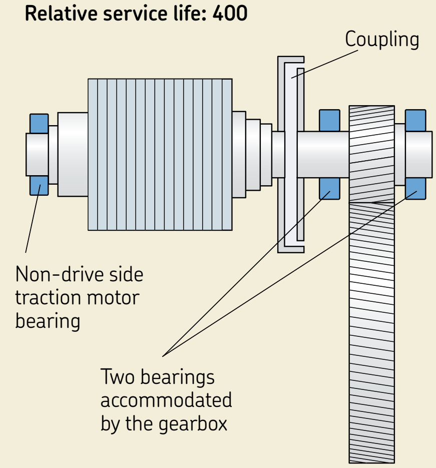
Drive-side bearing integrated into the gearbox

Relative service life: 200



Traction motor with elastic coupling and pinion supported by two bearings

Relative service life: 400



Drive design principles and their variations – selection criteria[1]

Arrangement

Wheelsets and wheels
- single-wheelset drive[2]
- two-wheelset drive
- multiple-wheelset drive[3]
- single-wheel drive[4]
- two single consecutive wheels[4]

Direction of transmission
- longitudinal
- transverse[2]
- vertical[4]
- inclined[4]

Suspension
- rigid, nose suspension
- semi-suspended
- fully-suspended

Gearbox

Number
- no gearbox, direct drive[4]
- one gearbox[2]
- two gearboxes connected with cardan shafts[5]

Arrangement
- spur gear[2]
- right-angled gear
- non-right angled gear[4]

Shifts
- one
- two
- more[5]

Gear teeth
- straight
- helical
- double helical[6]

Bearings per shaft
- one[7]
- two
- three and more[8]

Design
- no special design[2]
- planetary gear[4]
- truck axle design principle[9]

Traction motor

Arrangement
- pinion drive
- direct coupling
- elastic coupling
- other design

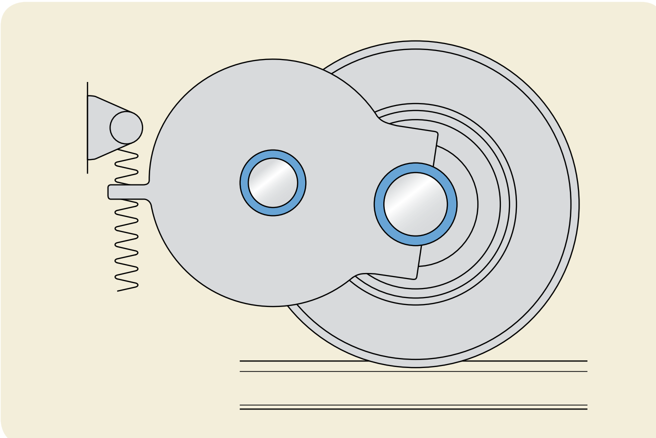
Bearings
- one[7]
- two
- three and more[8]

Designs
- no special design
- hollow shaft
- pinion pressed into the conical bore of the shaft

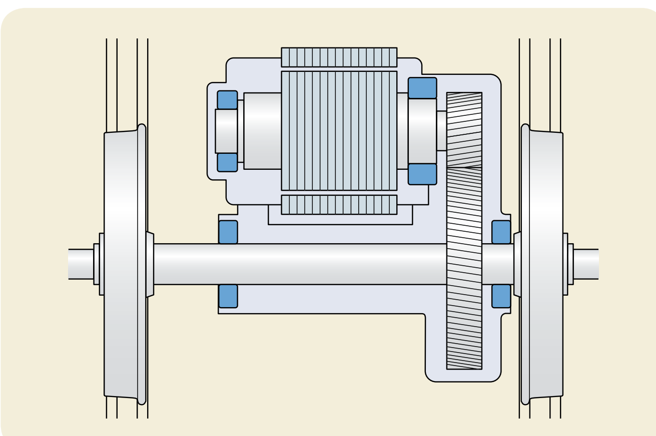
Attachments

Traction motor	Brake
• no attachments[11] • sensors e.g. speed[12] • compressor[13] • generator[13]	• no brake integrated[11] • brake on the motor shaft • brake on the gearbox shaft • brake on a special brake shaft of the gearbox
Earth brush	**Condition monitoring[15]**
• no earth brush attached to the gearbox/suspension tube[11] • on the traction motor shaft • on the suspension unit[14]	• no condition monitoring • sensors e.g. vibration, temperature, monitoring unit

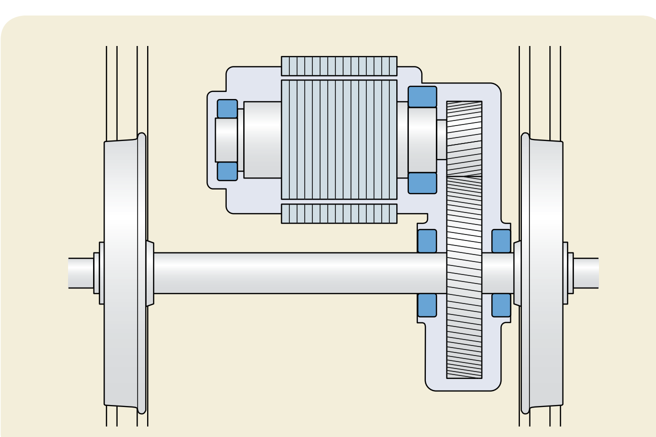
1) for electric transmission only, for hydraulic and mechanical transmission (→ page 58)
2) most common design
3) for older design, e.g. with rod drives
4) for low-floor vehicles and monorail
5) for high speed vehicles
6) to avoid axial load, also known as Chevron gear
7) one bearing in the gearbox and the other bearing located in the traction motor; both shafts can be connected with a stiff coupling
8) for very high helical angle, two bearings supporting the radial load and one or two bearing(s) supporting the axial load
9) e.g. metro pneu, SKF *Railway technical handbook, Volume 1*, **page 13**, left column
10) this enables use of the higher speed and to reduce the brake forces
11) most of the applications
12) for AC propulsion (→ chapter 8)
13) mainly for trolleybus (→ page 54)
14) e.g. mounted onto the suspension unit (→ page 47)
15) chapter 9



The traction motor is supported partly via springs with the bogie frame while the other part is directly connected via the suspension unit bearings with the wheelset



Nose-suspension drive design principle



Nose suspension drive design with shortened bearing distance on the axle shaft for more modern designs to save weight

Transverse drives

Nose-suspension drives

The nose-suspension drive design is one of the oldest design principles. This design was originally used for tramways and later also applied for locomotives and electrical and diesel powered multiple units (→ **chapter 1**).

The transverse situated traction motor is supported partly via the bogie frame while the other part is directly connected via the gearbox to the wheelset. When applied, this cost-effective design principle is very versatile. Because of the limited dynamic behaviour, the design is used for limited speeds only. Main applications today are freight locomotives. For this application, the nose-suspension drive is still very common.

Suspension tubes

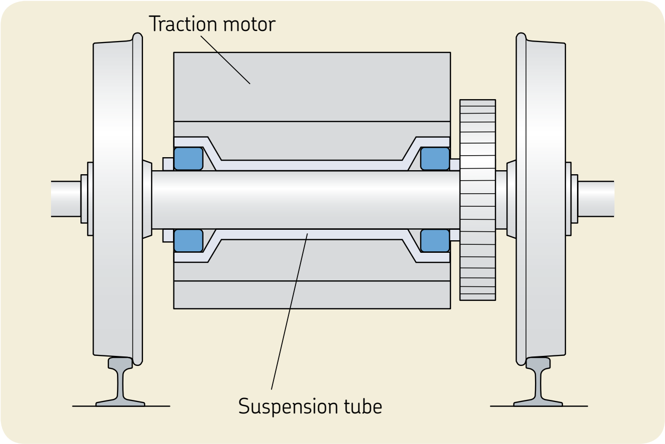
The suspension tube acts as a wheelset support for the traction motor. SKF offers tailor-made suspension tube designs based on different bearing type configurations, depending on the operational requirements and customer specifications (→ **pages 60** to **61**).

Tapered roller bearings

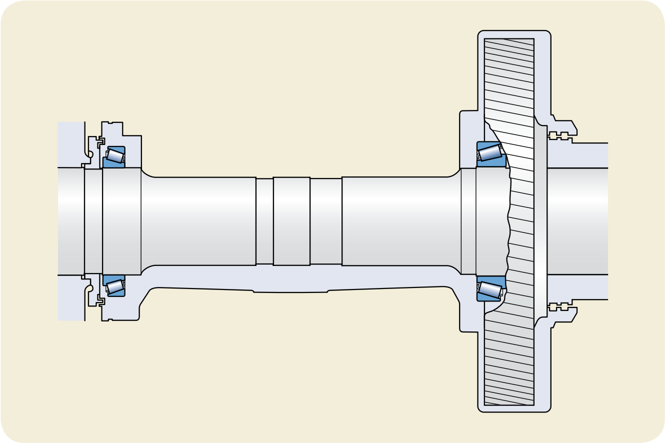
Tapered roller bearings offer a rigid and accurate arrangement, enabling highly precise gear meshing. The specified axial clearance has to be adjusted during the bearing installation and is a prerequisite for high reliability. Tapered roller bearing can also be supplied with a flanged outer ring (→ **page 91**). This enables to simplify adjacent components.

INSOCOAT tapered roller bearings

The INSOCOAT tapered roller bearings for suspension tubes have an electrically insulating coating on the external surfaces of the outer ring. The INSOCOAT design virtually eliminates premature bearing failures caused by stray electric currents (→ **chapter 4**).

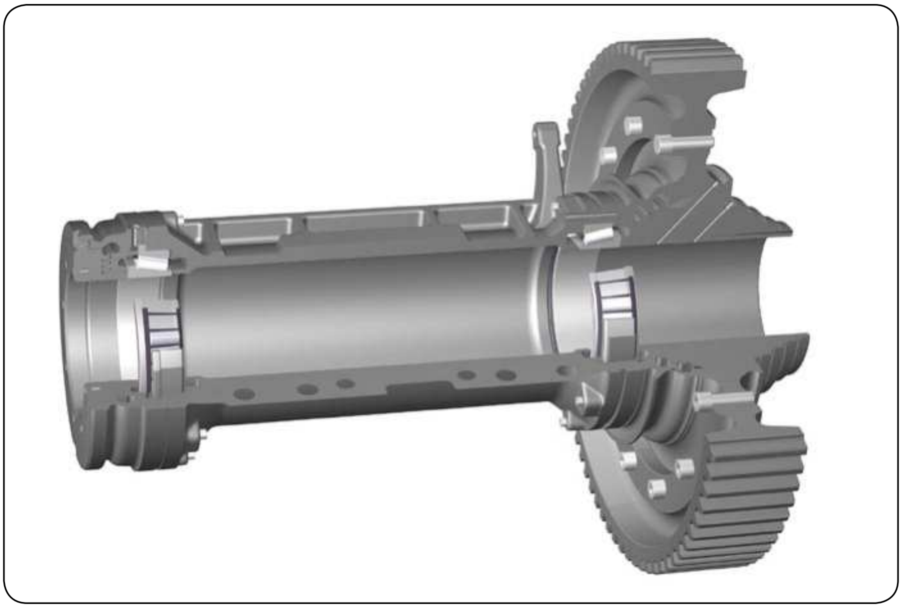


Suspension tube design principle

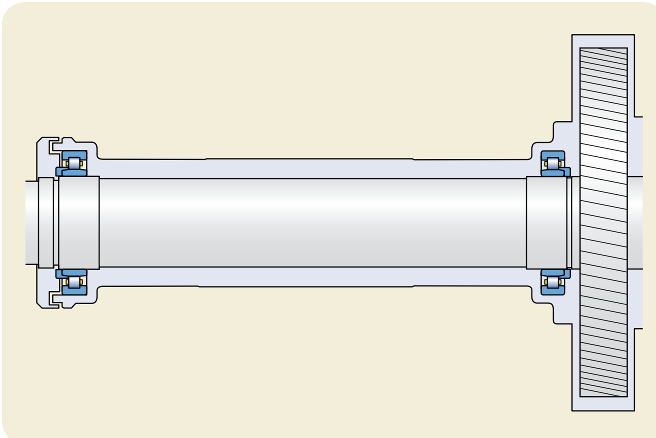


Suspension tube equipped with a tapered roller bearing on both sides

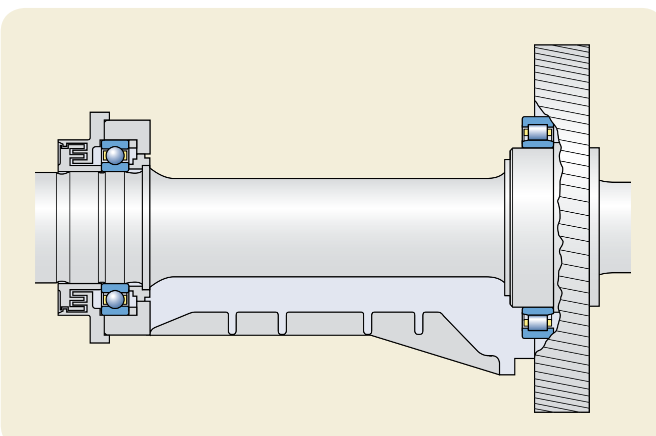
Suspension tube equipped with INSOCOAT tapered roller bearings with electrically insulating coating



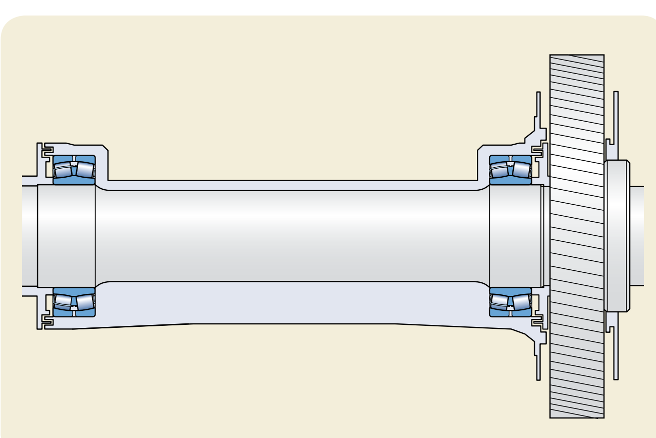
INSOCOAT flanged tapered roller bearing with electrically insulating coating (→ chapter 9)



Suspension tube equipped with a NU type cylindrical roller bearing and HJ angle ring on both sides



Suspension tube equipped with a NU type cylindrical roller bearing on the drive side and a deep groove ball bearing on the non-drive side



Suspension tube equipped with two spherical roller bearings

Cylindrical roller bearings

Cylindrical roller bearings have a higher speed capability and need less frequent relubrication, when compared to tapered roller bearings. The mounting and assembly operations are simplified, as the radial clearance after mounting is determined by selecting bearings with a certain radial internal clearance class (→ page 80), and shaft and housing fits. Different bearing designs can be applied. Often, two NU type cylindrical roller bearings with an HJ angle ring are used. During assembly, the appropriate axial clearance in the system needs to be set carefully.

Cylindrical roller bearing and deep groove ball bearing combination

A similar design is the combination of a NU type cylindrical roller bearing for the drive side and a deep groove ball bearing on the non-drive side. This design is used to accommodate heavier axial loads acting from the helical gearwheel. Another advantage is that adjustment of axial clearance is not needed.

Spherical roller bearings

Spherical roller bearings are mainly used for heavy loads and considerable axle bending. These bearings have a lower speed limit and require shorter re-lubrication intervals.

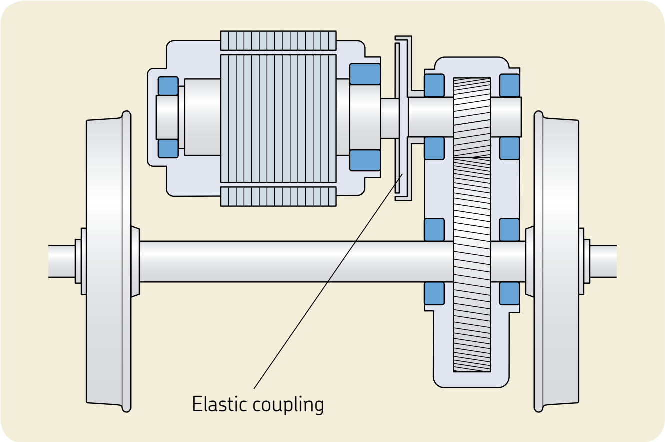
An advantage is that the suspension housing seats can be manufactured separately. Another main advantage is that spherical roller bearings are self-aligning and therefore can accommodate misalignment (shaft bending).

Semi-suspended drives

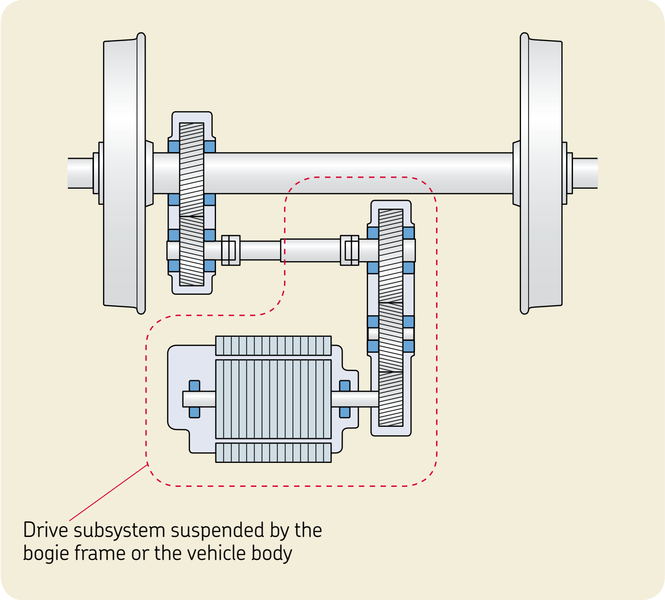
To reduce the acting forces on the traction motor, a more advanced design is used by applying a coupling between the traction motor and the shaft driving the gearbox. This helps to increase traction motor reliability and to reduce the unsprung weight of the drive system and to reduce dynamic forces acting on the traction motor bearings, which are mainly radially and axially loaded by the rotor weight.

Semi-suspended drives with two gearboxes

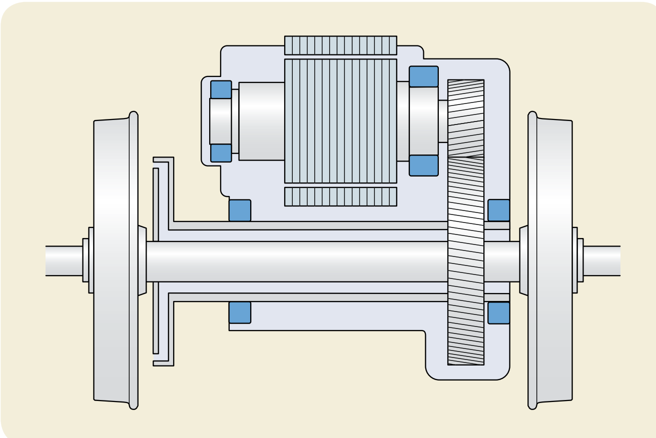
For high speed applications, the traction motor can be suspended on the vehicle body. In this case, two gearboxes are used. One is connected with the traction motor and connected with a cardan shaft to the second gearbox. The suspension drive is riding on the wheelset.



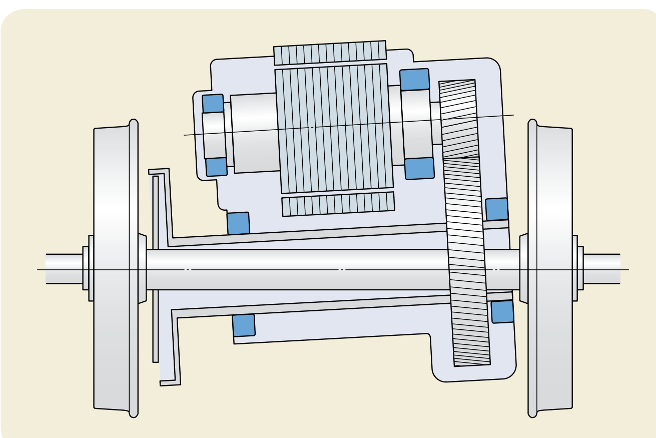
Suspension drive riding on the wheelset. Elastic coupling between the gearbox and the traction motor.



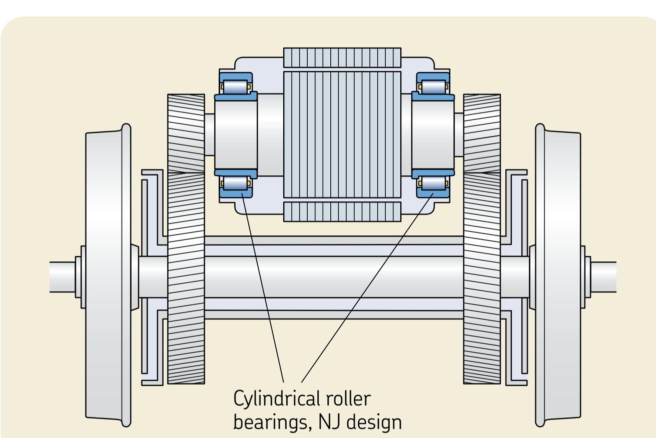
Semi-suspended drives with two gearboxes



Fully-suspended quill drive principle



Fully-suspended quill drive principle acting during operation



Fully-suspended quill drive with gearboxes and spring suspension on both sides
NJ design cylindrical roller bearings with a wider inner ring to provide inner ring offset, enabling larger axial displacement

Fully-suspended drives

The most common fully-suspended drive arrangement is the quill drive, which is based on a hollow shaft design. The traction motor is bolted to the gearbox, which is supported via the bogie frame. The torque is transmitted from the large gearwheel via a connecting star and several connecting rods with rubber suspension, which drive the connecting star of the hollow shaft. From the hollow shaft, the torque is transmitted via a further connecting star and several connecting rods with rubber suspension, which drive the wheel on one side. Relative movements are compensated via the elastic deformation of the rubber suspension of the connecting rods [10] (→ page 40, page 42, page 46, page 49 and page 51).

Quill drives are used for all kinds of electric powered rolling stock, especially for higher speeds or more demanding requirements for reduced wheel/rail wear. In the beginning of the quill drive design market introduction, spring suspensions on both sides were used for higher power ratings.

Longitudinal drives

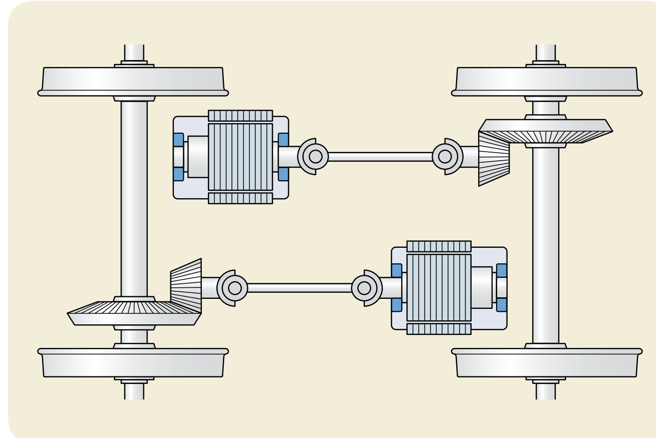
Semi-suspended drives

This very basic design principle is used for conventionally designed multiple units, metro cars, light rail vehicles and tramways. The traction motor is fully spring-supported on the bogie frame and drives a helical gearbox via an elastic coupling. This design principle (→ page 50) is used for more demanding requirements for reduced wheel/rail wear compared with one-engined drive designs (→ page 36).

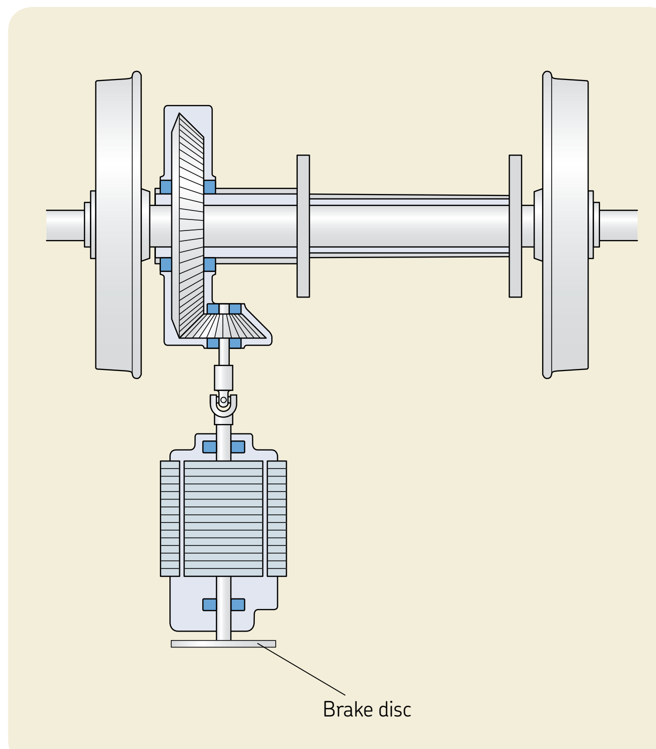
In some cases, additional axial forces are observed because the cardan shaft cannot accommodate axial movements during operation.

Fully-suspended drives

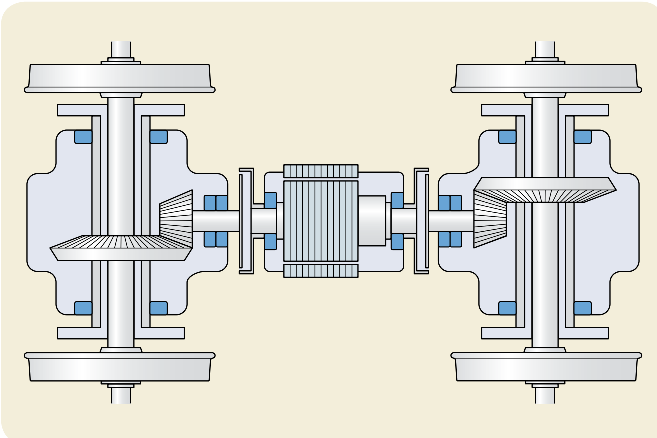
For high speed applications, longitudinal drive arrangements are used which are fully suspended. The traction motor is supported by the vehicle body and drives a cardan shaft. The shaft is connected with the gearbox through a hollow shaft. This shaft drives the wheelset via couplings.



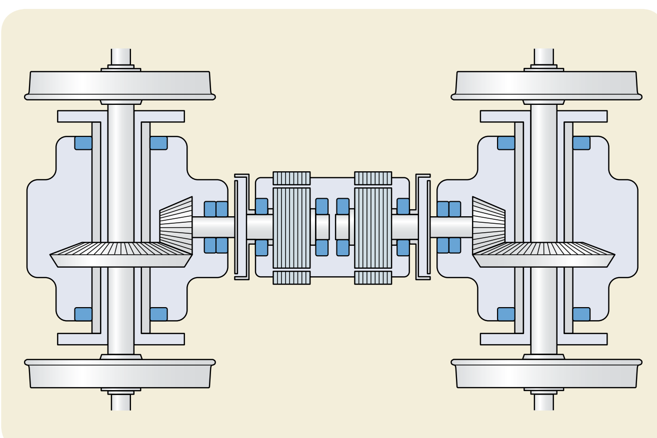
Semi-suspended longitudinal drive principle for mass transit vehicles



Fully-suspended longitudinal drive principle



Fully-suspended longitudinal drive with one traction motor driving two helical gearboxes



Fully-suspended longitudinal drive with one traction motor and two rotors driving two helical gearboxes

One-engined bogie designs

In the 1950s, bogies with one traction motor driving both axles were used. This arrangement is known as "one-engined design". The advantage of mechanically coupling two axles is the higher adhesive rating, enabling higher acceleration and braking even under wet and slippery rail/wheel conditions. The disadvantage is the reactive energy in case the wheel diameters will become different during operation from one axle to the other. The power is transmitted via both helical gearboxes to the wheels, which have to equalize by slight sliding because of the different wheelset speeds.

This design has not been applied for some decades, because recent designs of transverse drives resulted in lower mass. However, the basic principle is used today for low-floor light rail vehicles and tramways. In this case, single wheels are applied and one drive unit powers two consecutive wheels (→ page 52).

One-engined bogie designs with two rotors

To eliminate reactive energy in case of different wheel diameters, the traction motor is equipped with two rotors.

Traction motors

Step 1

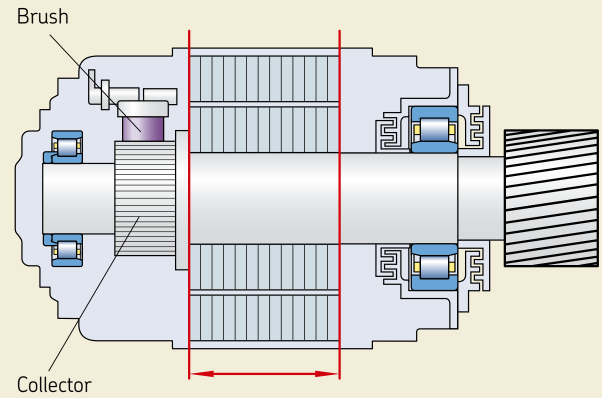
Since the beginning of traction motor development, the design was based on a collector that was electrically fitted by contacting a coal brush. Both the collector and brush required high maintenance (→ page 11 and page 47).

Step 2

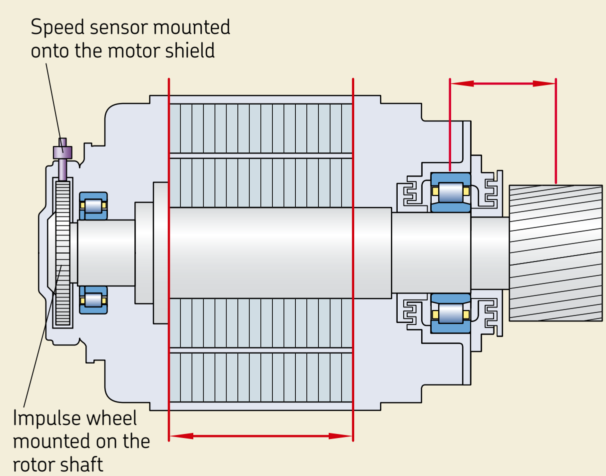
In the early 1980s, AC (three-phase alternating current) propulsion designs were commonly applied for all kinds of electric and diesel electric railway vehicles. AC technique enables development of traction motors with higher rotor speeds, more compactness or increased power for a given size. Heavier radial loads, especially those acting on the drive-side bearings, result from the increased motor torque derived from the increased traction power. Heavier axial forces act on the locating bearing because of the use of helical gearing and increased helix angles. This optimizes gearbox design and efficiency, thereby reducing size and minimizing noise levels.

Step 3

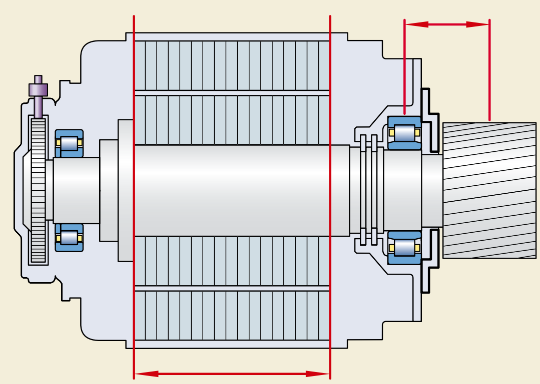
AC traction motors have led to the introduction of oil-lubricated bearings, particularly at the drive side. This reduces the overhang effect by reducing the distance between the pinion and the drive-side bearing. This results in a reduction of the resultant radial load and enables downsizing, and the use of bearings with higher speed ratings. Oil lubrication also allows high bearing speeds when compared to grease lubricated bearings (→ page 40).



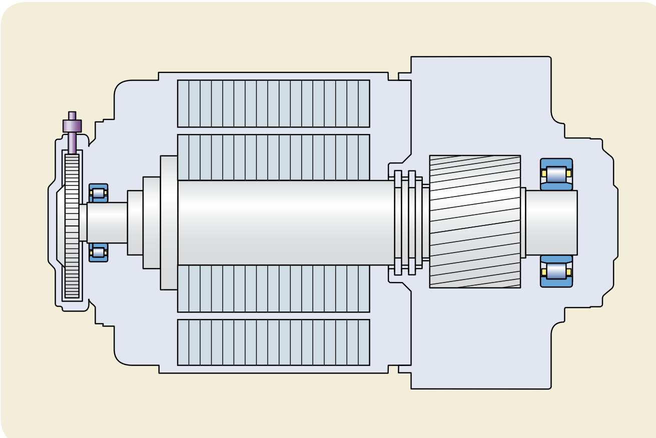
Step 1
Traditional design of a DC or early AC (single phase) traction motor with collector and brush



Step 2
Brushless AC (three-phase alternating current) traction motor, with an external speed sensor for the propulsion system. Very early, electrically insulated INSOCOAT bearings were used to avoid passage of damaging currents through the bearings (→ chapter 4).

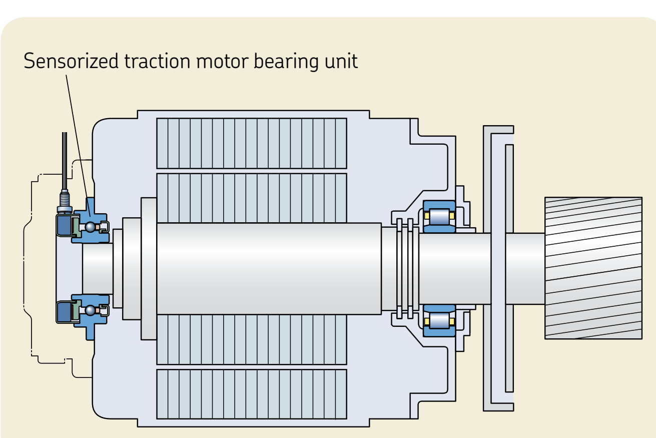


Step 3
AC traction motor where the drive side bearing on the pinion end is now oil lubricated with the gearbox oil thus enabling a reduced overhanging effect of the pinion. The lower bearing load enables down-sizing, resulting in using bearings with higher speed ratings, which are more suitable for the applied rotor speeds. This further enables the use of traction motors with an increased power rating. Electrically insulated INSOCOAT bearings are becoming more and more standard for traction motor design.



Step 4
AC traction motor with drive side non-locating bearing that is supported by the gearbox housing. There is no longer any overhang and the total bearing load is reduced. Therefore, bearing size can be further reduced, which makes the design more suitable for increased motor speed (→ pages 45 to 46).
Electrically insulated bearings have become standard. Depending on the frequency and capacitance versus the Ohmic resistance, like for applications with higher frequencies, hybrid bearings with ceramic rolling elements are used instead of INSOCOAT bearings.

Step 5
Sealed and pre-greased traction motor bearing unit (TMBU) design implemented on the non-drive side of a traction motor.
Depending on the frequency and capacitance versus the Ohmic resistance, like for applications with higher frequencies, hybrid bearing units with ceramic rolling elements are used instead of INSOCOAT bearings.



Step 4

Drive side traction motor bearing arrangements that form part of the gearbox arrangement eliminate the overhang effect completely and result in lower supporting loads. As part of the gearbox arrangement, these bearings are oil lubricated and are suitable for relatively high rotor speeds. This design is used for high-speed trains, locomotives and mass transit vehicles.

Due to the introduction of frequency converter controlled motors for propulsion systems in locomotives and multiple units, demands on traction motor bearings have significantly increased. High frequency stray electric currents are unavoidable in most current applications. The passage of electric current through rolling bearings can lead to damage in a short period of time.

SKF offers three basic design solutions for electrical insulation of traction motor bearings, depending on the application requirements. The electrical impedance is a vector function based on the Ohmic resistance, frequency and capacitance. The capacitance is a measure of the amount of electric charge stored for a given electric potential (→ chapter 4).

Step 5

There is an ongoing worldwide trend to use ready-to-mount factory pre-lubricated bearing units with an integrated sealing system on both sides. These units simplify the mounting process dramatically and contribute to higher reliability and safety.

The traction motor bearing unit (TMBU) concept offers new opportunities for space savings, easier mounting, extended maintenance intervals and improved performance. The TMBU is designed for flange mounting onto the housing. Non-drive side TMBU designs are typically lubricated with special grease to achieve extended grease life, even at high operating temperatures. The bearing unit is equipped with non-contact labyrinth seals that operate frictionless and thus do not wear.

To increase reliability, electrical insulation is realized by using either an INSOCOAT coating or a hybrid design with ceramic/ silicon nitride rolling elements.

The TMBU concept offers space saving opportunities, especially in axial direction. More traction motor power for a given motor size can be achieved when using TMBUs.

These bearing units designs provide, in many cases, a much longer SKF rating life.

This calculation is based on the load conditions, the reliability and the SKF life modification factor that takes the lubrication condition and level of contamination during operation into account. Because of the grease performance, limitation of field service life has to be considered (→ chapter 5).

Generators

To save space in axial direction, the generator is directly flanged onto the combustion engine via an elastic coupling. The non-drive side generator bearing accommodates only radial loads.

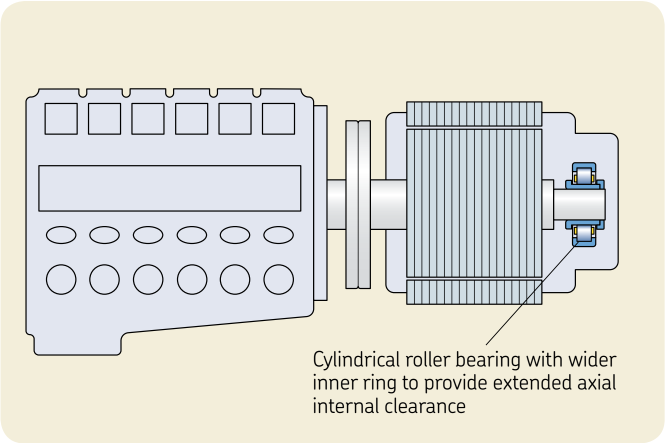
Medium size combustion engines combined with generators are also named power packs.

High speed vehicles

For medium travel distances of several hundred kilometres or even more, high-speed railways offer an attractive, environmentally friendly alternative to aircraft and cars. In most cases, trains directly serve city centres without time consuming shuttle transfers or driving on crowded motorways and encountering any parking problems.

Today, high speed trains are operated worldwide electrically, with only a few exceptions. For definitions of high speed and additional information, refer to page 226.

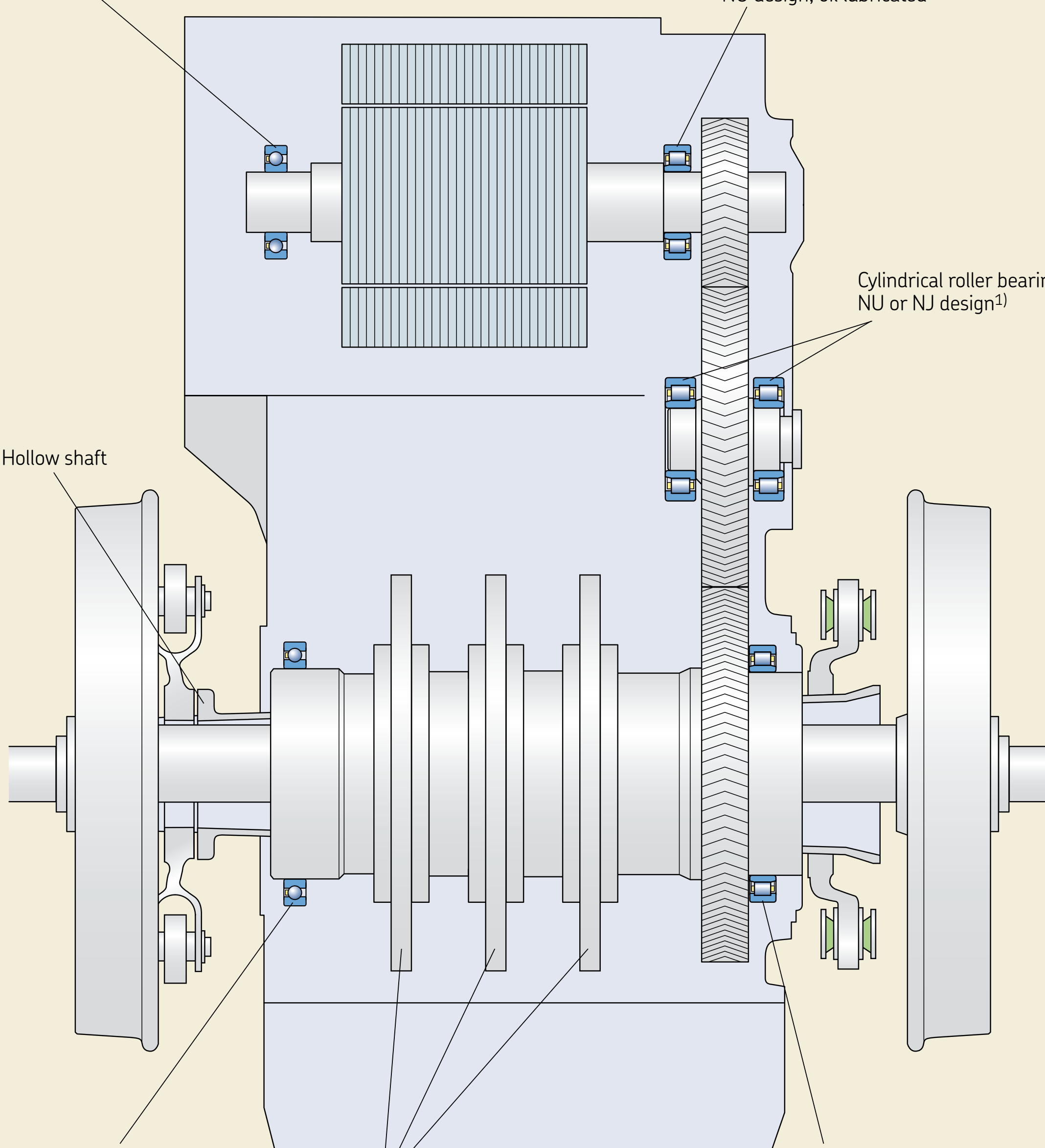
Generator with a one-bearing design principle
In case of axial movements, the axial clearance of the cylindrical roller bearing needs to be increased by several mm in both directions. This can be achieved by using a cylindrical roller bearing with a specially designed wider inner ring



Powered end-units

Some years ago, powered units, also called "power heads", situated on one or both ends of the train were used.

These units, beyond the passenger seating area, were very similar to a locomotive design. This configuration had a higher axle load because of the limited number of powered axles. The axle load caused negative dynamic effects on the tracks.

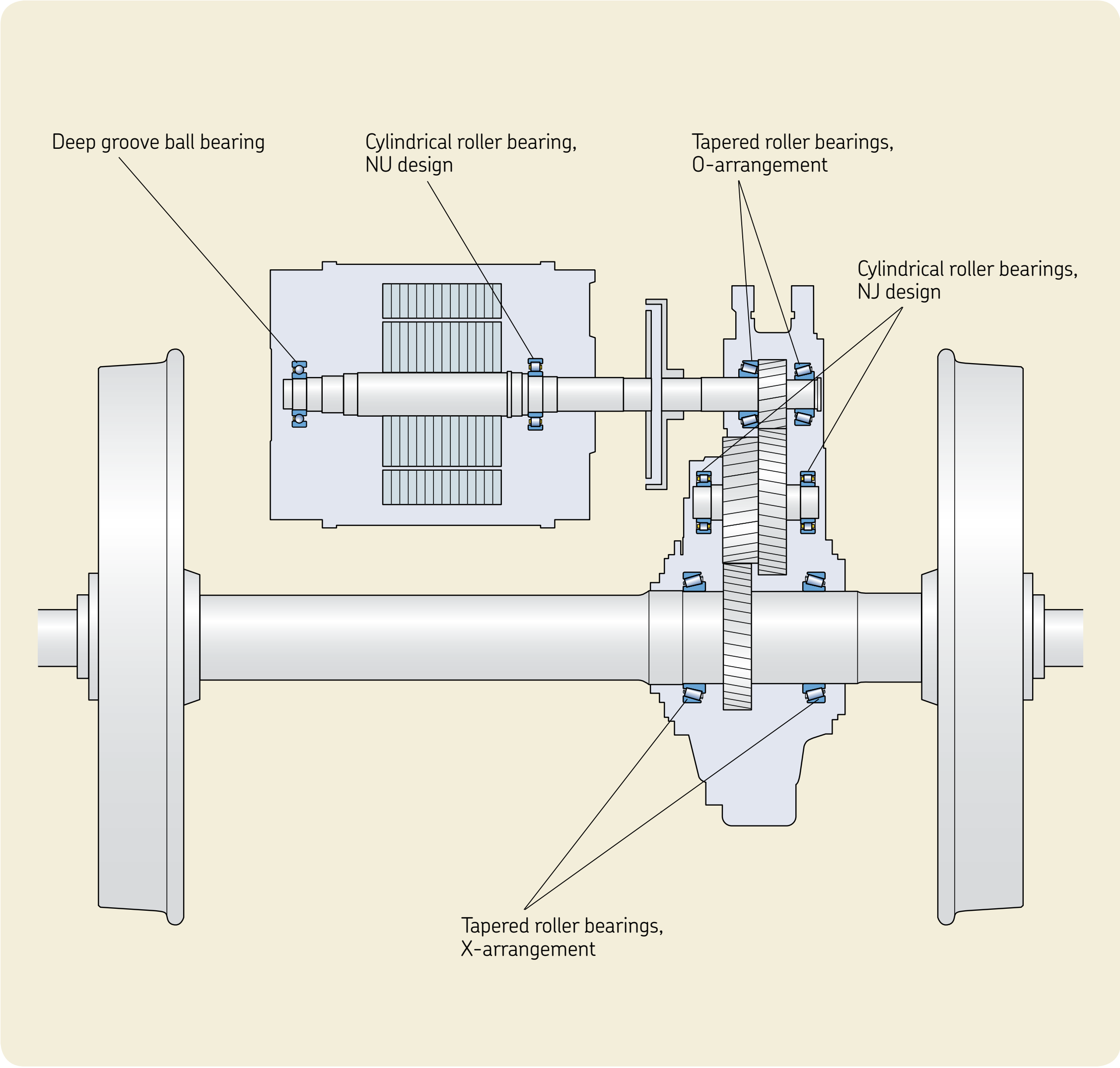


High speed powered end-unit drive system, horizontal view

1) The double helical gearbox is located axially with the traction motor shaft and the wheelset with deep groove ball bearings. The intermediate shaft needs not to be located. In principle, cylindrical roller bearings with NU design can be applied. In some cases, for handling reason NJ designs are used. In this application the inner/outer rings have to be mounted with an offset. Possible specifications are VA301 (→ page 80) or a wider inner ring raceway.

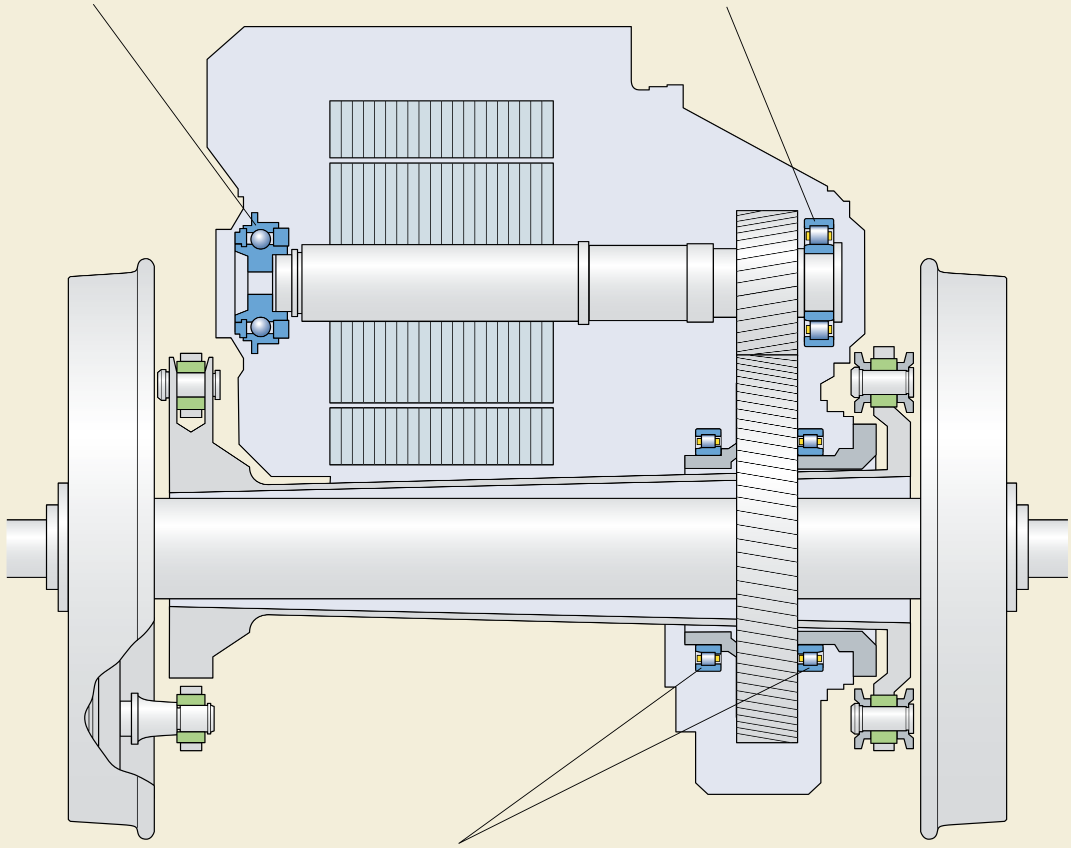
Powered coaches

The trend today is to use more coaches with powered axles to achieve a lower axle load. These multiple drive systems have much lower power per axle, are relatively small and have a lot of similarities with other electric multiple units used for lower speeds. Similar drive systems are used as well for mass transit vehicles.



Semi spring-suspended transverse drive system

Quill transverse drive system, fully spring-suspended



Electric and diesel-electric locomotives

Electric operated freight trains are hauled by electric locomotives. These can be designed for a typical freight car speed or as multi-purpose locomotives that can be used for passenger trains as well. Some locomotives, especially in Europe, are used for freight and passenger trains with speeds in the range of 230 km/h and a high power rating. This usage imposes quite different requirements on the drive design.

Diesel operated freight trains can be hauled by locomotives with electric transmission. In this case, a generator is flanged to the combustion engine while the gearbox (→ **page 39**) and traction motor are very similar to the electric locomotive application. Very typical for heavy haul freight trains is the usage of multiple locomotives with 4 and 6 axles and heavy axle load. Another solution is to use a hydraulic power transmission and a reversing gear (→ **pages 58** to **59**) for operating both directions, and cardan driven gears on the wheelsets. For limited power and speeds, mechanical and hydrostatic drive systems are used.

Nose suspension

Nose suspension drive arrangements are already mentioned in **chapter 1**, **page 11** and on **page 30** to **32**. Today, this drive principle has been developed further to more integrated solution concepts, so as to reduce the unsprung weight, which causes additional dynamic forces acting onto the wheel/rail system.

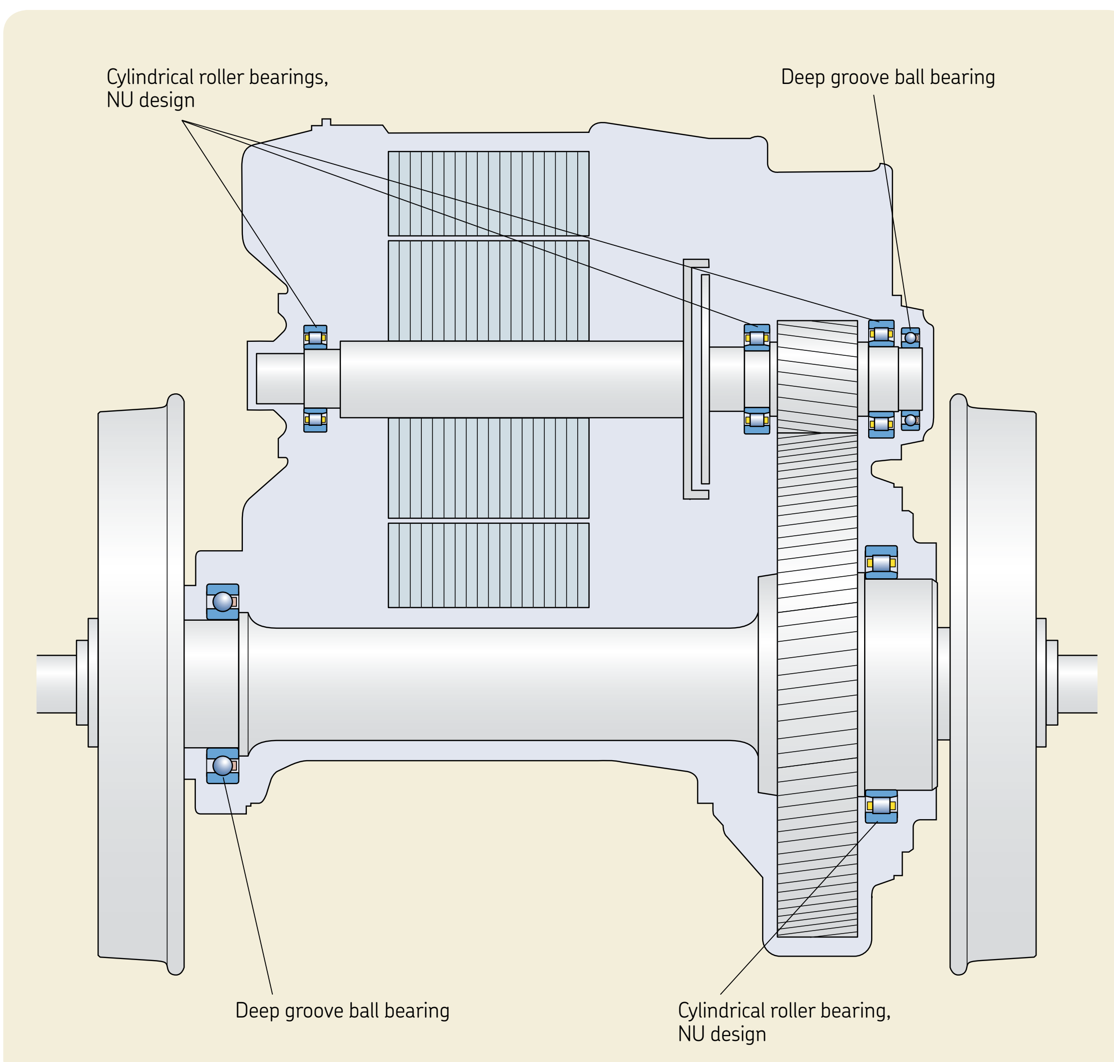
Integrated nose suspension drives

The integration principle enables the traction motor and gearbox to be embedded into one unit to save mass and space. Another advantage is that there are no more grease lubricated and heavily loaded overhanging pinion bearings. The design results in lower loaded bearings, thus enabling downsizing to much smaller bearings that are partly oil lubricated.

Input shaft with 3 or more bearings

This design is characterized by:

- traction motor: direct flanged, one bearing at the non-drive side only, cylindrical roller bearing, NU design or NUP/NH design (→ **page 75**) with special axial clearance to accommodate the axial movements of the elastic coupling.
- gearbox shaft connected via an elastic coupling with the traction motor: mainly, two NU type cylindrical roller bearings for radial load, a deep groove ball bearing for axial load.
- gearbox suspension: drive side equipped with a NU type cylindrical roller bearing, non-drive side equipped with a deep groove ball bearing that accommodates radial and axial loads.

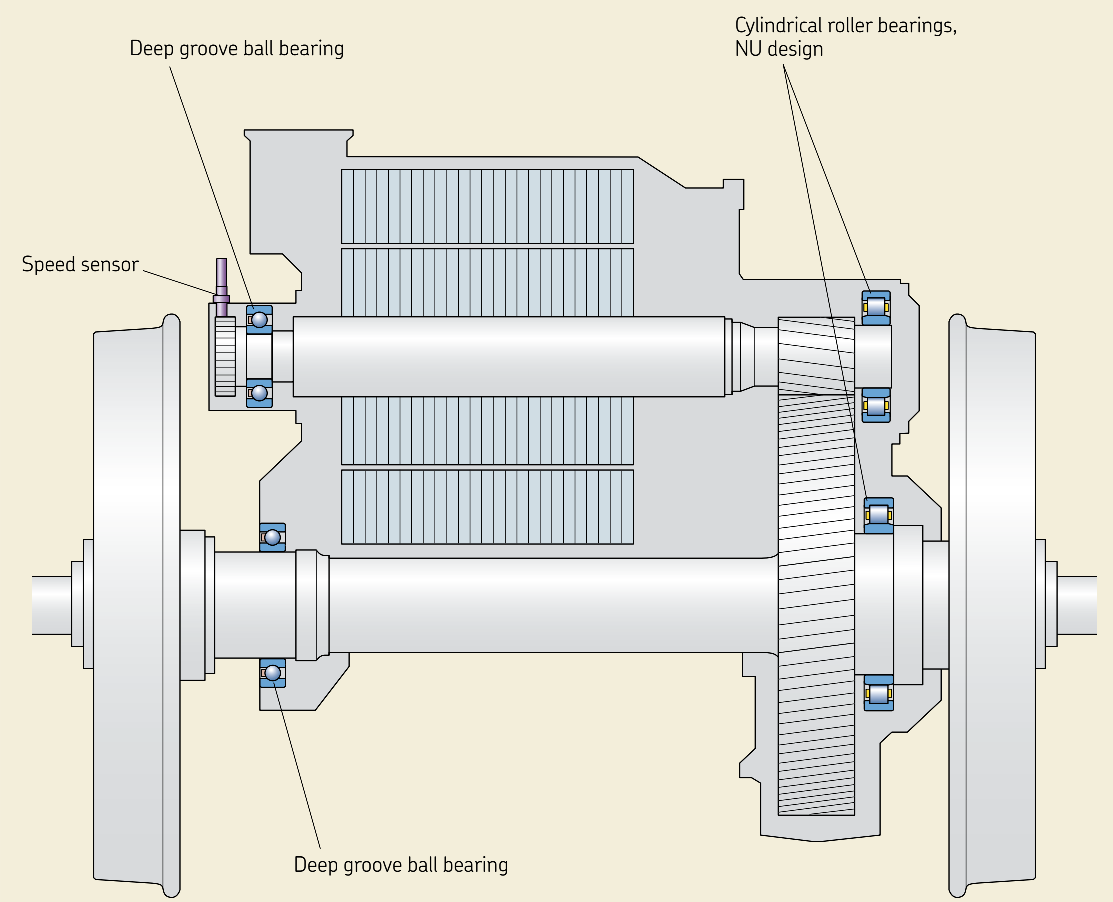


Integrated nose suspension drive

Input shaft with 2 bearings

This design is based on a substitution of the elastic coupling and one gearbox bearing or bearing arrangement. The traction motor shaft and gearbox input shaft functions are unified. This common shaft has an oil lubricated NU type cylindrical roller bearing on the drive side and a grease lubricated deep groove ball bearing on the opposite side that accommodates axial and radial loads.

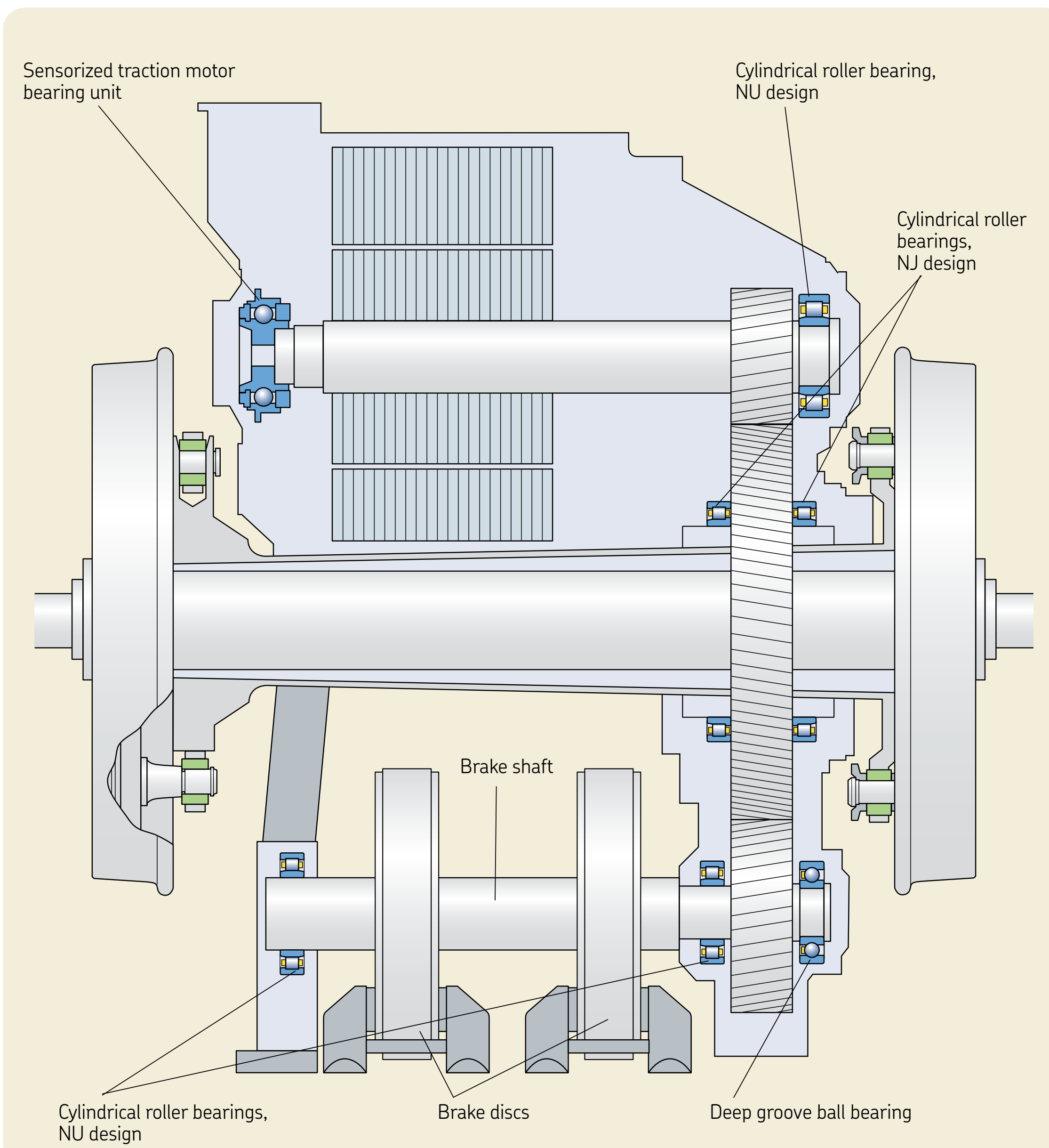
The gearbox suspension is equipped with a NU type cylindrical roller bearing on the drive side and a deep groove ball bearing that supports radial and axial loads on the non-drive side.



Nose suspension drive

Fully-suspended drives

The fully-suspended quill transverse drive principle can be applied to high speed locomotives to reduce dynamic vibrations. One design variant is a gearbox equipped with a special brake shaft. The much higher speed of this shaft compared with the speed of the wheelset contributes to better utilization of the brake, especially at high speed operation.



Quill transverse drive principle applied for high speed locomotives. The gearbox is equipped with an additional brake shaft

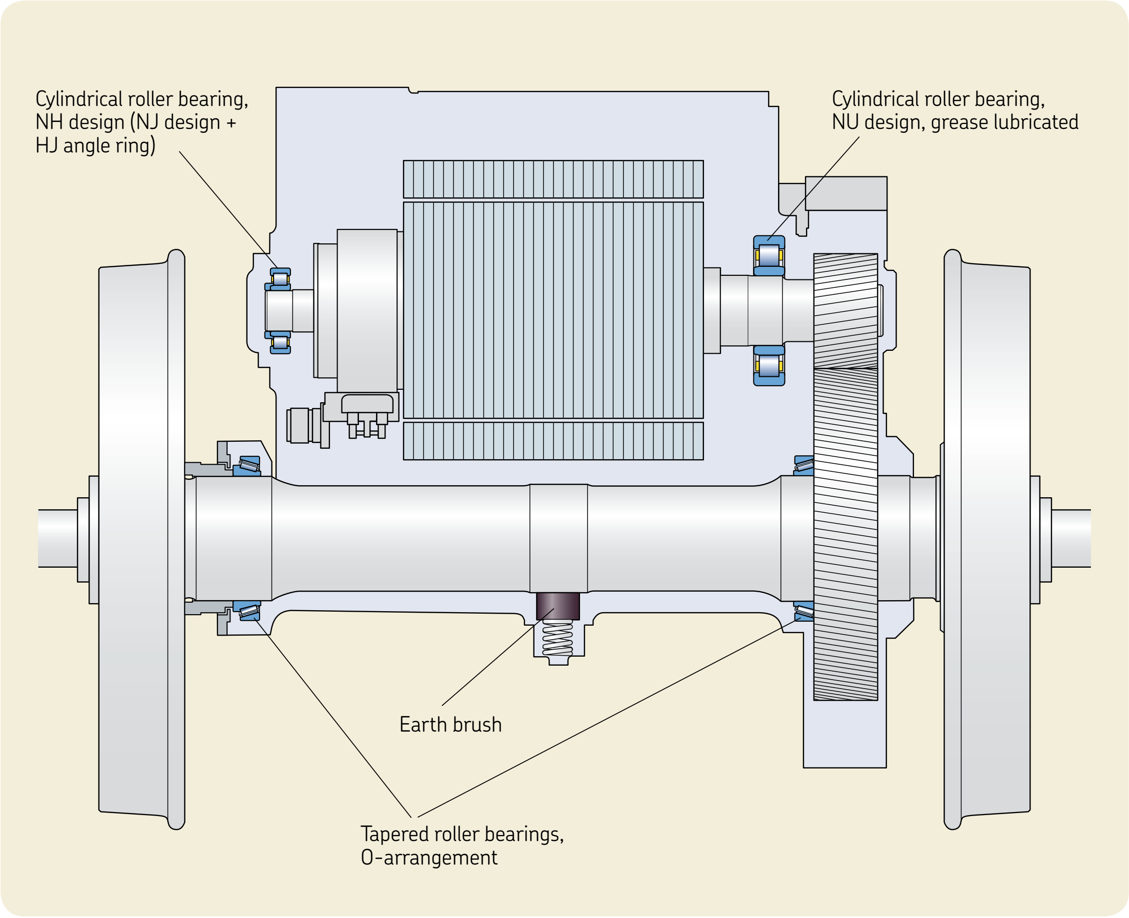
Electric and diesel-electric passenger vehicles

The principal drive design for electric and diesel-electric passenger vehicles can be used for very different vehicle types. These can be multiple units used for long distances and regional service as well as for mass transit applications. Mass transit covers commuter trains, also known as S-Bahn, metro cars and tramways. All these vehicles with high-floor designs have similar drive configurations.

The low-floor light rail vehicle and tramway drive designs are covered on pages 51 to 57.

Transverse drive

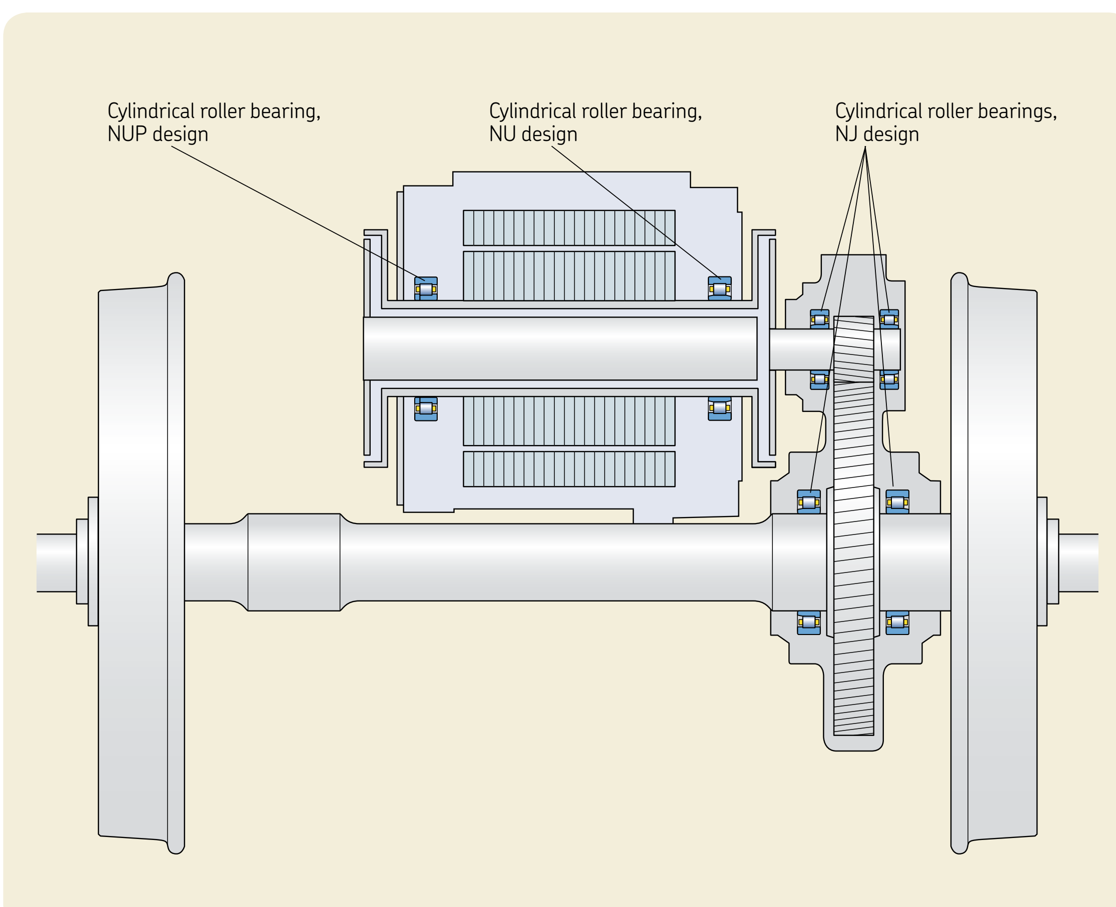
Despite the nose suspension drive principle, various drive principles are used that can be applied as transverse and longitudinal arrangements



Nose suspension drive for metro cars
The earth brush sliding on the wheelset axle is accommodated in the middle of the suspension tube

Half-suspended drive

The half-suspended drive system with an axle riding gearbox can be equipped with a hollow shaft traction motor design to reduce dynamic vibrations. The relatively large bearings are loaded only by the weight of the shaft and the rotor. These forces are very minor compared to the bearing load ratings. Smearing on the raceways and rollers can occur if no counteractions are foreseen.

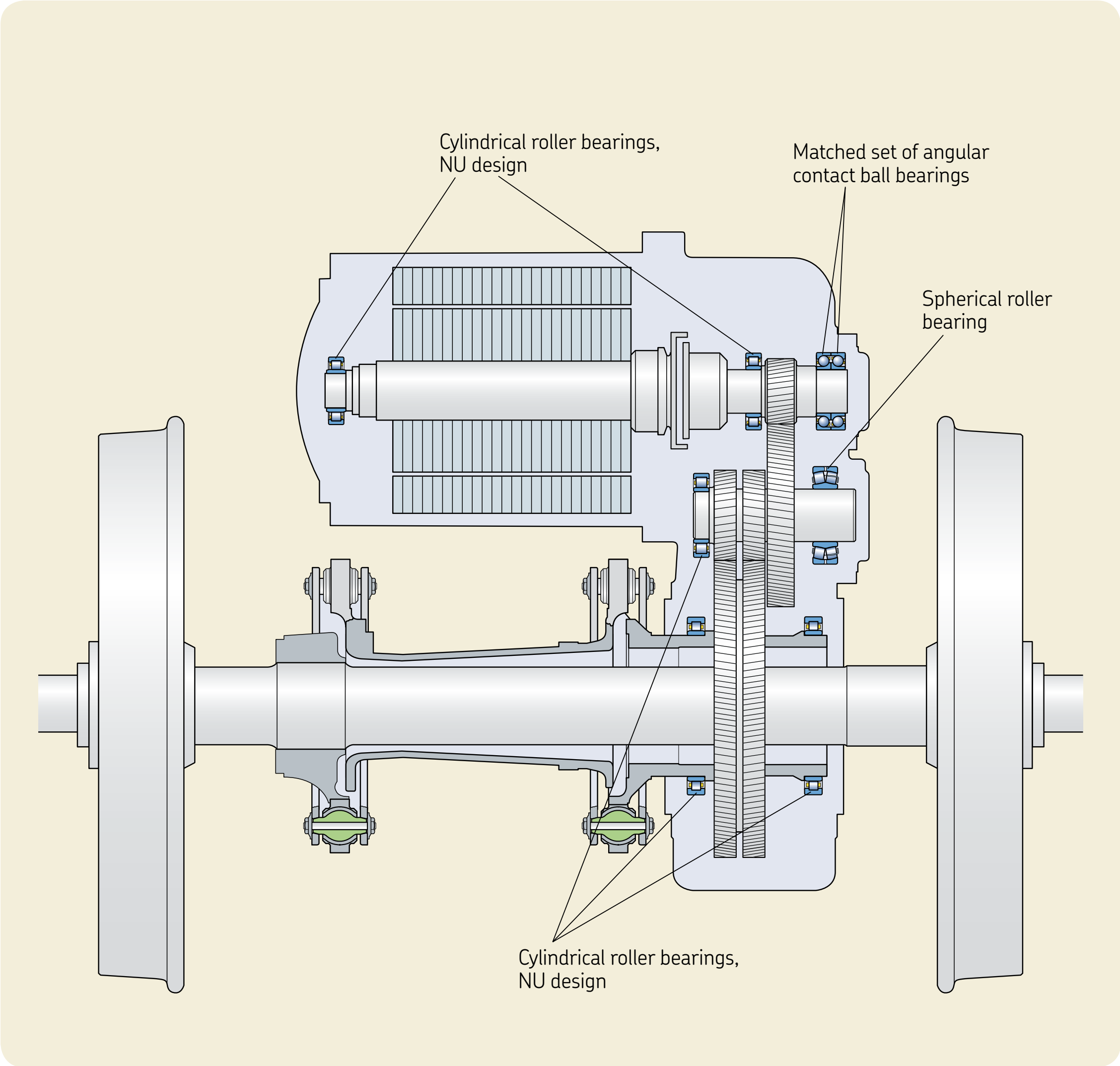


Transverse quill drive where the traction motor has a hollow shaft. The shaft is fitted with an elastic coupling on both sides

Fully-suspended drive

Like for high speed vehicle applications, the quill transverse drive principle is used for many other vehicle types as well. Because of the small spring deflection, the hollow shaft principle can be applied with a much shorter length compared with high speed vehicles. On the gearbox hollow shaft, a disc brake can be fitted [10].

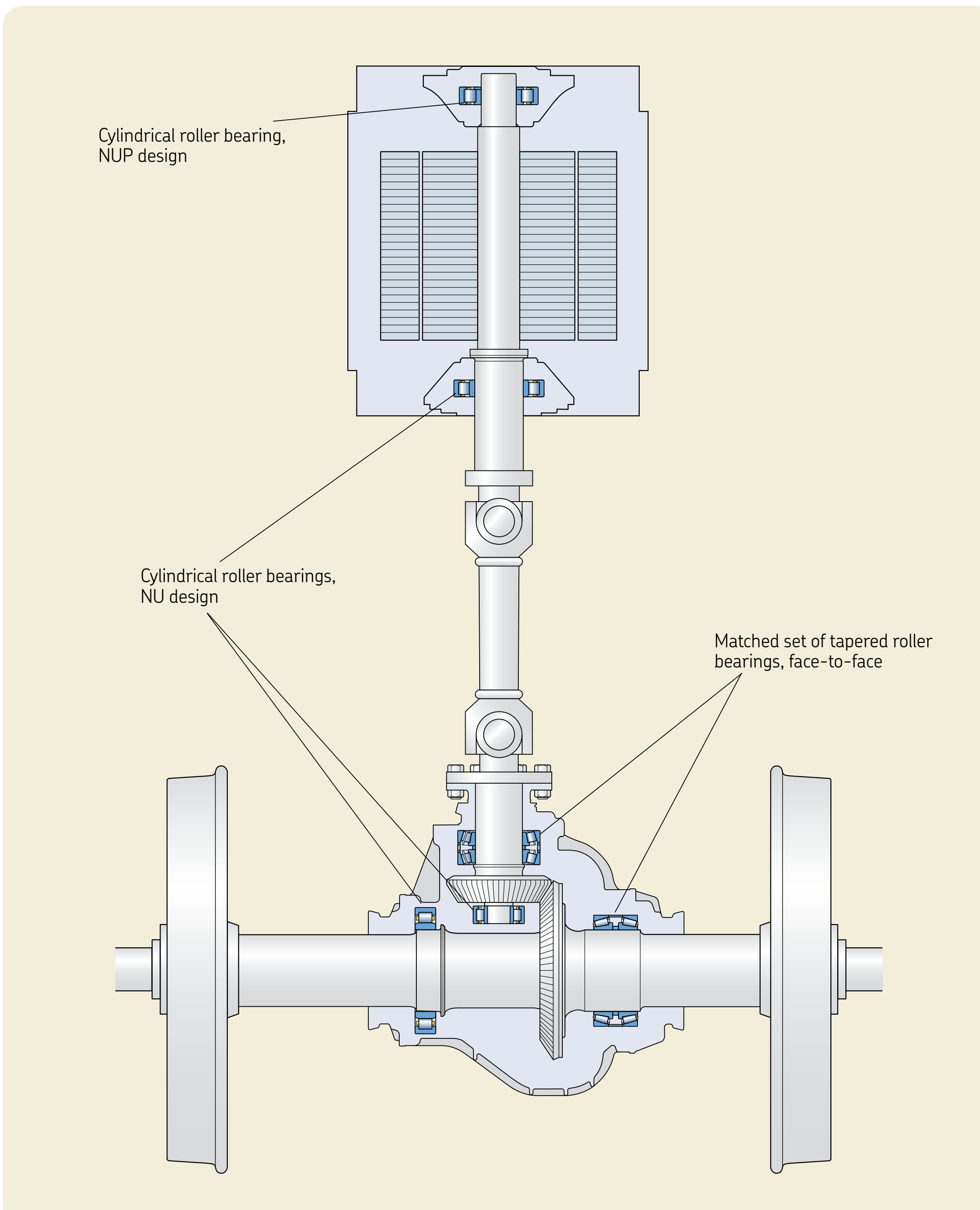
These drive systems are used for metros, high-level light rail vehicles, and partly for low-floor light rail vehicles and tramways. These vehicles have more conventional bogies on both ends and one or more low-floor sections with non-driven axles or independent wheels with smaller diameter.



Fully-suspended drive system for high-speed applications

Longitudinal drives

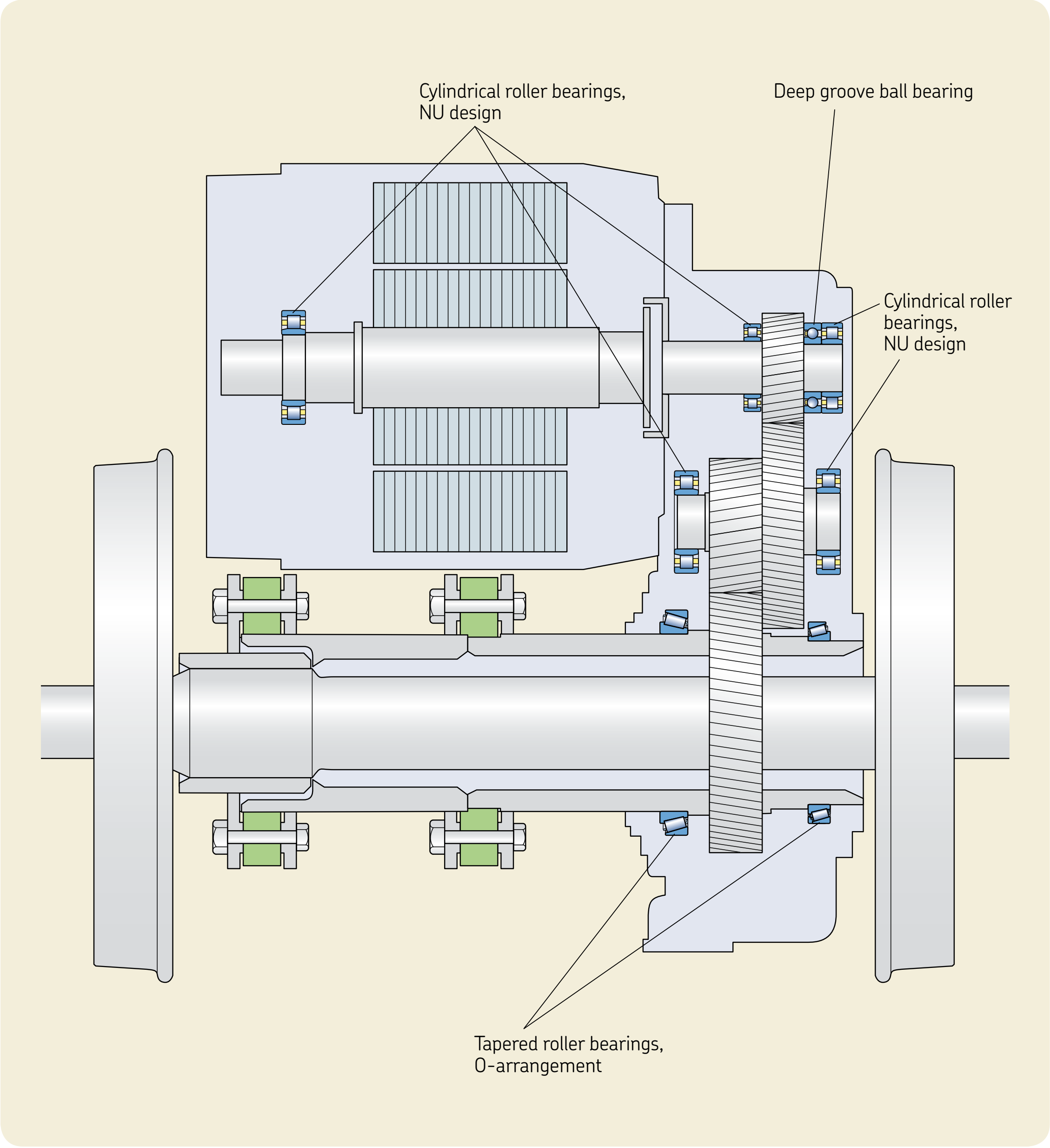
A longitudinal drive arrangement consists of a helical gearbox that can be arranged as axle riding or equipped with a quill drive, and a longitudinal cardan shaft with a traction motor. This design reduces the unsprung mass and the dynamic vibration acting on the traction motor. The traction motor can be supported either by the bogie design or the vehicle body [11]. The relatively long cardan shaft can elongate due to temperature differences. This can lead to induced axial loads on the bearings and if certain values are exceeded, early bearing damage can occur.



Longitudinal drive arrangement consisting of a helical gearbox that can be arranged axle riding or equipped with a quill drive, a longitudinal cardan shaft and a traction motor

Low-floor vehicles

Today, low-floor light rail vehicles and tramways have very different drive configurations. They are based on specific operational needs, manufacturer design principles and stringent space limitations.



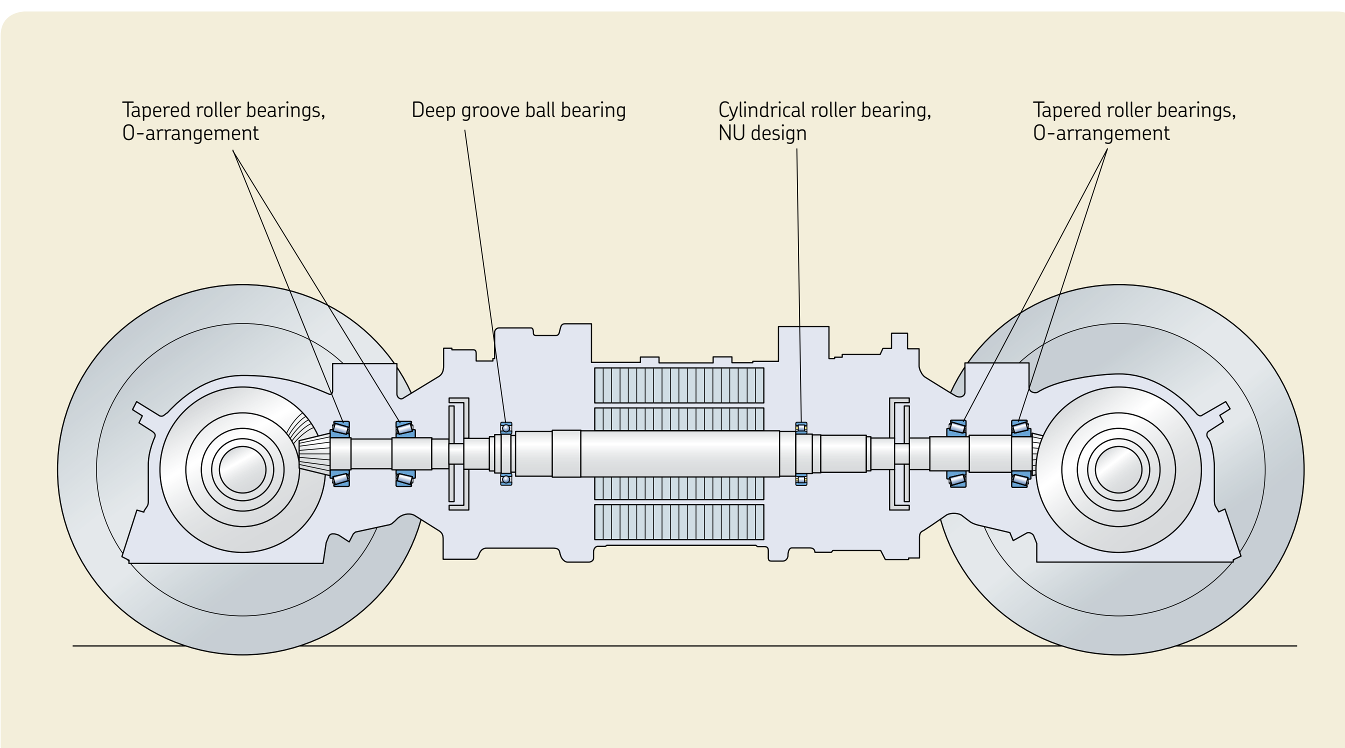
Transverse drive system for 70% low-floor light rail vehicles, fully spring-suspended. This integrated drive system is used for the remaining higher section of low-floor vehicles which offers more space. The axial positioning of the traction motor shaft is achieved by the coupling and the gearbox input shaft. The traction motor bearing on the non-drive side has a non-locating function and supports only radial loads.

Two-wheel drives

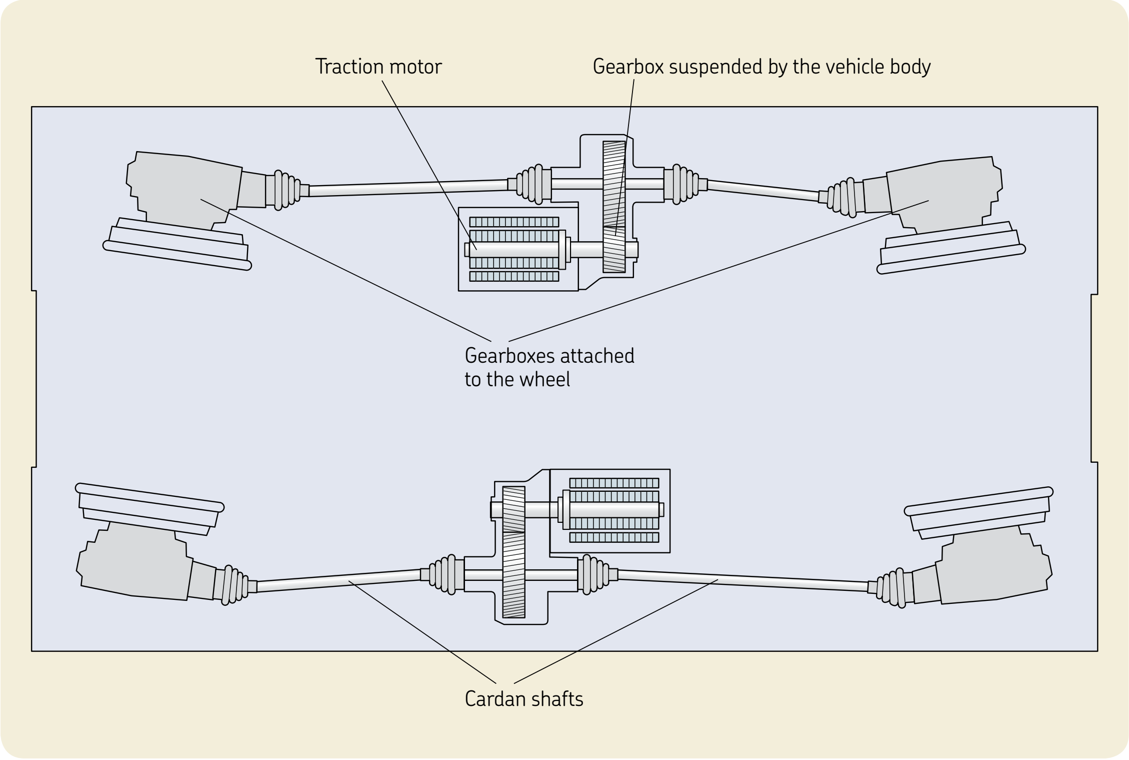
Longitudinal drives

A two-wheel drive system is a longitudinal drive where one traction motor drives two consecutive wheels of a bogie. The torque of the traction motor with two drive ends is transmitted via elastic couplings to the right angle gearboxes. The large gear wheel is connected to the wheel via a short hollow shaft [10].

Two consecutive wheels-drive for low-floor light rail vehicles



For the steered wheels of a low-floor vehicle section, a set up with a longitudinal traction motor and a transfer box gearing is used. The traction motor drives two cardan shafts via a spur gear. Each cardan shaft is connected to a gearbox that drives independent wheels. The brake (not shown here) is attached to the middle spur gearbox.

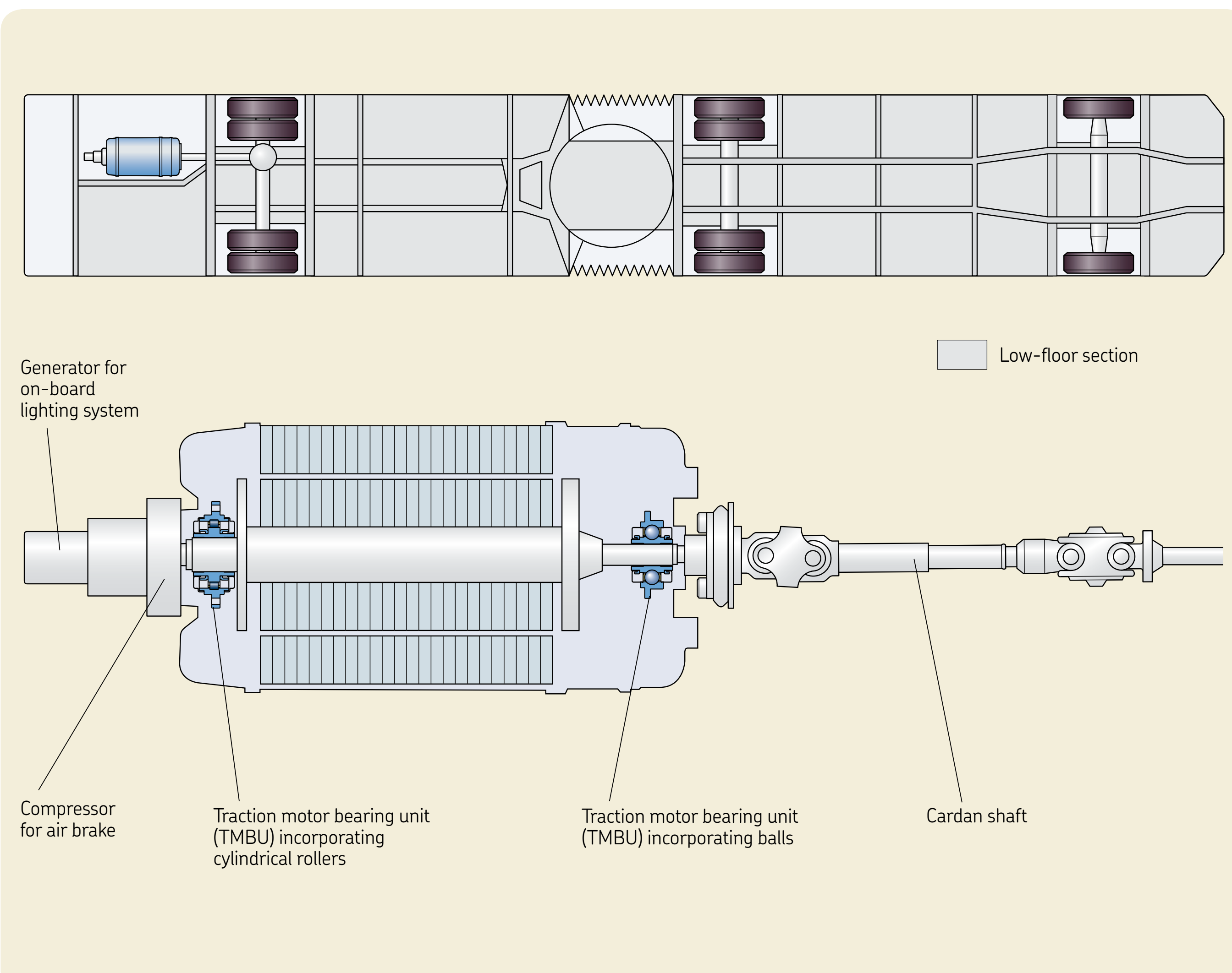


Two consecutive and steered wheels for low-floor light rail vehicles driven by a central, longitudinal traction motor, and a system of cardan shafts, gearboxes and independent wheels

Longitudinal drives for trolleybuses

Low-floor trolleybuses are equipped with a longitudinal traction motor. This typically drives the vehicle axle on one side via a cardan shaft. In many cases, articulated trolleybuses have a drive system working on the rear axle. On the other side of the traction motor, the compressor for the air brake system and the electric generator is flanged.

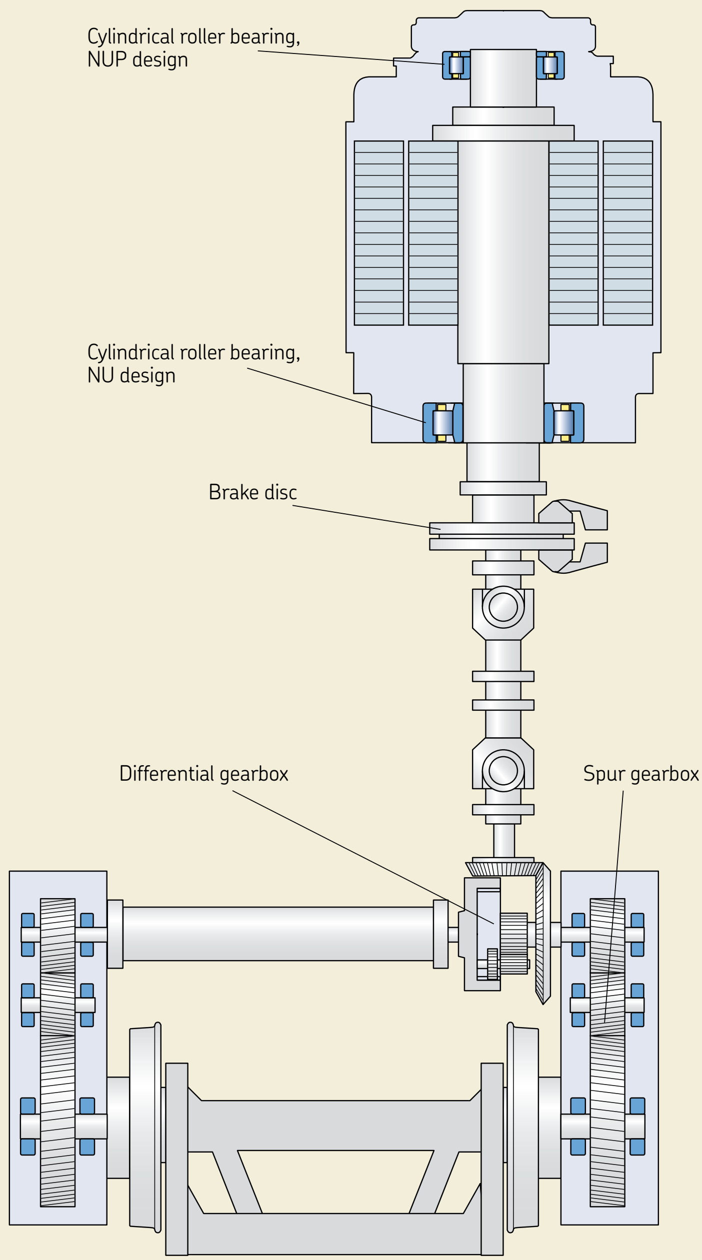
Longitudinal drive principle for low-floor trolleybuses. The drive system powers the rear axle. The traction motor is equipped with a traction motor bearing unit on both sides



Longitudinal/lateral drives

The longitudinal traction motor drives a transfer box gearing via a cardan shaft. This powers one wheel via a spur wheel and a lateral shaft via a right angle gear. This shaft is situated very low to gain free space that allows the floor to be positioned very low, thus providing easy passenger flow inside the vehicle. The shaft powers the opposite wheel via a spur gear. With this drive system, both wheels are mechanically coupled.[1)]

1) This drive system was used for the first time for the Bremen low-floor cars originally designed by MAN, later manufactured by Adtranz and Bombardier. This first serial applied design for 100% low-floor light rail vehicles was applied for several other German and Japanese cities.



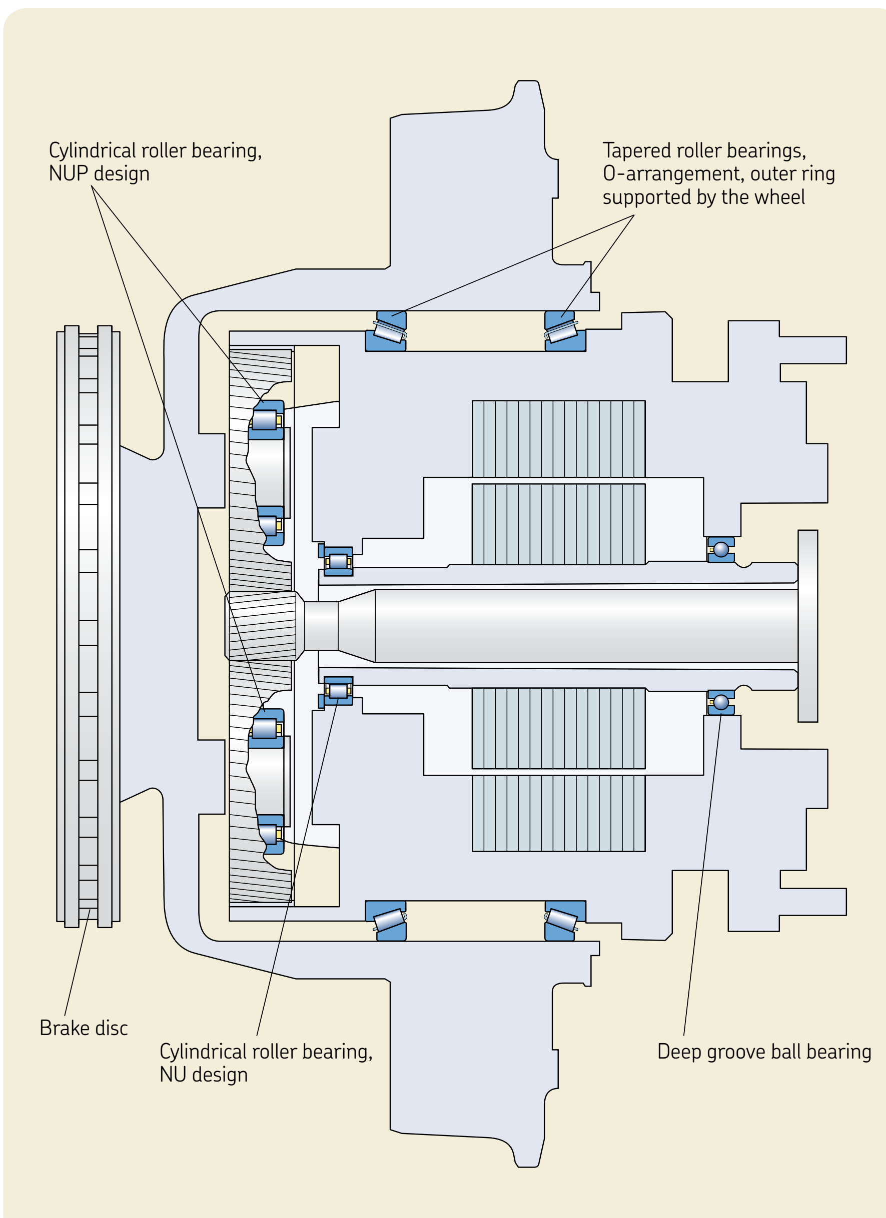
Longitudinal drive system for low-floor light rail vehicles

Single-wheel drives

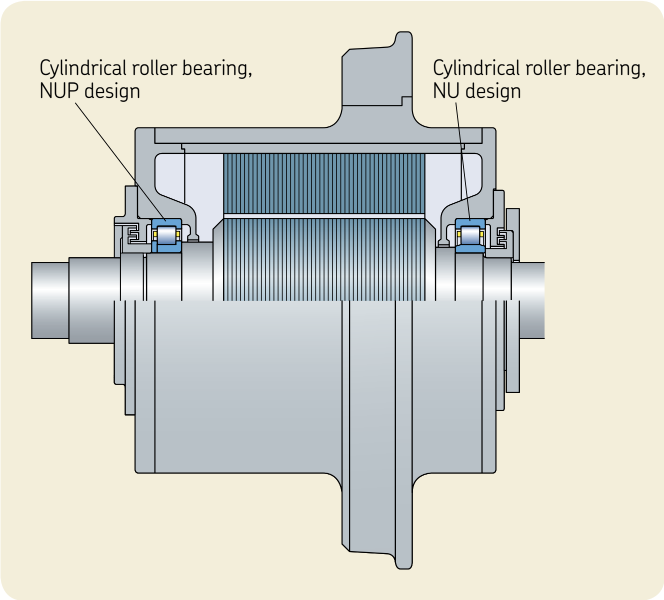
Because of space limitations for low-floor vehicle designs, single-wheel drive systems are applied. Very different designs are used to meet operator and OEM requirements. The main advantage is the free space between the single-wheel drive system that enables the floor to be positioned very low, thus providing easy passenger flow inside the vehicle.

Planetary gearing

The traction motor drives the sun wheel of the planetary drive gearbox via its rotor. The planet wheel carrier is connected with the wheel arrangement that has a rubber suspended wheel tire. Like the traction motor rotor, the wheel arrangement is supported on the traction motor stator housing via two tapered roller bearings.



Planetary drive system for single-wheel drive system used for low-floor light rail vehicles



Hub motor drive system,
supported by cylindrical roller bearings, outer ring rotation

Hub traction motor

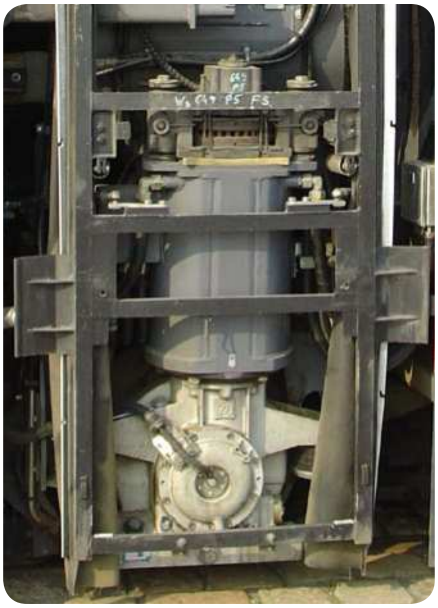
The hub traction motor concept is based on a direct drive system with an integrated wheel function. Today, very different design principles are applied. One of these is a traction motor design that directly powers the wheel and acts as wheel support and guidance without any gearbox or coupling components [4]. The outside rotor directly powers the rubber spring-suspended wheel tyre. This space saving arrangement is especially suitable for 100% low-floor tramways, which have a plain floor without any steps or ramps.

Vertical drives

The space between the vehicle sections of a low-floor vehicle can be used to accommodate the running gear and drive systems. The connecting portals of the vehicle sections are supported via a wheel/gearbox unit.

The vertical traction motor is suspended via the portal and drives the wheel/gearbox unit.

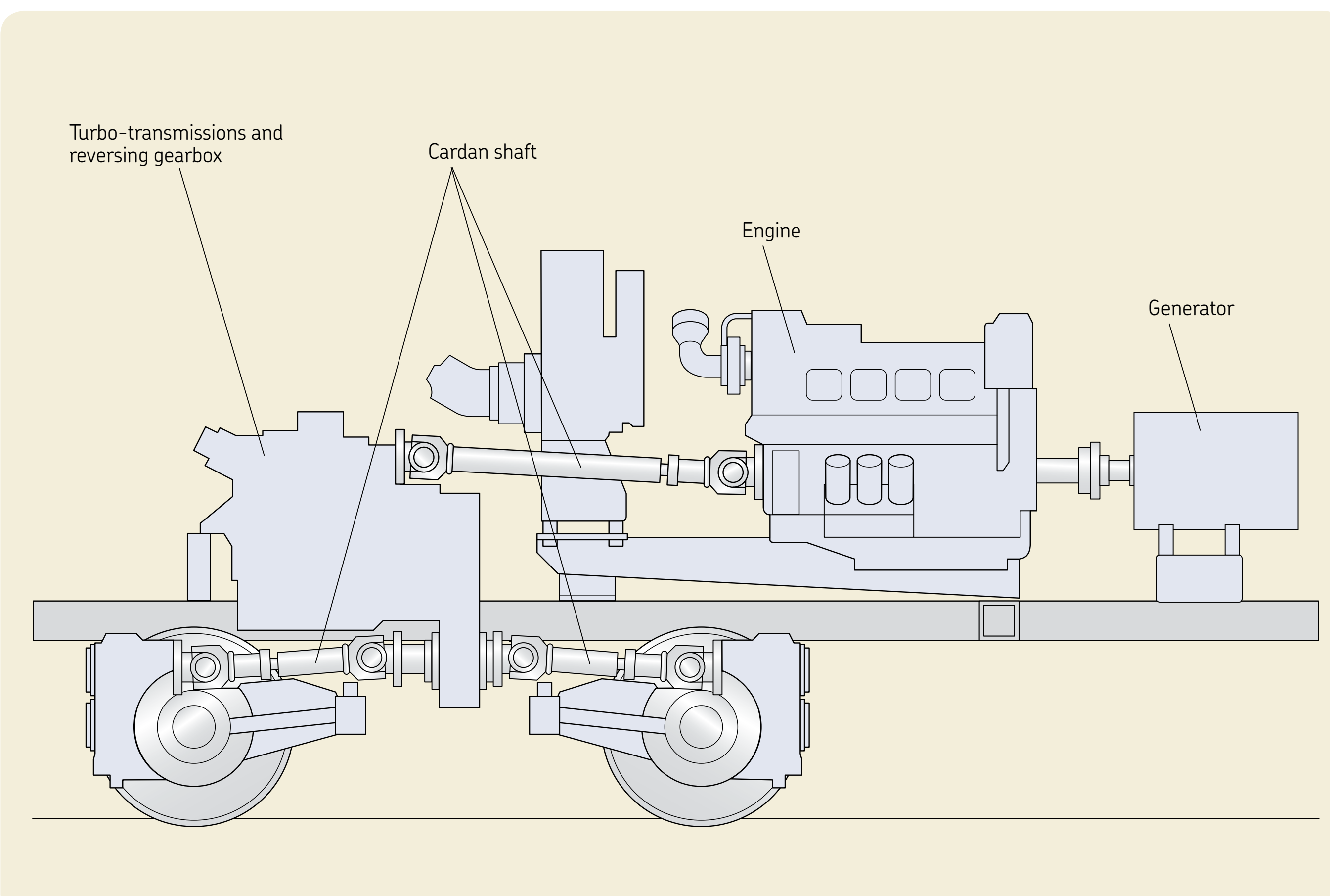
Vertical drive system for single-wheel system used for low-floor light rail vehicles

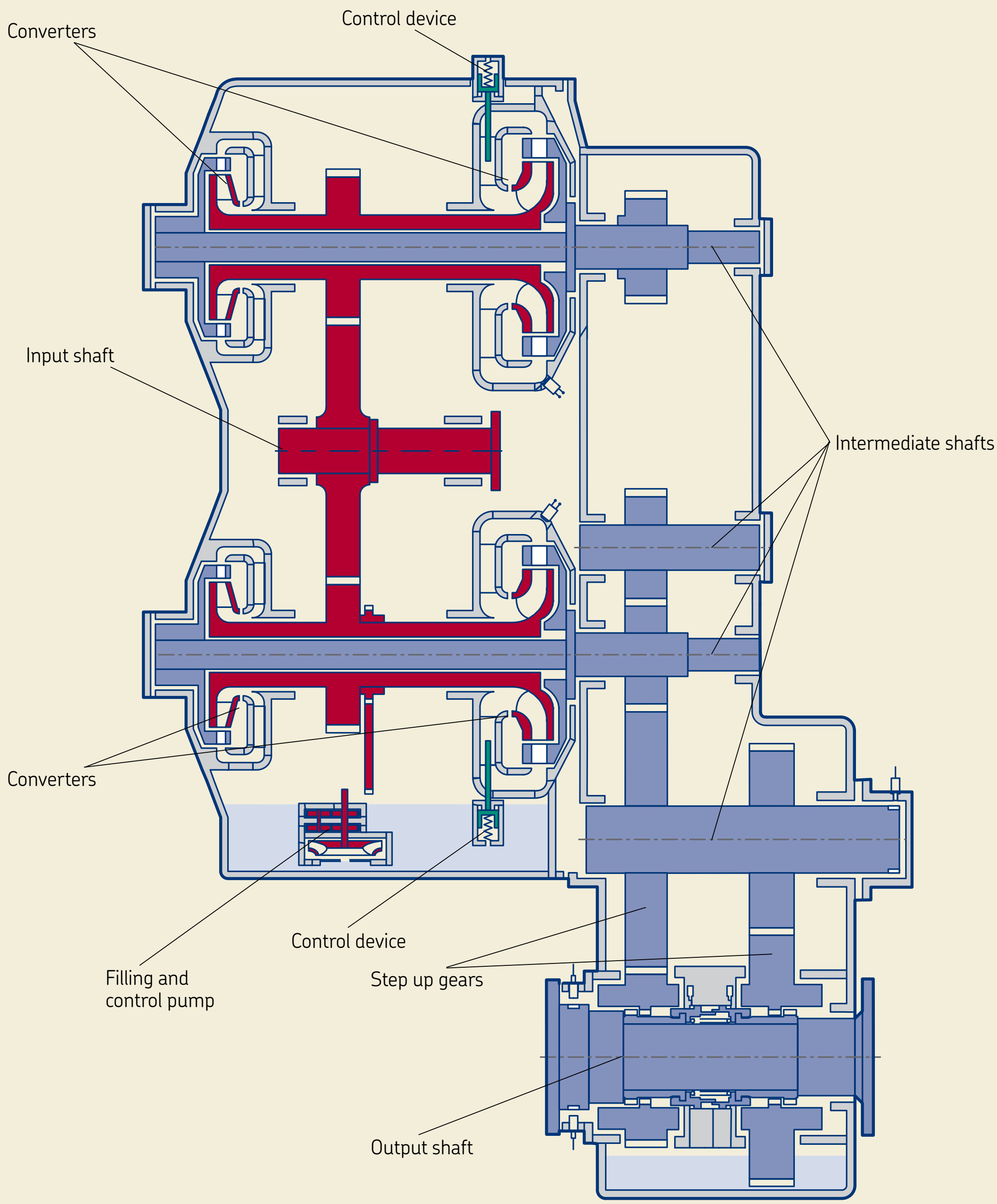


Diesel hydraulic vehicles

Hydraulic transmissions, also known as turbo transmissions, transform power and speeds by using hydraulic fluid to drive hydraulic machinery. The fluid is driven through rotor blade canals at high flow-rates and low pressure. Turbo-transmissions are hydrodynamic, and can be multi-stage drive assemblies. From the fluid transmission, the power is transmitted to the reversing gearbox and the axle gear. The two axles of a bogie are typically connected with additional cardan shafts.

Propulsion system principle for diesel-hydraulic vehicles with applied turbo-transmission





Turbo reversing transmission gear principle
Drawing: Voith Turbo

Bearing arrangement principle for the various shafts (→ page 72):

- Locating bearing arrangement: combination of a cylindrical roller bearing supporting the radial load and a four-point contact ball bearing supporting the axial loads in both directions
- Non-locating bearing: cylindrical roller bearing supporting the radial load

SKF suspension tube quality control

SKF suspension tubes

SKF has a long tradition in developing and manufacturing suspension tubes. The design principles are already mentioned on **pages 31** to **32**. In this subchapter the characteristics of suspension tube bearings are described in detail.

Today, suspension tubes are mainly applied for heavy-duty applications. The design has to provide optimized stiffness to ensure exact gear meshing and to reduce misalignment, noise and wear during operation. The suspension tube design has to consider the interaction with the complete transmission system.

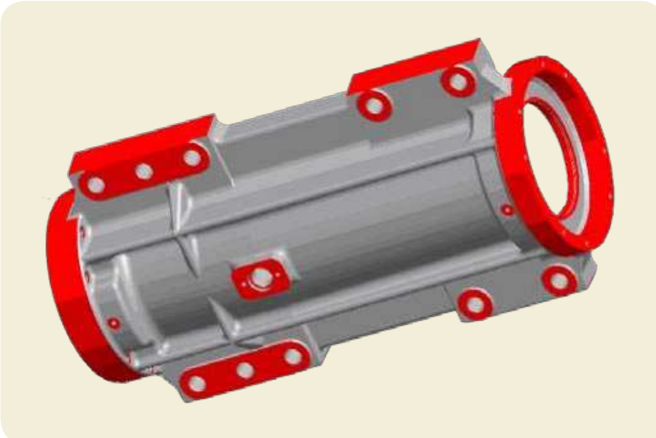
For full bore suspension tubes, glass fibre sleeves with the appropriate bearing fit in the bore can be applied. These inserted special sleeves enable easy bearing replacement during remanufacturing, if needed.

Based on customer specifications, SKF provides detailed design studies supported by application engineering knowledge to work out a tailor-made solution. SKF takes care of manufacturing, quality control and delivers a ready-to-mount package to the customer. SKF service engineers can train the mounting staff to ensure proper installation. In addition, a complete mounting service with SKF service engineers and fitters can be provided.

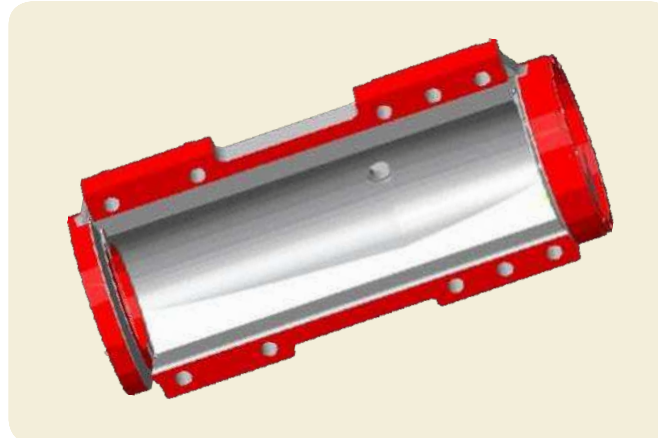
As part of the railway vehicle maintenance programme, SKF can offer quality inspection and remanufacturing of suspension tubes including turning, spiral welding and re-machining the bearing fits.

SKF suspension tube benefits

- comprehensive system solution supply integrated into the transmission subsystem
- one-stop shop
- competent handling of the interface between bearing and housing
- customized engineering and logistic solutions
- ready-to-mount packages
- high engineering competencies
- global customer support and project handling
- after-sales service options

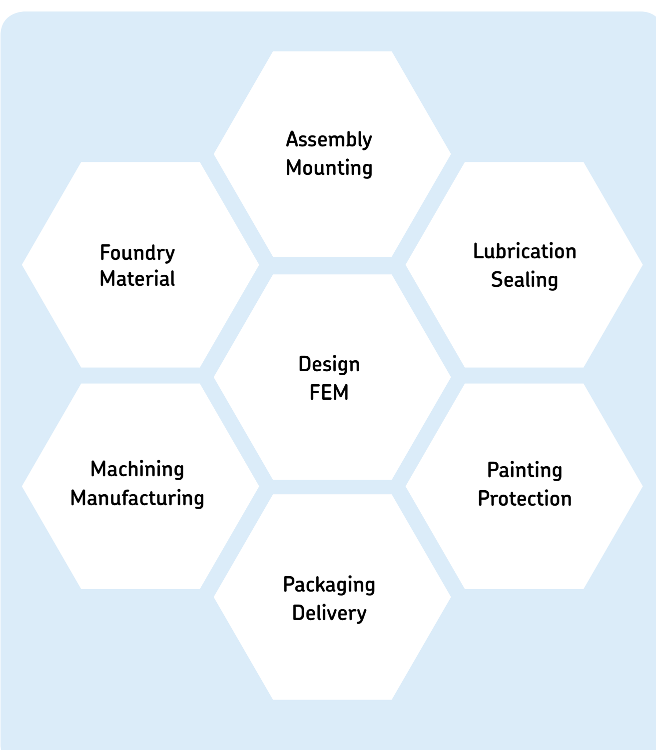


SKF suspension tube design
The red coloured areas refer to the machined surfaces



SKF suspension tube top view
The red coloured areas refer to the machined surfaces

Main competence requirements for suspension tube designs



SKF suspension tube ready for shipment
A glass fibre sleeve is fitted to the bore, which enables easy bearing replacement during remanufacturing, if needed.

3 Bearing designs

Bearing designs

SKF offers a wide choice of bearing designs for traction motor and gearbox applications. Information about INSOCOAT and hybrid bearings and units can be found in the following chapters. Information on other bearings not mentioned here, such as spherical roller bearings, can be found in SKF catalogues.

Bearing capabilities

The operating conditions for bearings in drive designs, such as used for traction motors and railway gearboxes, are very different from those normally encountered in electric motors in other industries. These railway sub-systems must be robust, reliable, light and compact. The bearings must also cope with difficult environments with high contamination and humidity levels, as well as variations in speed, temperature, load, vibration levels and shock loads.

High reliability is an essential requirement for modern designs with long maintenance intervals. SKF has developed solutions to increase both reliability and extend maintenance intervals. These solutions can be based on further improvement of special bearing design features or on more advanced designs such as electric insulated bearings and bearing unit designs. A further improvement step is the application of sensor bearings and monitoring systems which are described in the following chapters.

To design a rolling bearing arrangement, it is necessary to first

- select a suitable bearing type
- determine a suitable bearing size and design

But this is not all. Several other aspects have to be considered, such as

- a suitable form and design of other components of the arrangement
- appropriate fits and bearing internal clearance or preload
- holding devices
- adequate sealing systems
- the type and quantity of lubricant
- installation and removal methods, etc.

Each individual decision concerning each aspect affects the performance, reliability and economy of the bearing arrangement.

The amount of design efforts entailed depends on whether experience is already available about similar arrangements. When experience is lacking, when extraordinary demands are made, or when the costs of the bearing arrangement and any subsequent outline have to be given special consideration, then much more work is needed, including, for example, more accurate calculations and/or testing.

In the following chapters, the designer of a bearing arrangement can find a selection of drive application specific information. Further information is available in *SKF catalogues* and online at skf.com/bearings. For detailed information, contact the SKF application engineering service.

They can provide technical support about selecting the bearings, but also perform calculations on the complete bearing arrangement. The higher the technical demands placed on a bearing arrangement and the more limited the available experience of using bearings for particular applications, the more advisable it is to use this service.

Selection of bearing type

Each bearing type displays characteristic properties, based on its design, which makes it more or less appropriate for a given application. For example, deep groove ball bearings can accommodate moderate radial loads as well as axial loads. They operate with low friction and can be produced with high precision and in quiet running variants. Therefore, they are preferred for small and medium-sized electric motors.

Spherical and toroidal roller bearings can accommodate very heavy loads and are self-aligning. These properties make them popular, for example, for heavy engineering applications where there are heavy loads, shaft deflections and misalignments.

In many cases, however, several factors have to be considered and weighted against each other when selecting a bearing type, so that no general rules can be given.

The information provided here should serve to indicate the most important factors that need to be considered when selecting a standard bearing type and thus facilitate an appropriate choice.

- available space
- loads
- misalignment
- precision
- speed
- quiet running
- stiffness
- axial displacement
- mounting and dismounting
- integral seals

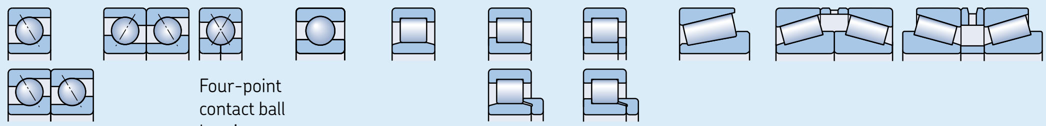
A comprehensive overview of the standard bearing types, their design characteristics and their suitability for the demands placed on a given application can be found in the matrix. The boxes refer to the most commonly used traction motor and gearbox bearings. Detailed information about individual bearing types, including their characteristics and the available designs, can be found in SKF catalogues.

The matrix permits only a relatively superficial classification of bearing types. The limited number of symbols does not allow an exact differentiation and some properties do not depend solely on bearing design. For example, the stiffness of an arrangement incorporating angular contact ball bearings or tapered roller bearings also depends on the applied preload and the operating speed, which is influenced by the precision of the bearing and its associated components, as well as by the cage design.

For special applications with higher operating temperatures, special dimensional material stability might be necessary.

Other important criteria to be observed when designing a bearing arrangement include load carrying capacity and life, friction, permissible speeds, bearing internal clearance or preload, lubrication and sealing. Information can be found in SKF catalogues and online at skf.com/bearings. For detailed information, contact the SKF application engineering service.

Bearing types – design and characteristics[1)]



	Angular contact ball bearings			Deep groove ball bearings	Cylindrical roller bearings			Tapered roller bearings		
			Four-point contact ball bearings							
Purely radial load	+	++	-	+	++	++	++	++	+++	+++
Purely axial load	+ ←	+ ←→	++ ←→	+ ←→	--	-	-	++ ←	++ ←→	++ ←→
Combined load	++ ←	++ ←→	+ ←→	+ ←→	--	+ ←	+ ←→	+++ ←	+++ ←→	+++ ←→
Moment load	-	+	+	-	--	--	--	-	+	+
High speed	++	+	++	+++	++	++	++	+	+	+
High running accuracy	+++	++	+	+++	++	++	++	+	+	+
High stiffness	+	++	+	+	++	++	++	++	+++	+++
Quiet running	++	+	+	+++	++	+	+	+	+	+
Low friction	++	+	+	+++	++	++	++	+	+	+
Compensation for misalignment in operation	-	--	--	-	-	-	-	-	-	-
Compensation for errors of alignment (initial)	-	--	--	-	-	-	-	-	--	--
Locating bearing arrangement	++ ←	++ ←→	++ ←→	++ ←→	--	++ ←	++ ←→	+++ ←	+++ ←→	+++ ←→
Non-locating bearing arrangement	--	+	-	+	+++	+ ←	+	--	-	-
Axial displacement possible in bearing	--	--	--	--	+++	+ ←	+	--	--	--

Symbols: +++ excellent, ++ good, + fair, - poor, -- unsuitable, ← single direction, ←→ double direction

1) This matrix can only provide a rough guide so that in each individual case it is necessary to make a more qualified selection referring to the information given in SKF catalogues.

3

Bearing installation

General advice about bearing installation can be found in SKF catalogues and the *SKF maintenance handbook*, also available online at skf.com/bearings.

In the subchapter below, some general advice about common bearing systems can be found.

Bearing system

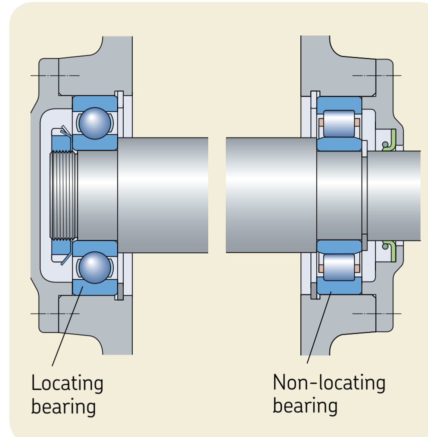
A bearing system, which is typically used to support a rotating shaft, generally requires two bearing arrangements to support and locate the shaft radially and axially, relative to stationary components, like housings. Depending on the application, loads, requisite running accuracy and cost considerations, various bearing systems can be designed:

- a locating/non-locating bearing system
- an adjusted bearing system
- a "floating" bearing system

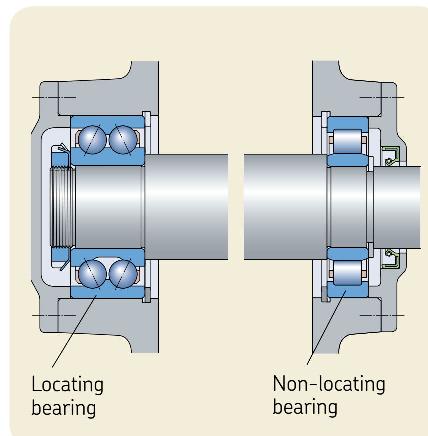
In a bearing system, the bearing arrangement at one end of the shaft must be able to locate the shaft axially. This is accomplished by securing one bearing axially on the shaft and in the housing. The bearing arrangement on the opposite end of the shaft is non-locating and is designed to accommodate thermal displacements of the shaft relative to the housing to avoid induced internal loads.

For the locating bearing position, radial bearings that can accommodate combined (radial and axial) loads are used. These include deep groove ball bearings, double row or matched single row angular contact ball bearings, self-aligning ball bearings, spherical roller bearings, matched tapered roller bearings, NUP design cylindrical roller bearings, or NJ design cylindrical roller bearings mounted with an HJ angle ring.

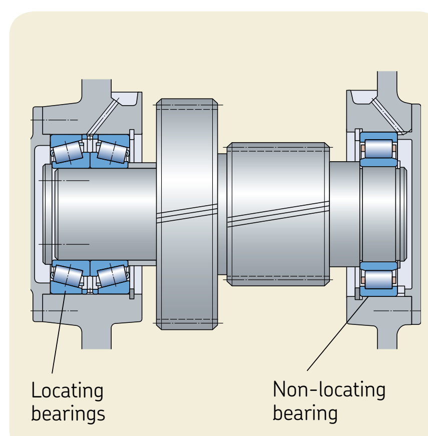
Alternatively, the bearing arrangement in the locating position can consist of a combination of two bearings: a radial bearing that accommodates radial load only, such as a cylindrical roller bearing that has one ring without flanges, and a bearing that provides axial location, such as a deep groove ball bearing, a four-point contact ball bearing, or a double direction thrust bearing. The bearing that locates the shaft axially must not be located radially and is typically mounted with a small radial gap in the housing.



Locating/non-locating bearing system incorporating a deep groove ball bearing and a NU (or N) design cylindrical roller bearing



Locating/non-locating bearing system incorporating a double row angular contact ball bearing and a NU (or N) design cylindrical roller bearing



Locating/non-locating bearing system incorporating a set of matched tapered roller bearings and a NU (or N) design cylindrical roller bearing

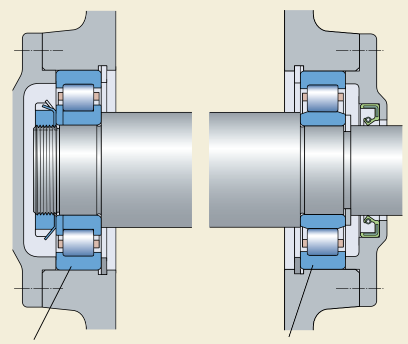
There are two ways to accommodate thermal displacements of the shaft at the non-locating bearing position. The first one is to use a bearing that accommodates radial loads only and enables axial displacement within the bearing. These include CARB toroidal roller bearings, needle roller bearings and cylindrical roller bearings that have one ring without flanges. The other method is to use a radial bearing mounted with a small radial gap in the housing so the outer ring is free to move axially.

Bearing fits

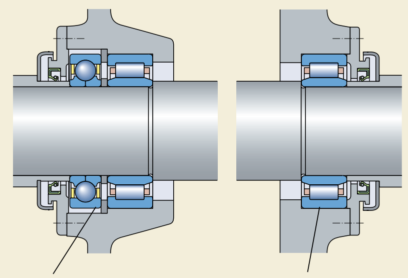
The tolerances for the bore and outside diameter of standard rolling bearings are internationally standardized. See SKF catalogues and the *SKF maintenance handbook*, also available online at skf.com/bearings

To achieve an interference or a clearance fit for bearings with a cylindrical bore and cylindrical outside diameter surface, suitable tolerance ranges for the seats on the shaft and in the housing bore are selected from the ISO tolerance system. Only a limited number of ISO tolerance grades need be considered for rolling bearing applications.

Tables with fit recommendations can be found in SKF catalogues and the *SKF maintenance handbook*, also available online at skf.com/bearings.



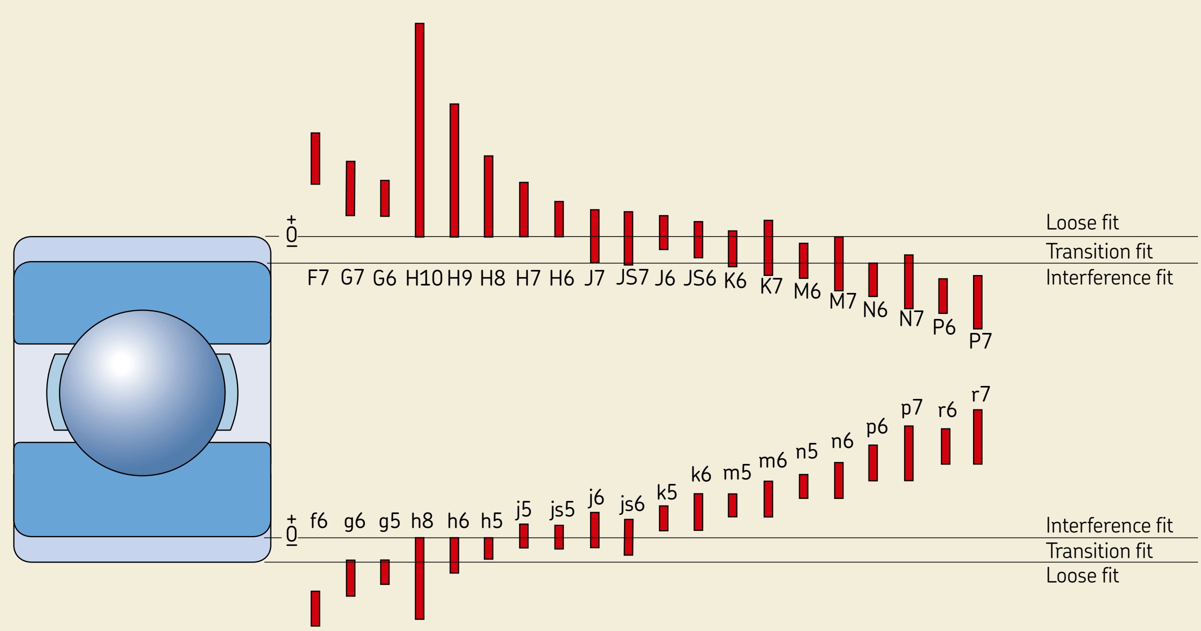
Locating/non-locating bearing system incorporating a NUP design cylindrical roller bearing and a NU (or N) design cylindrical roller bearing



Locating/non-locating bearing system incorporating a NU design cylindrical roller bearing with a four-point contact ball bearing, and a NU design cylindrical roller bearing

3

Location of the most commonly used tolerance classes relative to the bearing bore and outside diameter tolerances



Angular contact ball bearings and four-point contact ball bearings

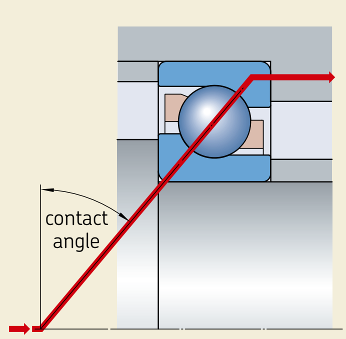
Angular contact ball bearings have raceways in the inner and outer rings that are displaced with respect to each other in the direction of the bearing axis. This means that they are designed to accommodate combined loads, i.e. simultaneously acting radial and axial loads.

Design features

The axial load carrying capacity of angular contact ball bearings increases with increasing contact angle. The contact angle is defined as the angle between the line joining the points of contact of the ball and the raceways in the radial plane, along which the load is transmitted from one raceway to another, and a line perpendicular to the bearing axis.

SKF angular contact ball bearings are produced in a wide variety of designs and sizes. The most commonly used designs are:

- single row angular contact ball bearings
- double row angular contact ball bearings
- four-point contact ball bearings



Contact angle and joining points of contact of the ball and the raceways

Single row angular contact ball bearings

SKF single row angular contact ball bearings can accommodate axial loads acting in one direction only. A single row bearing is typically adjusted against a second bearing.

The bearings are non-separable and the bearing rings have one high and one low shoulder. The low shoulder enables a large number of balls to be incorporated in the bearing, giving it a relatively high load carrying capacity.

These bearings have a 40° contact angle and therefore can support heavy axial loads.

Detailed information, especially about minimum axial and radial loads as well as a load ratio, can be found in SKF catalogues.

Basic design bearings

Basic design bearings are intended for arrangements where only one bearing is used at each bearing position. They have Normal tolerances concerning bearing width and standout of the rings. Therefore, they are not suitable for mounting adjacent to each other.

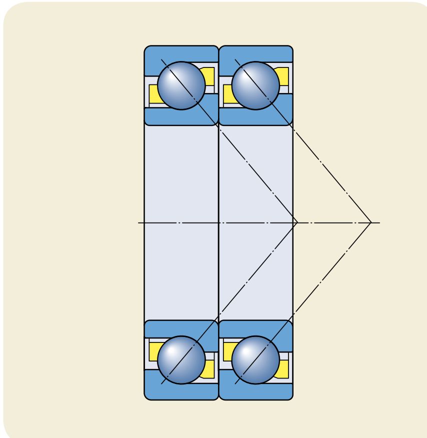
Bearings for universal matching

Bearings for universal matching are intended to be used in sets. The width and the standout of the rings are manufactured to close tolerances. When two bearings are mounted adjacent to each other, a given internal clearance or preload or an even load distribution between the two bearings is obtained, without the use of shims or similar devices.

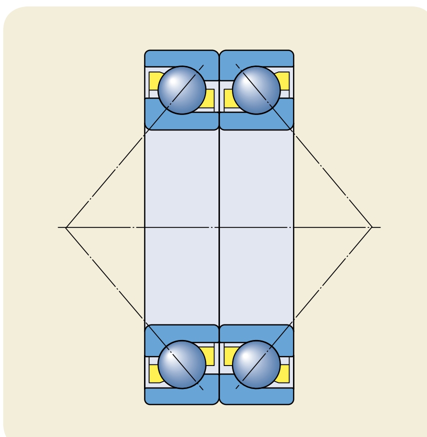
Bearings for universal matching can also be beneficial in arrangements with single bearings. Most bearings belong to the SKF Explorer performance class and as such have higher precision, increased dynamic load carrying capacity and speed capability.

Bearings for universal matching in the 72 B(E) and 73 B(E) series are identified by the suffix CA, CB or CC for internal clearance or GA, GB or GC for preload. Bearings for universal matching in the 70 B series are identified by the suffix G for clearance. When ordering, indicate the number of individual bearings required and not the number of sets.

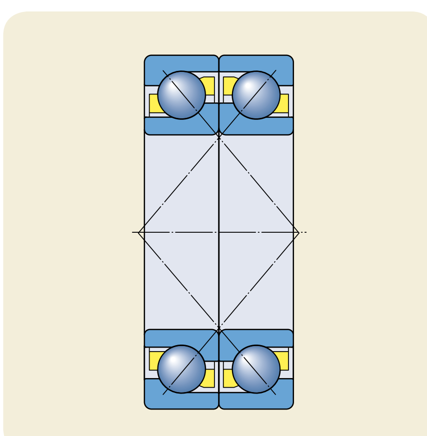
Tandem arrangement



Back-to-back arrangement



Face-to-face arrangement



Paired mounting

Paired mounting can be applied in three ways:

- **Tandem arrangement**
  A tandem arrangement is used when the load carrying capacity of a single bearing is inadequate. When arranged in tandem, the load lines are parallel and the radial and axial loads are equally shared by the bearings. However, the bearing set can accommodate axial loads acting in one direction only. If axial loads act in both directions, a third bearing adjusted against the tandem pair must be added.

- **Back-to-back arrangement**
  Mounting two bearings back-to-back provides a relatively stiff bearing arrangement, which can also accommodate tilting moments. When arranged back-to-back, the load lines diverge towards the bearing axis. Axial loads acting in both directions can be accommodated, but only by one bearing in each direction.

- **Face-to-face arrangement**
  Mounting two bearings face-to-face is not as stiff as a back-to-back arrangement, but less sensitive to misalignment. When arranged face-to-face, the load lines converge towards the bearing axis. Axial loads acting in both directions can be accommodated, but only by one bearing in each direction.

Four-point contact ball bearings

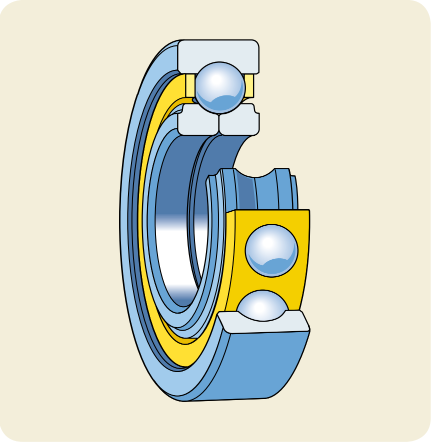
Four-point contact ball bearings are radial single row angular contact ball bearings with raceways that are designed to support axial loads acting in both directions. These bearings take up considerably less axial space than double row bearings.

The inner ring is split. This enables a large number of balls to be incorporated in the bearing, giving the bearing its high load carrying capacity. The bearings are separable, i.e. the outer ring with ball and cage assembly can be mounted separately from the two inner ring halves.

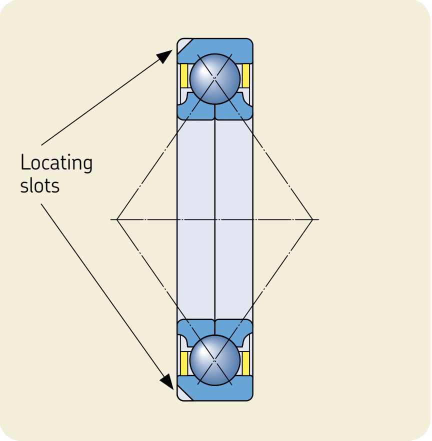
Both inner ring halves of SKF Explorer four-point contact ball bearings have a recessed shoulder. This improves oil flow when the bearing is used together with an SKF cylindrical roller bearing. In addition, these recesses can be used to facilitate dismounting.

Locating slots

SKF four-point contact ball bearings are supplied with two locating slots in the outer ring to prevent the outer ring from turning (designation suffix N2). The locating slots are positioned 180° apart.



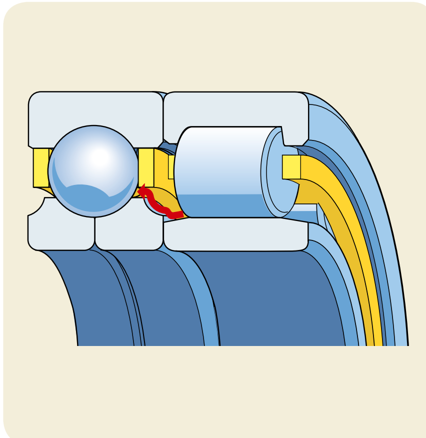
Four-point contact ball bearing

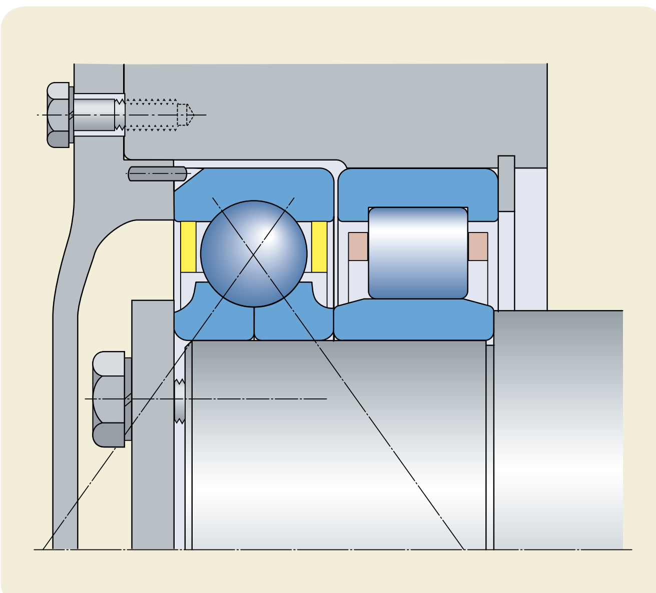


Four-point contact ball bearings with locating slots

3

The SKF design for Explorer four-point contact ball bearings enable improved oil flow to lubricate the contact areas and transfer heat





In many gearbox applications a radial bearing is used in combination with a four-point contact ball bearing which acts as a pure thrust bearing and is mounted with radial clearance in the housing

Width tolerance

For railway gearbox applications, SKF four-point contact ball bearings are offered with reduced width tolerance, suffix B20.

Cages

Preferable brass cages are used in railway applications, because of their increased mechanical properties.

Axial internal clearance

In many cases, C4 axial internal clearance is used for railway applications, because of increased geometrical contact performance.

Other technical features

Additional information about technical features, particularly cages and bearing clearance, can be found in SKF catalogues or online at skf.com/bearings.

Preferred range

Angular contact ball bearings for gearboxes

The standard assortment of angular contact ball bearings can be found in SKF catalogues or online at skf.com/bearings. For information about specific bearing executions for gearboxes and their selection, contact the SKF application engineering service.

Four-point angular contact ball bearings

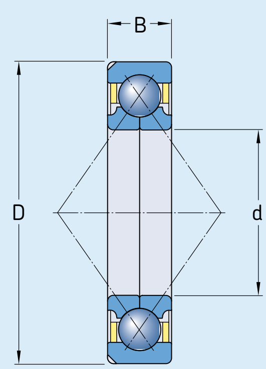
The most commonly used bearing sizes are listed in the table below.

The preferred range is based on the assortment of September 2012. This range is a living collection and will be updated and published in future if needed.

The standard range of four-point contact ball bearings, as well as additional information about these bearings, can be found in SKF catalogues or online at skf.com/bearings.

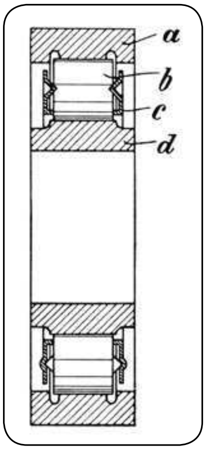
A comprehensive list of designation prefixes and suffixes can be found on **pages 94** to **96**.

Four-point contact ball bearings for gearboxes



Principal dimensions			Designation
d	D	B	
mm			–
60	110	22	**QJ 212 N2MA/C4B20**
70	125	24	**QJ 214 N2MA/C4B20**
75	130	25	**QJ 215 N2MA/C4B20**
80	140	26	**QJ 216 N2MA/C4B20**
85	150	28	**QJ 217 N2MA/C3**
90	160	30	**QJ 218 N2MA/C4B20**
100	180	34	**QJ 220 N2MA/C4B20**

Principal dimensions			Designation
d	D	B	
mm			–
110	200	38	**QJ 222 N2MA/C4B20**
120	215	40	**QJ 224 N2MA/C4B20**
130	230	40	**QJ 226 N2MA/C4B20**
140	250	42	**QJ 228 N2MA/C4B20**
150	270	45	**QJ 230 N2MA/C3**
160	290	48	**QJ 232 N2MA/C4B20**



In 1909, Dr.-Ing. Josef Kirner, a leading engineer at the Norma Compagnie in Cannstatt, Germany, invented a cylindrical roller bearing with modified raceway. The Norma Compagnie, Germany, later joined SKF [12].

Cylindrical roller bearings

Cylindrical roller bearings are used for all kinds of railway traction motors and gearboxes. The bearing ring with the two integral flanges and roller and cage assembly can be separated from the other ring. This enables easy mounting and dismounting.

The rollers are guided between the integral "open" flanges of the outer rings. These "open" flanges, combined with the specially designed and surface treated roller ends, provide improved lubrication, reduced friction and consequently lower operating temperature (→ page 76). Depending on the arrangement of the guiding flanges, cylindrical roller bearings can also take limited thrust loads.

Bearing design principles

The most common single row cylindrical roller bearing designs are described below. For specific application requirements and specific designs and applications, contact the SKF application engineering service.

SKF single row cylindrical roller bearings are available in several different designs, the main difference being in the configuration of the flanges. The most popular are the NU, N, NJ, NH and NUP designs.

NU design

NU design bearings have two integral flanges on the outer ring and no flanges on the inner ring. These bearings can accommodate axial displacement of the shaft relative to the housing in both directions. The bearings are, therefore, used as non-locating bearings.

N design

N design bearings have two integral flanges on the inner ring and no flanges on the outer ring. These bearings can accommodate axial displacement of the shaft relative to the housing in both directions. The bearings are, therefore, used as non-locating bearings.

NJ design

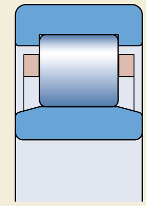
NJ design bearings have two integral flanges on the outer ring and one on the inner ring. These bearings are used to locate the shaft axially in one direction. They can accommodate axial displacement of the shaft relative to the housing in one direction only.

NH design (NJ design + HJ angle ring)

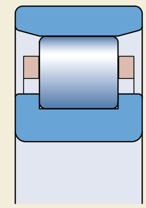
NJ design bearings with an HJ angle ring are used to locate the shaft axially in both directions. This combination is also known as NH design.

NUP design

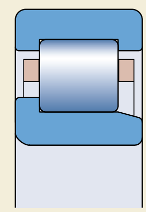
NUP design bearings have two integral flanges on the outer ring and one integral flange and one non-integral flange i.e. a loose flange ring, on the inner ring. These bearings are used to locate the shaft axially in both directions.



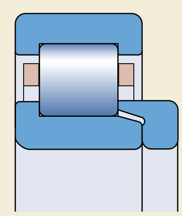
NU design



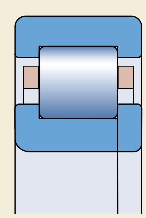
N design



NJ design

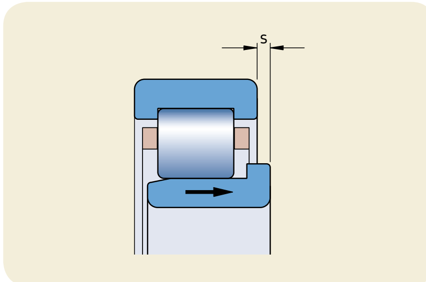


NH design (NJ design + HJ angle ring)

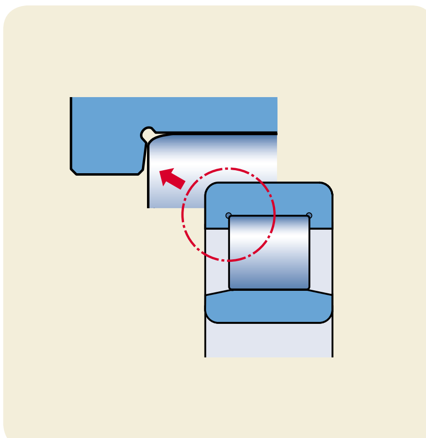


NUP design

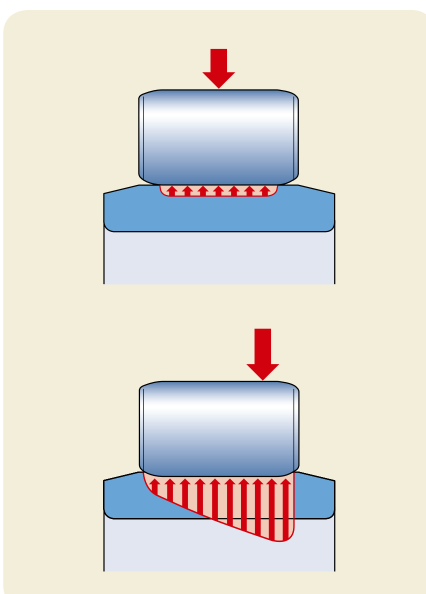
Permissible axial displacement



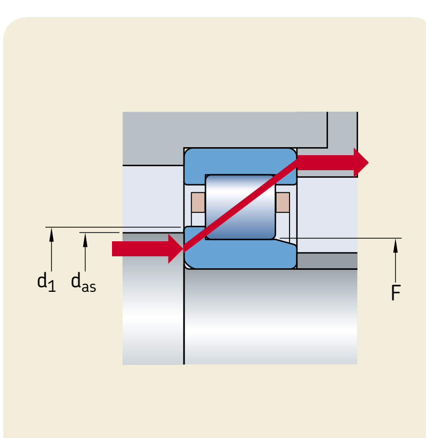
Opened flange design principle



Logarithmic roller profile



The inner ring should be axially supported at the height corresponding to half the flange height.



Axial displacement

Bearings having no flange on either the inner or outer ring (NU or N design respectively), or only one integral flange on the inner (NJ design) can accommodate axial displacement of the shaft relative to the housing within certain limits.

There is virtually no increase in friction when the bearing rotates, because the axial displacement takes place within the bearing and not between the bearing and shaft or housing bore. Values for the permissible axial displacement "s" from the normal position of one bearing ring relative to the other are provided in the product table in SKF catalogues.

Internal geometry and material properties

SKF cylindrical roller bearings have two integral flanges on either the inner or outer ring to guide the rollers. The bearings have "open" flanges, i.e. the inward face of the flange is inclined by a defined angle. The flange design, together with the roller end design and surface finish, promote the formation of a lubricant film to reduce friction and frictional heat.

The roller profile determines the stress distribution in the roller/raceway contact area. As a result, the rollers in SKF cylindrical roller bearings have a logarithmic profile to distribute loads evenly along the rollers. This prevents stress peaks at the roller ends to extend bearing service life. The logarithmic profile also reduces sensitivity to misalignment and shaft deflection.

The surface finish on the contact surfaces of the rollers and raceways maximizes the formation of a hydrodynamic lubricant film and optimizes the rolling motion of the rollers. Some of the benefits derived from this, when compared with traditional designs, include enhanced operational reliability.

Cylindrical roller bearings with flanges on both the inner and outer rings can support axial loads in addition to radial loads. The axial load carrying capacity is primarily determined by the ability of the sliding surfaces of the roller end / flange contact to support loads. Factors having the greatest effect on this ability are the lubricant, operating temperature and the ability of the bearing to dissipate heat.

SKF Explorer and E2 bearing design

SKF introduced the SKF EXPLORER performance class of cylindrical roller bearings in 2002. SKF Explorer cylindrical roller bearings outperform the earlier standard SKF cylindrical roller bearings, whilst maintaining the same boundary and main internal dimensions.

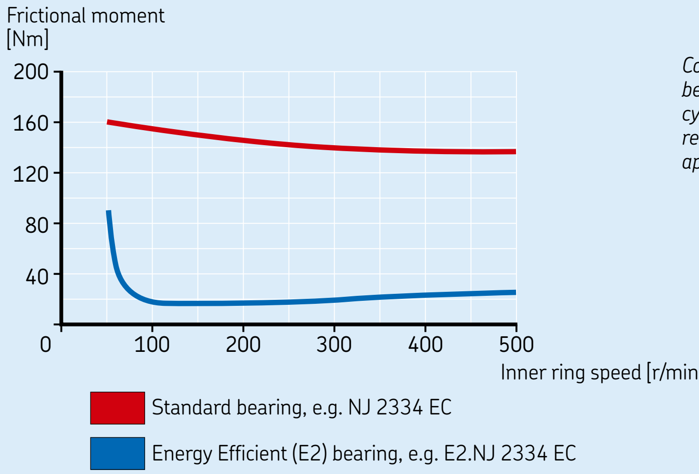
To respond to the ever-increasing demand to reduce friction and thereby reduce energy use, SKF introduced the concept of Energy Efficient (E2) rolling bearings in 2007.

Main improvements and benefits

- Bearing material with extremely clean and homogenous steel with a minimum of inclusions. The oxygen content, which is a measurement for cleanliness, has been reduced to extremely low levels. This also increases the fatigue strength in the rolling contacts and extends the bearing life.
- New heat-treatment procedures optimize the bearing's resistance to operational damage and temperatures without affecting dimensional stability.
- Hardness of the rings and rollers has been selected for optimum performance. This makes them less sensitive to contaminants and contributes to their extremely long service life.
- Upgraded manufacturing processes have contributed to a significant improvement in product quality. This means that the rings can be produced with an improved roundness, and the deviation from optimum form of the rollers has also been further reduced. The results of the tighter tolerances may be invisible, but the bearings run markedly quieter and with less vibration.
- Logarithmic contact profile of the rollers has been further refined. The bearings are thus even less sensitive to minor misalignment and can carry heavier loads.
- The excellent design of the transition from the cylindrical section to the roller end drop of the logarithmic profile avoids damaging stresses.
- The surface finish of the raceways on the rings and rollers has been further refined and provides enhanced lubrication conditions so that bearings can operate longer even under poor lubrication conditions.

The improvements of the internal geometry and material properties of cylindrical roller bearings have been taken into account to establish the frictional moment and calculate the rated bearing life.

Test: measurement of frictional moment in cylindrical roller bearings

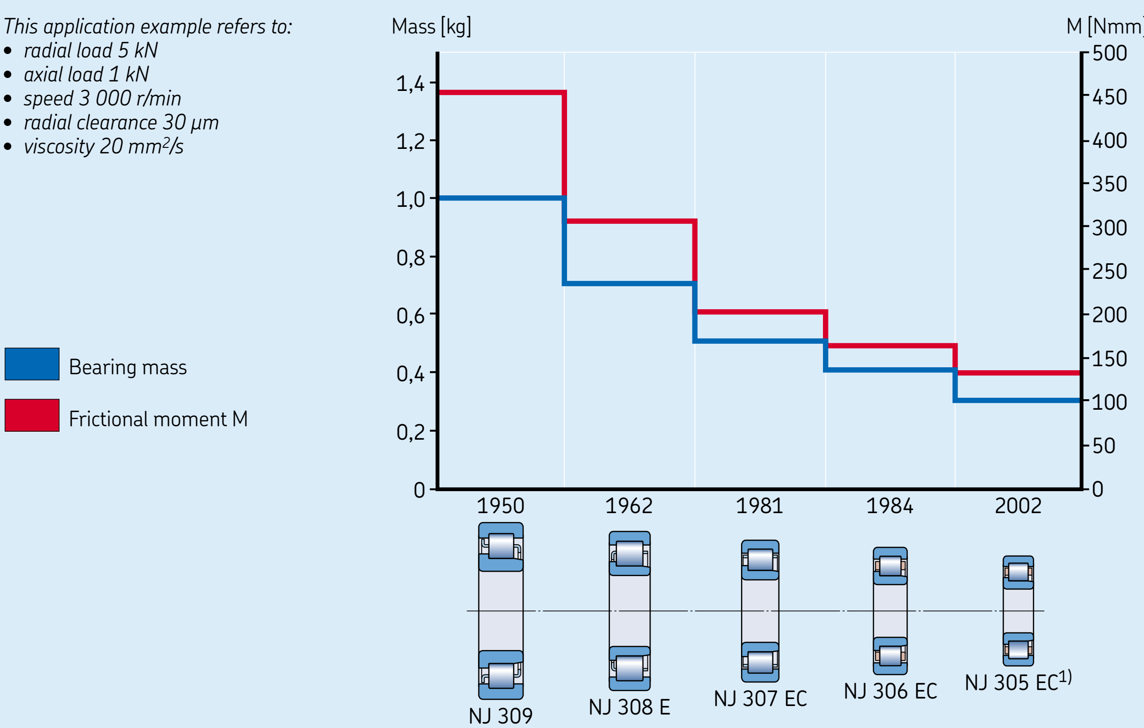


Compared with the current SKF standard bearing, the new SKF Energy Efficient (E2) cylindrical roller bearings exhibit a friction reduction of up to 85% in axially loaded applications [13]

Continues development has led to significant downsizing [13]

This application example refers to:

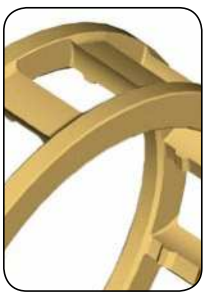
- *radial load 5 kN*
- *axial load 1 kN*
- *speed 3 000 r/min*
- *radial clearance 30 µm*
- *viscosity 20 mm²/s*



Dynamic load rating [kN]	52	53	44,6	51,2	46,5
Mass [kg]	1,0	0,7	0,5	0,4	0,3
Frictional moment M [Nmm]	450	300	200	166	129

1) SKF Explorer

Two-piece machined brass cage, designation suffix MR



One-piece machined brass cage, outer ring centred, designation suffix ML

Glass fibre reinforced polyamide cage

Cages

Depending on bearing series, size and design, SKF single row cylindrical roller bearings are fitted as standard with one of the following cages.

Cage performance is influenced by different factors such as load levels, load cycles, duration, lubricants and temperature range during operation. The possibility of the cage to coping with these factors results from the main features as well as material properties, geometrical design and the guidance. The material properties include ductility, fatigue resistance, stiffness, creep resistance, wear resistance and aging resistance. The geometrical design and guidance result from the stress distribution in the cage system.

Traction motor application

Typically, cylindrical roller bearings for traction motor bearings are fitted with a two-piece machined brass cage that is roller centred, designation suffix M.

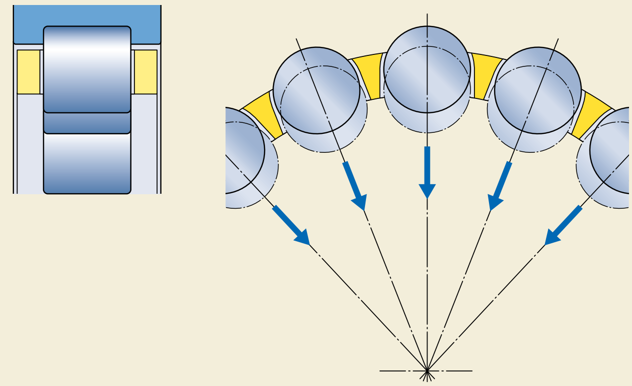
For heavy shock loads a one-piece machined brass cage is fitted that is roller centred, designation suffix MR.

To enable easier handling during maintenance, a one-piece machined brass cage is fitted that is roller and outer shoulder guided and has a roller-drop function, designation suffix MRD or MR3D.

Glass fibre reinforced polyamide and polyetheretherketone (PEEK) cages are used for some specific applications. These cages provide material and design benefits in connection with lubrication. For specific applications, contact the SKF application engineering service.

Gearbox application

Typically, one-piece machined brass cages are fitted that are outer ring centred, designation suffix ML or MP. These high performance cages have an optimized mass and geometry. The cage pocket design provides improved roller contact.



One-piece machined brass cage, roller guided that has a roller-drop function [14], designation suffix MRD or MR3D

Main cylindrical roller bearing cage designs for drive applications

Application	Lubricant	Cage material Brass two-piece, riveted	One-piece	Polymer
Traction motor	Grease	M	MR and variants	PEEK
	Oil		ML	PEEK
Gearbox	Oil		ML	PEEK

Tolerances

SKF single row cylindrical roller bearings are manufactured to Normal tolerances for dimensional accuracy and to P6 tolerances for running accuracy as standard. Some bearings, particularly those of the narrow series 18, 19 and 10, are also available with higher accuracy to tolerance class P6 or P5. Details about the product range and tolerances can be found in SKF catalogues.

Radial internal clearance

SKF single row cylindrical roller bearings are manufactured with Normal radial internal clearance as standard. For railway traction motor and gearbox applications, most of the bearings have a larger C3 radial clearance. Some applications require larger C4 or even C5 radial clearance. Sometimes, C5H is applied.

Values of radial clearance are listed in SKF catalogues. The values are valid for unmounted bearings under zero measuring load. The components of cylindrical roller bearings belonging to the same clearance class are interchangeable.

Axial internal clearance

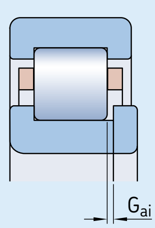
For traction motor applications, NUP and NJ + HJ design cylindrical roller bearings can be supplied with increased axial clearance, designation suffix VA301.

In some older literature, the German DIN 43 283 standard is mentioned as a reference for cylindrical roller bearings in traction motor applications. This standard was first developed in the 1950s when a large number of special specifications existed for traction motor applications. This German standard was cancelled in 2000 because of major overlapping with other existing general bearing standards. Today, the specifications contained in the VA301 designation suffix cover the requirements of this obsolete standard.

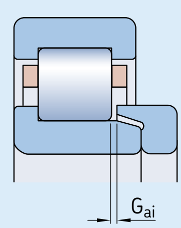
Width tolerance

To limit the build up of tolerances from different components, SKF can supply cylindrical roller bearings with a reduced width tolerance. The width tolerance of 0 .. –40 µm is contained in the suffix B20.

Axial internal clearance for cylindrical roller bearings to SKF VA301 specifications



NUP



NJ + HJ

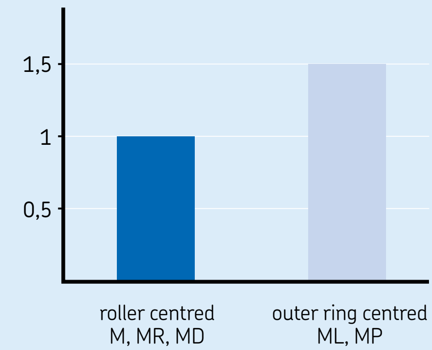
Diameter series, bore d						G_{ai} 1)	
9, 0, 2		3		4		NUP, NJ + HJ	
>	≤	>	≤	>	≤	min.	max.
mm		mm		mm		µm	
45	90	–	60	–	–	150	250
90	160	60	105	45	80	180	300
160	280	105	200	80	130	230	380
280	450	200	320	130	300	300	500
450	700	320	500	300	500	400	650

1) The values of axial internal clearance G_{ai}, as listed in the table, refer to the axial clearance between the inner ring flange and the loose flange ring (NUP design) or the angle ring (NJ + HJ design). For the total axial bearing clearance, also the axial clearance between the roller length and the outer ring flanges has to be considered.

Speed ratings

The speed limit is determined by criteria that include the form stability or strength of the cage, lubrication of cage guiding surfaces, centrifugal and gyratory forces acting on the rolling elements and other speed-limiting factors.

Relative speed rating capabilities depending on the cage design



Minimum load

To achieve satisfactory operation, single row cylindrical roller bearings, like all ball and roller bearings, must always be subjected to a given minimum load, particularly if they are to operate at high speeds or are subjected to high acceleration or rapid changes in the direction of load. Under such conditions the inertia forces of the rollers and cage, and the friction in the lubricant, can have a detrimental influence on the rolling conditions in the bearing arrangement and may cause damaging sliding movements to occur between the rollers and raceways. The formula to calculate the minimum load can be found in SKF catalogues.

For suspension tube applications, black oxide can be applied to reduce the risk of skidding or sliding damage in service.

Black oxide surface treatment

Black oxide is a chemical surface treatment which in bearing applications may enhance bearing performance in specific operating conditions. This treatment is successfully applied in the field to ease the running-in process of bearings and to enhance resistance against smearing damage in critical lubrication conditions with thin lubricant films and high slip.

Black oxide surface treatment benefits

- Improved running-in behaviour
- Increased oil and grease adhesion
- Better corrosion resistance
- Decrease of fretting risk in the fits
- Improved resistance against smearing damage
- Better performance in low viscosity ratio κ conditions
- Reduction of the chemical attack to the bearing steel from, for example, aggressive oil additives (like EP-additives in gearbox oil)
- Reduced hydrogen permeation into the bearing steel

3

Preferred range

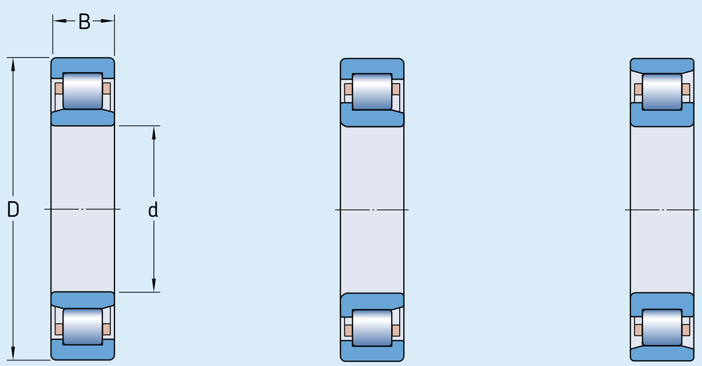
The preferred range is based on the assortment of September 2012. This range is a living collection and will be updated and published in future if needed.

The standard range of cylindrical roller bearings, as well as additional information about these bearings, can be found in SKF catalogues or online at skf.com/bearings.

The preferred range of INSOCOAT and hybrid cylindrical roller bearings for traction motors can be found in chapter 4.

A comprehensive list of designation prefixes and suffixes can be found on pages 94 to 96.

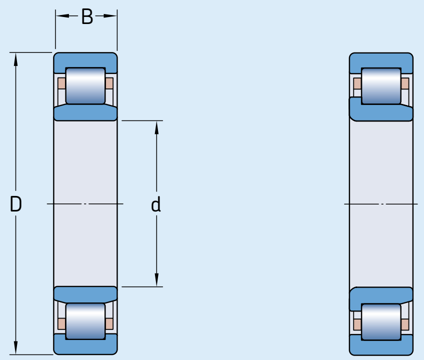
Cylindrical roller bearings for traction motors



Principal dimensions d	D	B	Designation	Principal dimensions d	D	B	Designation
mm			–	mm			–
70	150	35	**NJ 314 ECM/C4VA301**[1]	**120**	215	40	**NU 224 ECM/C4VA301**
	150	35	**NU 314 ECM/C4VA301**		215	58	**NU 2224 ECML/C4VA301**
75	130	25	**NU 215 ECM/C4 VA301**		260	55	**NJ 324 ECM/C4VA301**[1]
	160	37	**NJ 315 ECM/C4VA301**[1]		260	55	**NU 324 ECM/C4VA301**
80	170	39	**NJ 316 ECM/C4VA301**[1]	**130**	200	33	**NJ 1026 M/C4VA301**[1]
85	150	28	**NU 217 ECM/C4VA301**		280	58	**N 326 ECMR/C4VA301**
90	160	40	**NJ 2218 ECM/C4VA301**[1]		280	58	**NJ 326 ECM/C4VA301**[1]
	190	43	**NJ 318 ECM/C4VA301**[1]		280	58	**NU 326 ECMR3D/C4VA322**
	190	43	**NU 318 ECM/C4VA301**	**140**	300	62	**NU 328 ECMRD/P54VA334**
95	170	32	**NJ 219 ECM/C3VA301**[1]	**150**	320	65	**NU 330 ECM/C4VA301**
100	180	34	**NJ 220 ECM/C4VA301**[1]	**160**	340	68	**NU 332 ECM/C4VA301**
	180	34	**NU 220 ECM/C4VA301**	**170**	310	52	**NU 234 ECM/C4VA301**
	215	47	**NJ 320 ECM/C4VA301**[1]		360	72	**NU 334 M/C4VA301**
	215	47	**NU 320 ECM/C4VA301**	**180**	280	46	**NU 1036 M/C4VA301**
110	170	28	**NU 1022 M/C4VA301**	**220**	340	56	**NU 1044 M/P63RVA305**
	240	50	**NJ 322 ECM/C4VA301**[1]				
	240	50	**NU 322 ECM/C4VA301**				

[1] In addition to NJ series cylindrical roller bearings, appropriate HJ series angle rings with VA301 designation suffix can be supplied.

Cylindrical roller bearings for gearboxes



NU NJ

Principal dimensions d	D	B	Designation
mm			–
55	100	25	**NJ 2211 ECML/C3[1)]**
	120	43	**NJ 2311 ECML/C3[1)]**
60	110	22	**NU 212 ECNML/C3B20**
	130	31	**NJ 312 ECML/C3[1)]**
65	140	48	**NJ 2313ECML/C3[1)]**
70	125	24	**NJ 214 ECML/C3[1)]**
	125	24	**NU 214 ECML/C4**
75	130	25	**NJ 215 ECML/C3[1)]**
	130	25	**NU 215 ECML/C4**
	160	55	**NJ 2315 ECML/C3[1)]**
	160	55	**NU 2315 ECML/C3B20**
80	140	26	**NJ 216 ECML/C3[1)]**
	140	26	**NU 216 ECML/C3H**
	140	33	**NJ 2216 ECML/C3[1)]**
	140	33	**NU 2216 ECML/P63**
	170	39	**NU 316 ECML/C3**
85	150	28	**NU 217 ECML/C3**
	150	36	**NJ 2217 ECML/C3[1)]**
90	160	30	**NJ 218 ECML/C3[1)]**
	160	40	**NU 2218 ECML/C4**
95	170	43	**NJ 2219 ECML/C4[1)]**
100	180	34	**NJ 220 ECML/C3[1)]**
	180	34	**NU 220 ECML/C3**
	180	46	**NU 2220 ECML/C3**
110	200	38	**NJ 222 ECML/C4[1)]**
	200	38	**NU 222 ECML/C3B20**
	200	53	**NU 2222 ECML/C3**
120	180	28	**NU 1024 N1ML/C3**
	260	55	**NU 324 ECML/C5H**
130	200	33	**NU 1026 ML/C3**
	230	40	**NU 226 ECML/C3**
	230	64	**NU 2226 ECML/C3**
140	210	33	**NU 1028 ML**
	250	42	**NU 228 ECML/C3**
	250	68	**NU 2228 ECML/C3**
150	225	35	**NU 1030 ML**
160	240	38	**NU 1032 ML**
170	260	42	**NU 1034 ML**
180	320	52	**NU 236 ECMA/C3**
190	290	46	**NU 1038 ML/C3**
	340	55	**NU 238 ECNML/C3VE656**
200	360	58	**NU 240 ECN3ML/C3**

[1)] In addition to NJ series cylindrical roller bearings, appropriate HJ series angle rings with VA301 designation suffix can be supplied.

Deep groove ball bearings

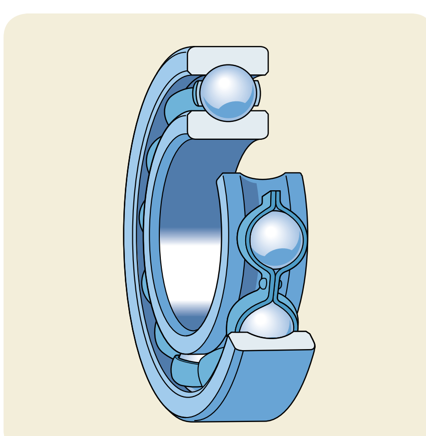
Deep groove ball bearings are particularly versatile. They are simple in design, non-separable, suitable for high and very high speeds and are robust in operation, requiring little maintenance. Because deep groove ball bearings are the most widely used bearing type, they are available from SKF in many designs, variants and sizes.

For railway applications, single row deep groove ball bearings are used in traction motors, mainly as the locating bearing in combination with a non-locating cylindrical roller bearing. Many modern traction motor designs require electrical insulation. In addition to the bearings presented in this chapter, electrical insulated deep groove ball bearings like INSOCOAT and hybrid bearings are covered in chapter 4.

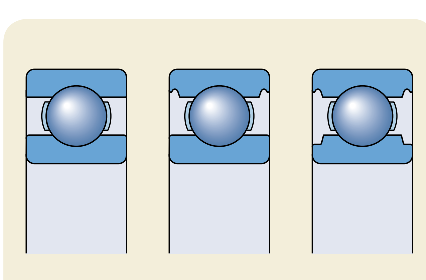
In gearbox applications, deep groove ball bearings are used in the locating bearing position, especially for lighter loads. These bearings are also used in railway vehicles for auxiliary equipment like:

- ventilators for traction motor cooling systems
- motors for air compressors in brake systems
- rotational converters

as well as for many other applications.



Deep groove ball bearing



Deep groove ball bearings
Left: without recess
Middle: with recess on the outer ring
Right: with recesses on outer and inner rings

Design features

Single row deep groove ball bearings have deep, uninterrupted raceway grooves. These raceway grooves have a close osculation with the balls, enabling the bearings to accommodate radial loads and axial loads in both directions.

Single row deep groove ball bearings are available open or capped (with seals or shields). Open bearings that are also available capped may have recesses in the outer ring.

Sealing solutions

The most popular sizes of deep groove ball bearings can be obtained (supplied) capped with a seal or shield on one or both sides. Selection guidelines for different sealing solutions under various operating conditions are listed in SKF catalogues.

Shields

Bearings with shields are primarily intended for applications where the inner ring rotates. Shields are fitted in the outer ring and do not make contact with the inner ring, but form a narrow gap with it. Shields are made of sheet steel.

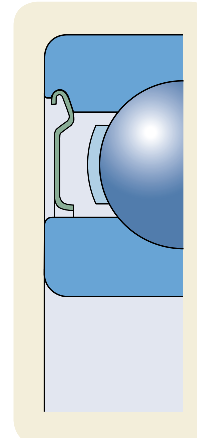
Depending on the bearing design, series and size, SKF supplies shields in different designs. Shields identified by the designation suffix Z typically have an extension in the shield bore to form a long, narrow gap with the land of the inner ring shoulder. Some shields do not have the extension.

Non-contact seals

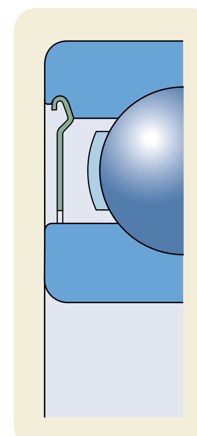
Bearings with non-contact seals can be operated at the same speeds as bearings with shields, but with improved sealing effectiveness.

The seals form an extremely narrow gap with the land of the inner ring shoulder. Non-contact seals are made of oil and wear-resistant acrylonitrile-butadiene rubber (NBR) that is reinforced by a sheet steel insert.

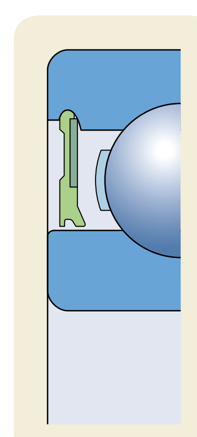
SKF deep groove ball bearings with a non-contact seal on one or both sides are identified by the designation suffix RZ or 2RZ.



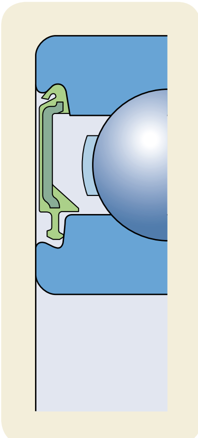
Extension in the shield bore to form a long, narrow gap with the land of the inner ring shoulder



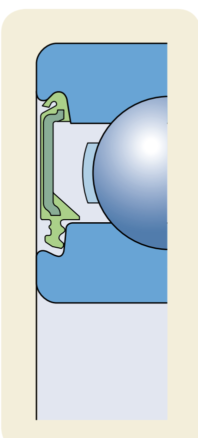
Some shields do not have an extension



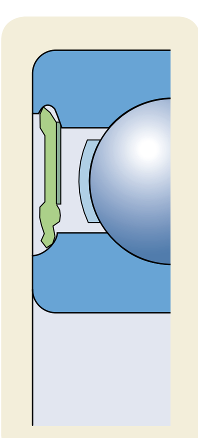
Non-contact RZ seal



Low-friction RSL seal
25 mm < D ≤ 52 mm



Contact RSH seal
25 mm < D ≤ 52 mm



Contact seal RS1
(example)

Low-friction seals

Bearings with low-friction seals can accommodate the same speeds as bearings with shields, but with improved sealing effectiveness. The seals are practically non-contacting with a recess in the inner ring shoulder.

Single row deep groove ball bearings with a low-friction seal on one or both sides are identified by the designation suffix RSL or 2RSL. The seals are made of oil and wear-resistant NBR that is reinforced with a sheet steel insert.

Contact seals

Contact seals are made of NBR or fluoro rubber (FKM) and are reinforced with a sheet steel insert. These seals, which are fitted in a recess on the outer ring, make good, positive contact with the recess, without deforming the outer ring. SKF deep groove ball bearings with a contact seal made of NBR on one or both sides are manufactured in different designs depending on the bearing:

- Bearings in the 60, 62 and 63 series are equipped with RSH seals when 25 mm < D ≤ 52 mm.
- Other bearings have RS1 seals, which seal against the land of the inner ring shoulder or against a recess in the inner ring side face. The difference is indicated by dimension d_1 or d_2 in SKF catalogues or online at skf.com/bearings.

Bearings with a snap ring groove

Deep groove ball bearings with a snap ring groove can simplify the design of an arrangement because the bearings can be axially located in the housing by a snap ring. This saves space and can significantly reduce installation time. Appropriate snap rings are shown in the product tables with their designation and dimensions. They can be supplied separately or fitted to the bearing. For additional information, see SKF catalogues or online at skf.com/bearings.

Cages

Depending on their design, series and size, SKF deep groove ball bearings are fitted with different types of cages.

The lubricants generally used for rolling bearings do not have a detrimental effect on cage properties. However, some synthetic oils and greases with a synthetic oil base and lubricants containing a high proportion of EP additives, when used at high temperatures, can have a detrimental effect on polyamide cages. For additional information about the suitability of cages, see SKF catalogues or online at skf.com/bearings.

Radial internal clearance

SKF single row deep groove ball bearings are manufactured with Normal radial internal clearance as standard. Most of the bearings are also available with C3 radial internal clearance. For traction motor applications, clearances much greater than C4 or C5 are used because of the tighter fits. Bearings with internal clearances not to standard can be supplied on request.

Performance classes

SKF Explorer bearings

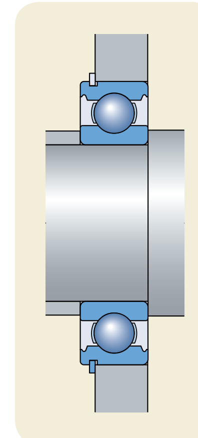
In response to the ever-demanding performance requirements of modern machinery, SKF developed the SKF Explorer performance class of rolling bearings.

SKF Explorer deep groove ball bearings realized a substantial improvement in performance by optimizing the internal geometry and surface finish of all contact surfaces, redesigning the cage, combining extremely clean and homogenous steel with a unique heat treatment and improving the quality and consistency of the balls.

Deep groove ball bearings within this performance class provide superior performance especially in applications like electric motors and other applications. These improvements provide the following benefits:

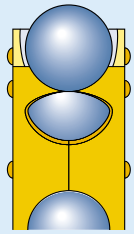
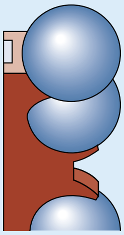
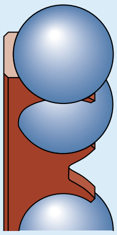
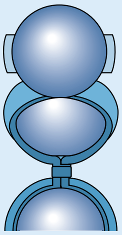
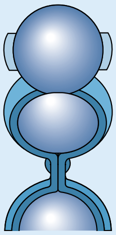
- higher dynamic load carrying capacity
- reduced noise and vibration levels
- less frictional heat
- significantly longer bearing service life

These bearings reduce environmental impact by enabling downsizing and reducing both lubricant and energy consumption. Just as importantly, SKF Explorer bearings can reduce the need for maintenance and contribute to increased productivity. For additional information, see SKF catalogues or online at skf.com/bearings.



Application of a deep groove ball bearing with a snap ring groove and snap ring

Cages for deep groove ball bearings

	Brass cages		Polymer cages			Steel cages	
							
Cage type	Riveted, ball centred	Riveted, outer ring centred	Snap-type, ball centred			Ribbon-type, ball centred	Riveted, ball centred
Material	Machined brass		PA66, glass fibre reinforced	PA46, glass fibre reinforced	PEEK, glass fibre reinforced	Stamped steel	
Suffix	M	MA	TN9	VG1561[1)]	TNH	–	–
Application	Traction motor	Gearbox	Auxiliary machines		Traction motor	Auxiliary machines	
Lubrication	Grease	Oil	Grease			Grease	

[1)] Standard for SKF E2 bearings, check availability for other bearings

SKF Energy Efficient (E2) bearings

To meet the ever-increasing demand to reduce friction and energy consumption, SKF has developed the SKF Energy Efficient (E2) performance class of rolling bearings. Deep groove ball bearings within this performance class are characterized by a frictional moment in the bearing that is at least 30% lower when compared to a same-sized SKF Explorer bearing.

The bearings achieved the substantial reduction of the frictional moment by optimizing the internal geometry of the bearing, redesigning the cage and applying a new low friction grease.

SKF E2 deep groove ball bearings have been shown to last longer and consume less lubricant than comparable SKF Explorer deep groove ball bearings. Typical applications include electric motors, pumps, conveyors and fans. For additional information, see SKF catalogues or online at skf.com/bearings.

Assortment

A complete assortment of deep groove ball bearings can be found in SKF catalogues or online at skf.com/bearings. Due to the heavy operational conditions in traction motors and gearboxes, mainly deep groove ball bearings with brass cages and tighter fits are applied. Because of the tighter fits, larger radial internal clearances like C4 and C5 are necessary. For further information about the selection of the right bearing execution, see SKF catalogues or contact the SKF application engineering service. The preferred range of INSOCOAT and hybrid deep groove ball bearings for traction motors is mentioned in chapter 4.

Tapered roller bearings

Tapered roller bearings are produced by SKF in many designs and sizes to match their many uses:

- single row tapered roller bearings
- matched single row tapered roller bearings
- double and four row tapered roller bearings

SKF also manufactures sealed, greased and pre-adjusted units based on tapered roller bearings, especially for automotive and railway wheelset applications. These tapered roller bearing units are mentioned in the SKF *Railway technical handbook, Volume 1*.

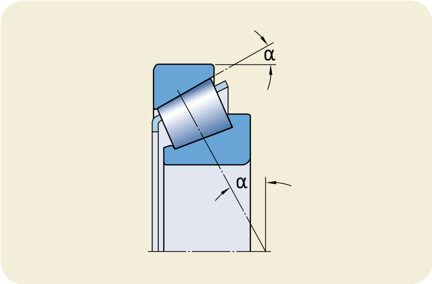
Design features

Tapered roller bearings have inner and outer ring raceways that are tapered and tapered rollers. They are designed to accommodate combined loads, i.e. simultaneously acting radial and axial loads. The projection lines of the raceways meet at a common point on the bearing axis to provide true rolling and low friction. The axial load carrying capacity of tapered roller bearings increases by increasing contact angle α.

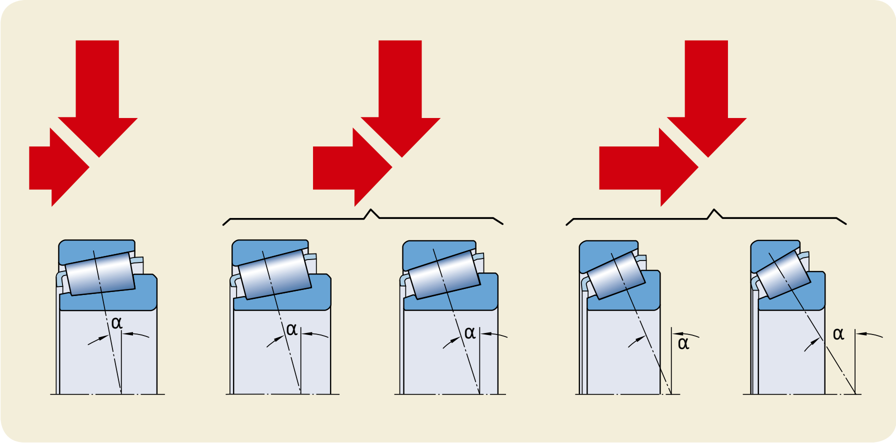
An indication of the angle size is given by the calculation factor e; the larger the value of e, the larger the contact angle and the greater the suitability of the bearing for carrying axial loads.

Tapered roller bearings are generally separable, i.e. the cone, consisting of the inner ring with roller and cage assembly, can be mounted separately from the cup (outer ring).

SKF tapered roller bearings of the TQ-line assortment have a logarithmic contact profile that provides optimum stress distribution over the roller/raceway contacts. The special design of the sliding surfaces of the guide flange and large roller ends considerably promote lubricant film formation in the roller end/flange contacts. The resulting benefits include increased operational reliability and reduced sensitivity to misalignment.

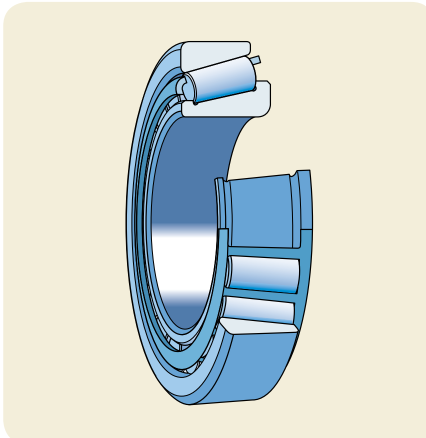


The axial load carrying capacity of tapered roller bearings is largely determined by the contact angle α



The larger the contact angle α, the higher the axial load carrying capacity.

Single row tapered roller bearing



Single row tapered roller bearings

SKF tapered roller bearings for general use, including SKF bearings to Q specifications, have been optimized with regard to the sliding contact surfaces of the guide flange of the inner ring, the roller end faces and the contact profile.

In addition, highly accurate manufacturing processes make adjustment of the bearings against each other more reliable, which dramatically improves performance especially during the very first hours of operation.

TQ-line bearings

TQ-line tapered roller bearings are identified by the designation suffix Q and have operating characteristics that clearly set them apart from bearings made to conventional designs. The logarithmic contact profile provides optimum load distribution in the roller / raceway contact area to keep stress peaks within acceptable limits, even under slight misalignment. Like SKF Explorer bearings, the roller end / flange contact area of TQ-line tapered roller bearings is designed to reduce friction and wear at start-up. The bearings do not need special running-in procedures after installation. Bearings that are preloaded experience only a small, controlled loss of initial preload.

QCL7C bearings

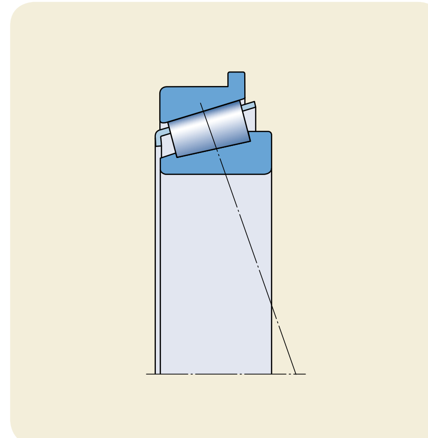
Bearings identified by the designation suffix QCL7C, were originally designed for use as pinion bearings in the differential of industrial transmissions to provide a constant, accurate gear mesh. The bearings are characterized by a high degree of running accuracy and a high preload capability. They have special friction characteristics and can be axially adjusted within narrow limits using the friction-torque method. Their internal design promotes the formation of a hydrodynamic oil film to substantially reduce friction and consequently operating temperature during the running-in period. When installed, lubricated and maintained properly, bearings with a QCL7C designation suffix retain their preload setting.

Bearings with a flanged outer ring

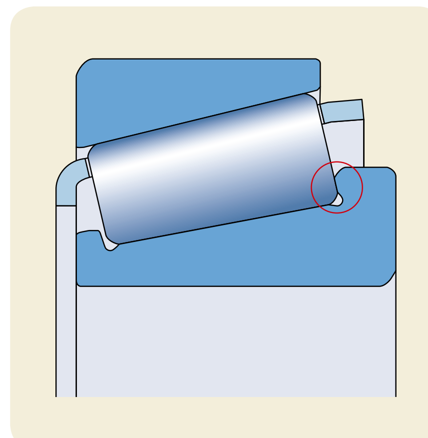
Certain sizes of SKF single row tapered roller bearings are also available with a flange on the outer ring. Bearings having this external flange can be axially located in the housing to provide a simplified, more compact bearing arrangement. The housing bore is simpler to produce, as no shoulders are required, for additional information, refer to page 31.

Running-in

Tapered roller bearings typically have a running-in period. During the running-in period, a conventional design tapered roller bearing experiences a significant amount of friction, resulting in wear, which can be noticed as a temperature spike. With current SKF tapered roller bearing designs, friction, wear and frictional heat are significantly reduced, provided the bearings are mounted and lubricated correctly.



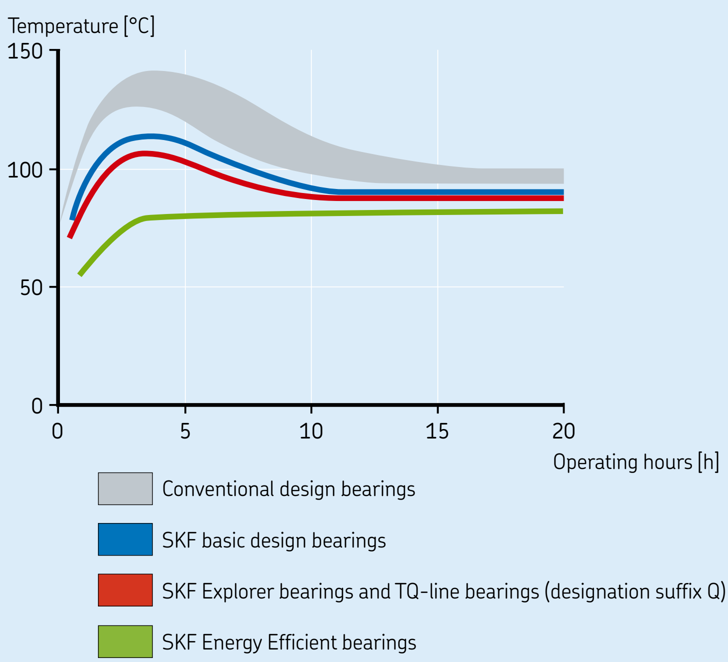
***Single row tapered roller bearing with a flange on the outer ring** (→ page 115)*



Roller end / flange contact area

The geometry and surface finish of the roller ends and the area on the flange that makes contact with the roller ends have been optimized to promote and maintain the formation of a lubricant film. This reduces friction and frictional heat as well as flange wear. The bearings can better maintain preload and run at reduced noise levels.

Typical temperature gradation of tapered roller bearings during the running-in period
(approximate values)



Cages

SKF single row tapered roller bearings for gearbox applications in railways are mainly fitted with a pressed window-type steel cage, roller centred, no designation suffix or suffix J1, J2 or J3.

For very heavy operating conditions, optimized cage designs are used:

- high strength steel cage material
- increased material thickness

Internal clearance and preload

The internal clearance of single row tapered roller bearings can only be obtained after mounting and is determined by adjustment of one bearing against a second bearing, which provides location in the opposite direction.

Depending on the application, it may be necessary to have either a positive or a negative operational clearance in the bearing arrangement. In the majority of applications, the operational clearance should be positive, i.e. when in operation, the bearing should have a residual clearance, however slight.

Matched single row tapered roller bearings

For bearing arrangements where the load carrying capacity of a single tapered roller bearing is inadequate, or where the shaft has to be axially located in both directions with a given positive or negative axial play, the bearings can be supplied as matched bearings. The bearing set is supplied complete, with the appropriate intermediate spacer ring(s).

DB

Matched single row tapered roller bearing pair, arranged back-to-back. A number immediately following the DB identifies the design of the intermediate rings.

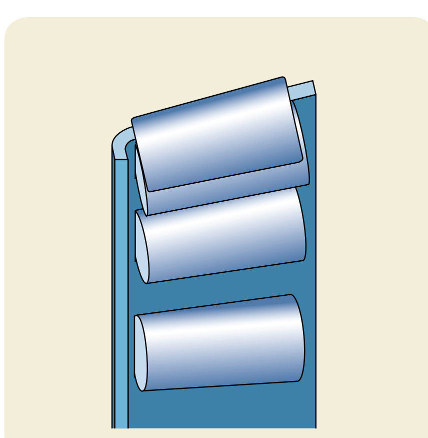
DF

Matched single row tapered roller bearing pair, arranged face-to-face. A number immediately following the DF identifies the design of the intermediate ring.

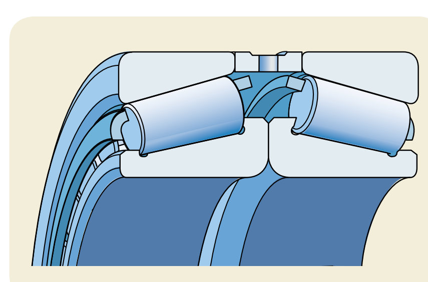
DT

Matched single row tapered roller bearing pair, arranged in tandem. A number immediately following the DT identifies the design of the intermediate rings.

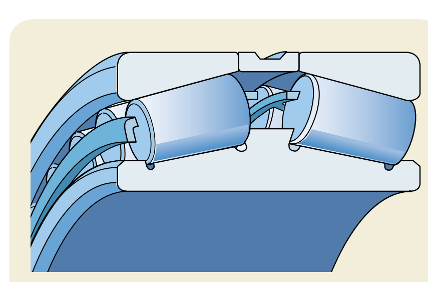
For additional information, contact the SKF application engineering service.



Pressed window-type steel cage, roller centred



Matched single row tapered roller bearing pair



Double-row tapered roller bearing

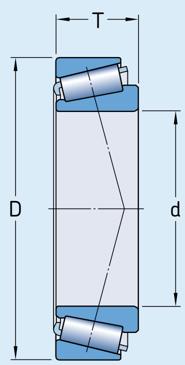
Preferred range

The preferred range is based on the assortment of September 2012. This range is a living collection and will be updated and published in future if needed.

The standard range of tapered roller bearings, as well as additional information about these bearings, can be found in SKF catalogues or online at skf.com/bearings.

A comprehensive list of designation prefixes and suffixes can be found on pages 94 to 96.

Tapered roller bearings for gearboxes



Principal dimensions			Designation
d	D	T	
mm			–
95	170	45,5	**32219 J2/VE141**
120	215	61,5	**32224 J1/VG237**
140	250	71,75	**32228 J2/VG237**
177,800	227,012	30,162	**36990/36920 N1/VA833**
	227.012	33,274	**BT1-0410/VA833**
178,595	265,112	51,595	**M 336948/912**
180	250	45	**BT1-0005/VE141**
189,738	282,575	50,800	**BT1-0729**
190	260	46	**JM 738249/210/VE141**
198,298	300,000	49,212	**BT1-2111**
199,949	282,550	46,038	**BT1-0704/HA4**
	282,575	46,038	**BT1-2110**
200,025	276,225	42,862	**LM 241147/110/VE673**
210	285	41	**T2DC 220/210/VE679**

Principal dimensions			Designation
d	D	T	
mm			–
213	285	41	**T2DC 220/213/VE679**
216,408	285,75	46,038	**LM 742747/710**
216,5	285	41	**BT1-0667/VE679**
220	285	41	**T2DC 220/VE679**
	340	76	**32044 X/VA805**
231,775	300,038	33,338	**544091/544118/VE141**
	317,5	47,625	**LM 245848/810**
	317,5	47,625	**LM 245848/810/VE141**
240	320	42	**T4EB 240/VE679**
255,6	342,9	57,15	**M 349547/510/VG237**
257,175	342,90	57,15	**M 349549/510/VE174**
	358.775	71.440	**M 249747/710/VG237**
	385,775	71,438	**M 249747/710/VG237**

Supplementary designations

Prefixes

Prefixes are used to identify components of a bearing and are usually then followed by the designation of the complete bearing, or used to avoid confusion with other bearing designations. Further information can be found in SKF catalogues or online at skf.com/bearings.

For customized bearing designs, the following prefixes are used. The complete bearing designation consists of the prefix and a drawing number.

Examples:

BB1 Single row ball bearing, customized design

BC1 Single row cylindrical roller bearing, customized design

BT1 Single row tapered roller bearing, customized design

Suffixes

The most common designation suffixes used to identify certain features of SKF bearings in railway applications are explained below. For additional information, contact the SKF application engineering service.

B20 Reduced width tolerance

C3 Bearing internal clearance greater than Normal (CN)

C4 Bearing internal clearance greater than C3

C4H Bearing internal clearance greater than C3 (upper half of C4 clearance)

C5 Bearing internal clearance greater than C4

C5H Bearing internal clearance greater than C4 (upper half of C5 clearance)

CA
1. Spherical roller bearing of C design, but with retaining flanges on the inner ring and a machined cage
2. Single row angular contact ball bearing for universal matching. Two bearings arranged back-to-back or face-to- face will have an axial internal clearance smaller than Normal (CB) before mounting

CB
1. Single row angular contact ball bearing for universal matching. Two bearings arranged back-to-back or face-to-face will have a Normal axial internal clearance before mounting
2. Controlled axial clearance of a double row angular contact ball bearing

CC
1. Spherical roller bearing of C design but with enhanced roller guidance
2. Single row angular contact ball bearing for universal matching. Two bearings arranged back-to-back or face-to-face will have an axial internal clearance larger than Normal (CB) before mounting

CL7C High-performance design for tapered roller bearings in pinion arrangements

DB Matched single row tapered roller bearing pair, arranged back-to-back. A number immediately following the DB identifies the design of the intermediate rings

DF Matched single row tapered roller bearing pair, arranged face-to-face. A number immediately following the DF identifies the design of the intermediate ring

DT Matched single row tapered roller bearing pair, arranged in tandem. A number immediately following the DT identifies the design of the intermediate rings

EC Optimized internal design incorporating more and/or larger rollers and with modified roller end/ flange contact

G Single row angular contact ball bearing for universal matching. Two bearings arranged back-to-back or face-to-face will have a "Normal" axial clearance

GA Single row angular contact ball bearing for universal matching. Two bearings arranged back-to-back or face-to-face will have a light preload

GB Single row angular contact ball bearing for universal matching. Two bearings arranged back-to-back or face-to-face will have a moderate preload

GC Single row angular contact ball bearing for universal matching. Two bearings arranged back-to-back or face-to-face will have a heavy preload

HA Case-hardened bearing or bearing components. For closer identification, HA is followed by one of the following figures
0: Complete bearing
1: Outer and inner rings
2: Outer ring
3: Inner ring
4: Outer ring, inner ring and rolling elements
5: Rolling elements
6: Outer ring and rolling elements
7: Inner ring and rolling elements

HB Bainite-hardened bearing or bearing component. For closer identification, HB is followed by one of the figures explained under HA

HC Bearing or bearing components of ceramic. For closer identification, HC is followed by one of the figures explained under HA
Example: HC5 Rolling elements made of silicon nitride

J, J1, J2 Pressed window-type steel cage

M Machined brass cage, rolling element centred

MA Machined brass cage, outer ring centred, used for oil lubrication

ML, MP Machined one-piece window-type brass cage, outer ring centred, used for oil lubrication

MR Machined one-piece window-type brass cage, rolling element centred

MR3D Machined one-piece window-type brass cage, special design

N Snap ring groove in the outer ring

N1 One locating slot (notch) in one outer ring side face

N2 Two locating slots (notches) 180° apart in one outer ring side face

N3 Snap ring groove in the outer ring, one locating slot (notch) in one outer ring side face

P4 Dimensional and running accuracy to ISO tolerance class 4

P5 Dimensional and running accuracy to ISO tolerance class 5

P54 P5 + C4

P6 Dimensional and running accuracy to ISO tolerance class 6

P63 P6 + C3

P64 P6 + C4

P65H P6 + C5H

Q Optimized contact geometry and surface finish

RS1 Sheet steel reinforced contact seal of acrylonitrile-butadiene rubber (NBR) on one side of the bearing

2RS1 RS1 contact seal on both sides of the bearing

RSH Sheet steel reinforced contact seal of acrylonitrile-butadiene rubber (NBR) on one side of the bearing

2RSH RSH contact seal on both sides of the bearing

RSL Sheet steel reinforced low-friction contact seal of acrylonitrile-butadiene rubber (NBR) on one side of the bearing

2RSL RSL low-friction contact seal on both sides of the bearing

RZ Sheet steel reinforced low-friction seal of acrylonitrile-butadiene rubber (NBR)

2RZ RZ low-friction seal on both sides of the bearing

S0 Bearing rings or washers dimensionally stabilized up to +150 °C

T T, followed by a figure, identifies the total width of single row tapered roller bearing pairs arranged back-to-back or in tandem

TNH Injection moulded cage of glass fibre reinforced polyetheretherketone (PEEK), rolling element centred

TN9 Injection moulded cage of glass fibre reinforced polyamide 66, rolling element centred

V… V combined with a second letter, identifies a variant group, and followed by a three- or four-figure number denotes variants not covered by “standard” designation suffixes.
VA: Application oriented variants
VB: Boundary dimension deviations
VE: External or internal deviations
VL: Coatings
VQ: Quality and tolerances other than standard
VS: Clearance and preload
VT: Lubrication
VU: Miscellaneous applications

Z Shield of pressed sheet steel on one side of the bearing

2Z Z shield on both sides of the bearing

Examples for VA and VL designations

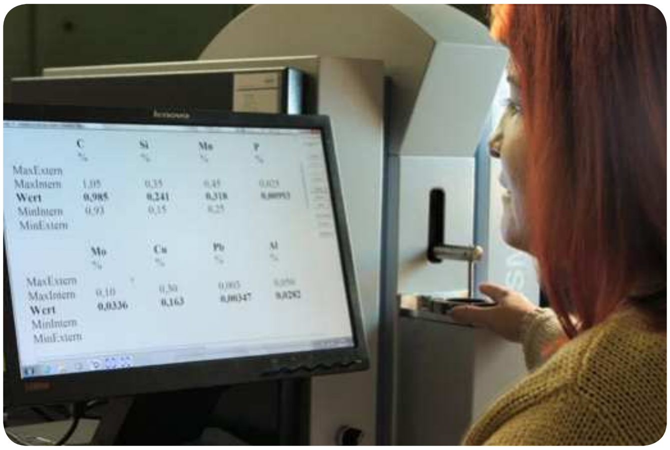
- VA301 Bearing for traction motors
- VA3091 Bearing for traction motors with aluminium oxide coated outside surface of outer ring for electrical resistance up to 1 000 V DC
- VL0241 Aluminium oxide coated outside surface of outer ring for electrical resistance up to 1 000 V DC
- VL0271 Aluminium oxide coated outside surface of inner ring for electrical resistance up to 1 000 V DC

Additional suffixes concerning INSOCOAT bearings are listed on page 117.

Bearing testing

The key for long-term reliability and performance of railway rolling stock is rigorous testing. SKF bearings and units are tested in the Railway Test Centre at the SKF Business and Technology Park in Nieuwegein, the Netherlands. This facility complies with the accreditation criteria for test laboratories according to ISO/IEC 17025. Further test rigs are located at the development centres and production units.

For information about hybrid bearing testing, refer to **page 125**; for additional information about field testing, refer to **chapter 6**, **pages 164** and **165**.



Chemical testing

Dynamic testing

SKF grease test rig used to determine the most suitable grease quality

4 INSOCOAT and hybrid bearings

INSOCOAT and hybrid bearings

Demands on traction motor bearings have significantly increased due to the introduction of frequency converter controlled traction motors for propulsion systems. The passage of electric current through rolling bearings can cause damage in a short period of time. INSOCOAT and hybrid bearings greatly reduce the risk of electric current passing through the bearing.

4

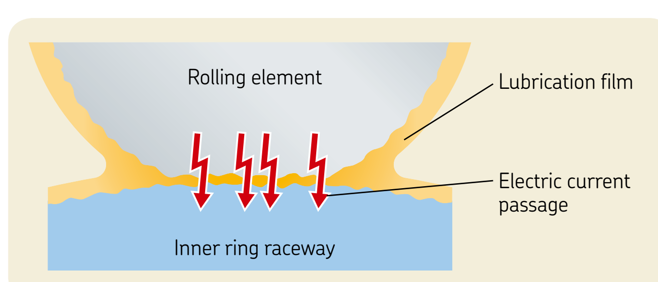
Electric current prevention

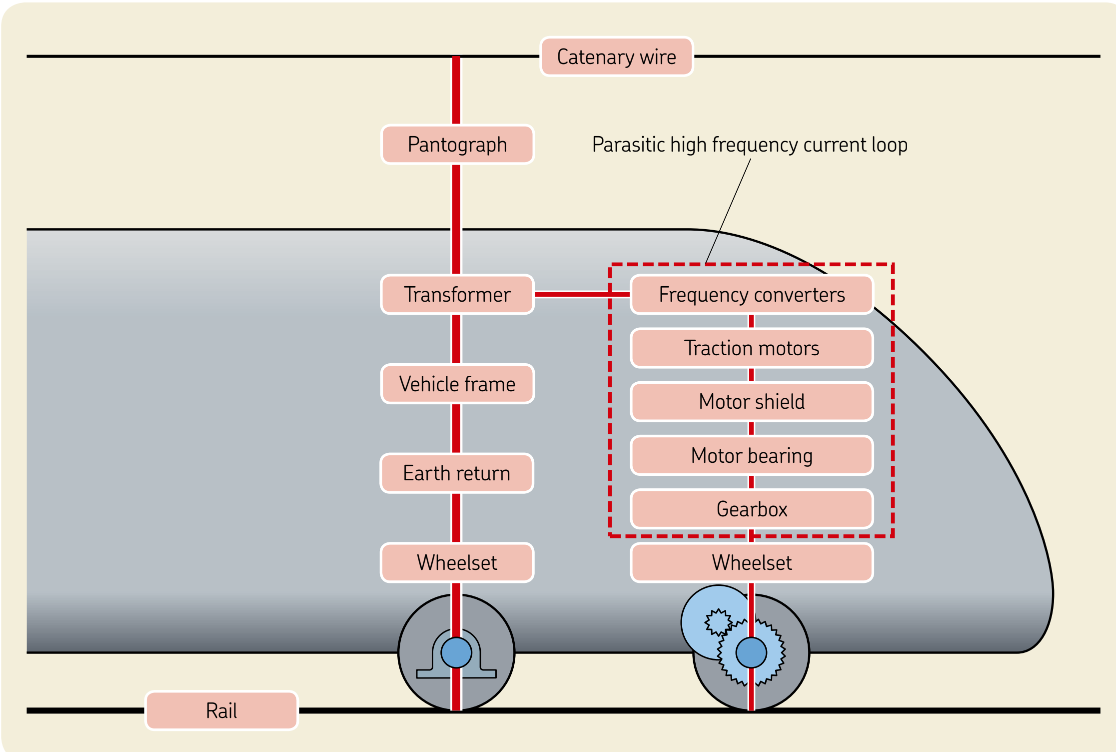
Introduction

Reliability is an essential requirement for modern bearings together with extended maintenance intervals. For example, they must be robust enough to operate in electrical equipment with modern AC technology. The passage of electric current through rolling bearings can cause damage in a relatively short period of time.

To enable smooth, trouble-free operation, it is necessary to prevent electric current from passing through the bearing. The contact areas between the housing, the outer ring, the rolling elements, the inner ring and the shaft act as electric contacts. Bearing damage can occur depending on the electrical regime, the bearing impedance and its tribological behaviour in the rolling contact. Electrical discharges in the form of arcs/sparks can damage rolling elements as well as raceways of bearing rings. This process is characterized by very high temperatures similar to that produced by the melting and the welding processes. Craters are typical damage and in a later stage, as a secondary effect, fluting or washboarding occurs (→ **pages 104** to **106** and → **chapter 7**) [15, 16].

Principle of electrical current passage on the rolling contact area





Principle of electric current flow

Potential risks

Starting in the 1940s, in depth research into the phenomena of electric current passage was published [17]. In the 1960s, SKF conducted several theoretical research activities, which were supported by extensive laboratory and field tests [18]. The results of these tests were compared with field experience from the operators. The conclusion was that the risk of electrical discharges and subsequent bearing damage can occur if the voltage exceeds 0,5 V. An electric current density of more than 0,1 A/mm^2 (related to the contact area of rolling elements) is deemed harmful [19]. These values are very commonly stated in the current literature and in DIN VDE 0123.

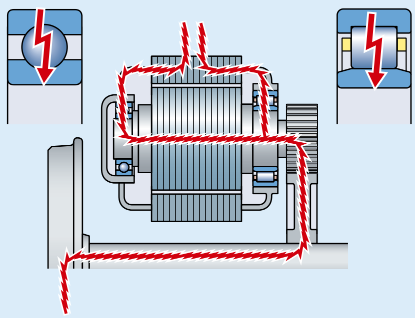
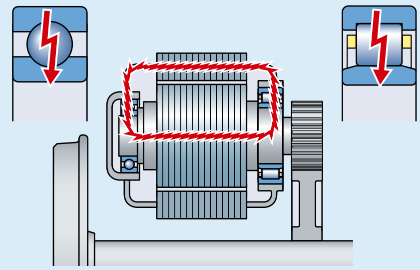
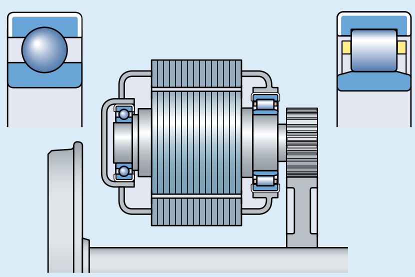
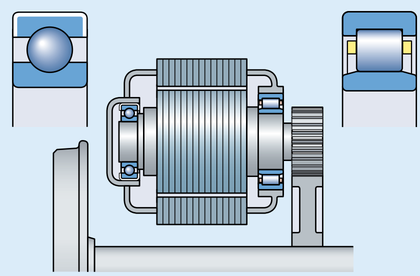
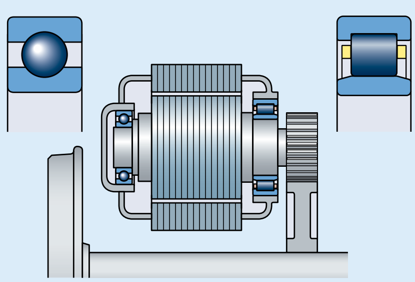
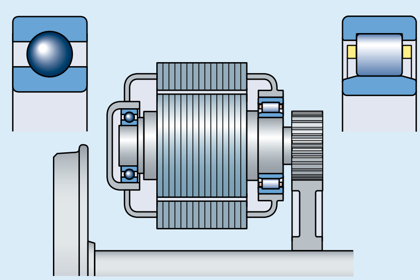
However, for a detailed risk analysis, in addition to the energy of the current flow, the frequency and the power have to be considered as well. This applies especially for frequency converter controlled propulsion systems because of high frequency voltages and current signals.

Prevention solutions

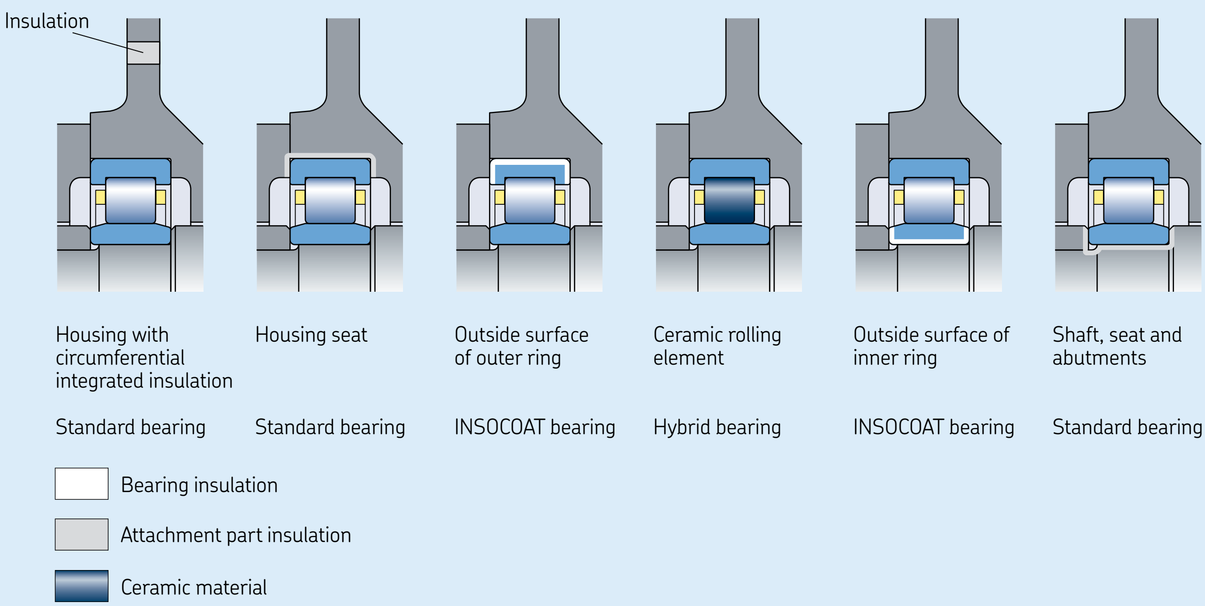
Electric current passage prevention was applied in electrical machines at an early stage. Older designs of stationary electrical machines with special plummer block housings were insulated by inserting an electrically insulated sheet between the housing and its foundation. In the 1950s, electric traction motors were equipped with bearing shields incorporating electrical insulation between the part connected to the stator and the part accommodating the bearing. At this time, SKF produced its first bearings that had an electrically insulating layer pressed onto the outer ring [20].

Later, in the 1970s, insulation designs from manufacturers were based on flame sprayed coatings on the motor shield bore or on the shaft bearing seat. These insulation layers typically had a break down voltage in the range of 100 V DC. These insulation efforts by the traction motor manufacturer were very costly and sometimes the required performance and reliability were not sustainable enough [21].

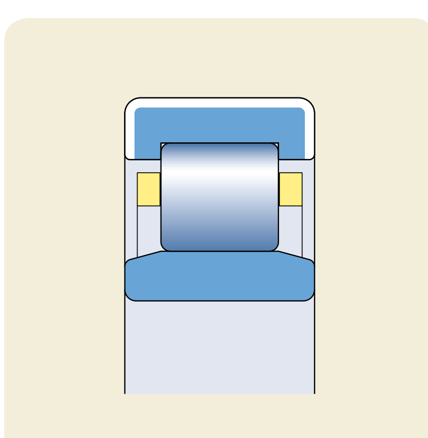
Potential electric current flow in traction motors and its prevention [15]

	Parasitic electric current flow through the traction motor – grounding current	Parasitic electric current flow inside the traction motor – circulating current
No insulation		
INSOCOAT bearing	DC and single phase AC traction motors INSOCOAT bearings on both sides 	DC and single phase AC traction motors INSOCOAT bearing on one side 
Hybrid bearing	Three phase traction motors with frequency converters Hybrid bearings on both sides 	Three phase traction motors with frequency converters Hybrid bearing on one side 

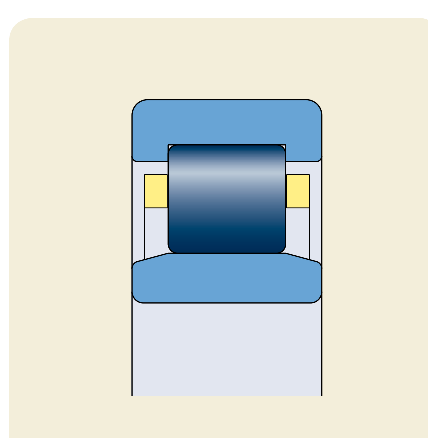
Design variants of electrically insulated bearing arrangements [15]



In the 1970s, SKF already started the serial production of the first electrically insulated bearings known as INSOCOAT bearings [15]. Some years later, tests were initiated to use ceramic balls and rollers as an electric insulator. These so called hybrid bearings were applied in traction motors in the late 1990s when ceramic rolling elements became available from serial production in a reliable quality [22]. Around 2000, the first traction motor bearing units (TMBUs) were equipped with ceramic rolling elements (→ chapter 5).

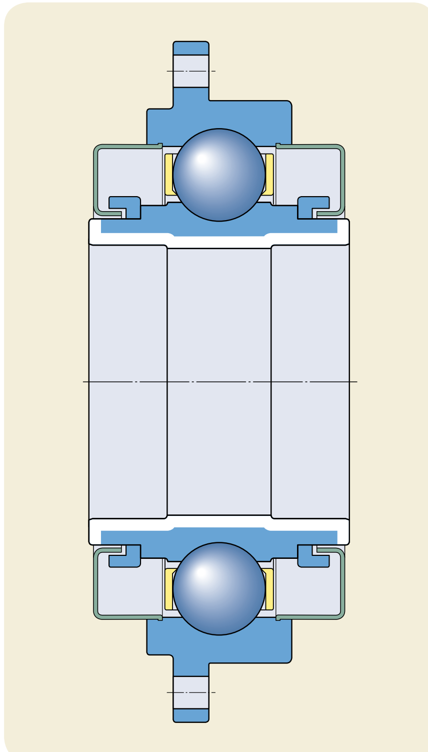


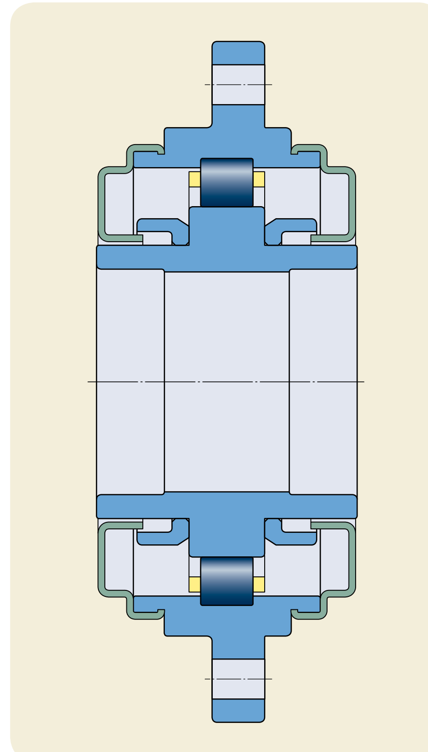
INSOCOAT bearing, basic design



Hybrid bearing, basic design

INSOCOAT traction motor bearing unit, basic design

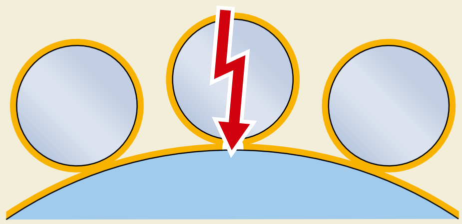




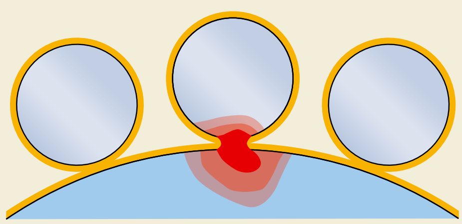
Hybrid traction motor bearing unit, basic design

4

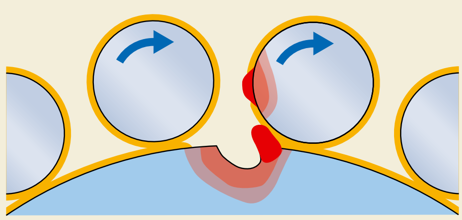
Bearing damage caused by electrical erosion [15]



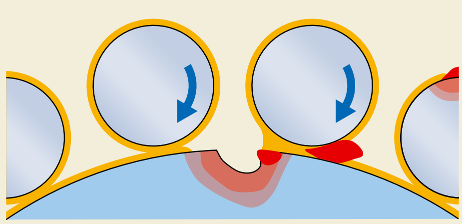
Electrical breakdown of lubricant film



Strong localized heating leads to melting of the metal materials of rolling element and ring in the contact area



When the rolling element leaves the contact area, molten material particles and small craters will be left behind



Protruding material is flattened when rolling over, or worn away, detached particles are distributed within the bearing

Lubricant

Remolten material

Rehardened material

Annealed (tempered) material

Excessive voltage
Ball bearing raceway with large spalls

Electrical erosion process

Excessive voltage

When an electric current passes through a bearing by going from one ring to the other via the rolling elements, damage can occur. At the contact surfaces, the process is similar to electric arc welding where there is a high current density over a small contact surface.

The material is heated to temperatures ranging from tempering to melting levels. This causes the appearance of discoloured areas, varying in size, where the material has been tempered, re-hardened or melted. Craters are formed where the material has been melted.

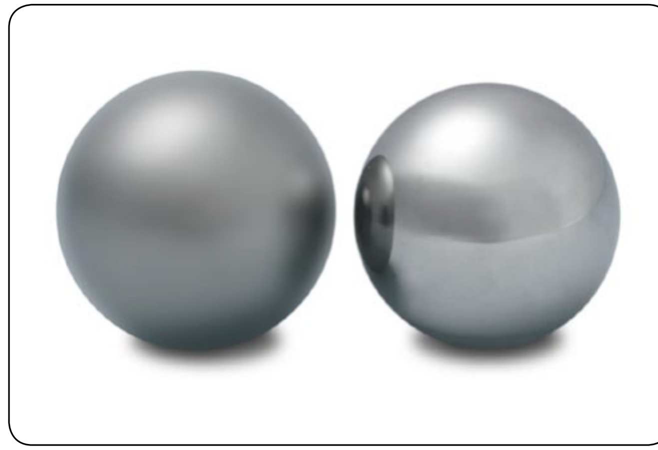
Appearance: Single craters in raceways and/or rolling elements. Localized burns in raceways and on rolling elements.

Current leakage

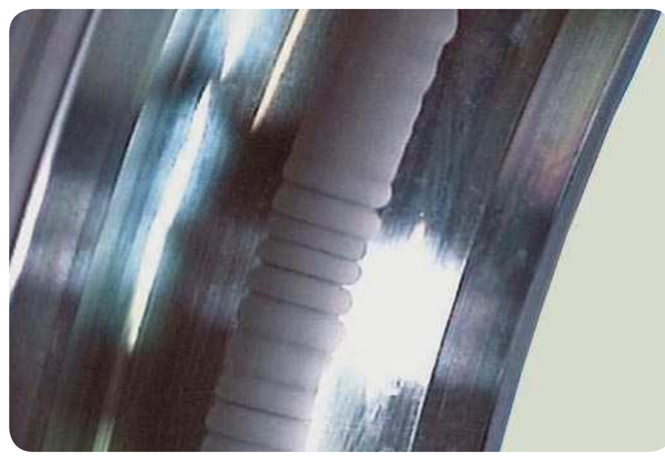
Where current flows continuously in the form of arcs through the bearing in service, even at low intensity, the raceway surfaces are affected by the heat and erode as many thousands of micro-craters are formed, mostly on the rolling contact surface. These craters are closely positioned to one another and are small in diameter compared to the damage from excessive voltage. Flutes (washboarding) will develop from craters over time as a secondary effect and are found on the raceways of rings and rollers.

The extent of damage depends on a number of factors: type of bearing, bearing size, electrical regime, bearing load, speed and lubricant. In addition to bearing steel surface damage, the grease close to the damage might be carbonized, eventually resulting in poor lubricating conditions and consequently to surface distress and spalling.

Very similar electrical erosion damages appear in axlebox applications [1] and sometimes in gearbox applications.
DIN VDE 0123 describes the current flow in railway vehicles in detail.



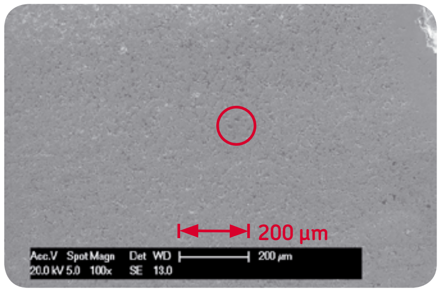
A dull grey surface of the rolling elements can be a sign of microcratering.
Left: ball with dull gray surface
Right: new ball with mirrored picture of the ball to the left

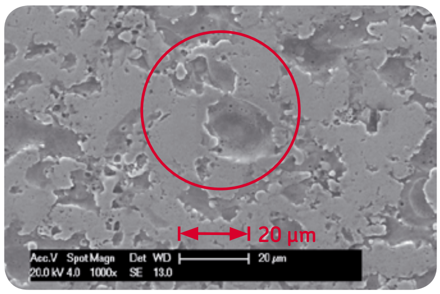


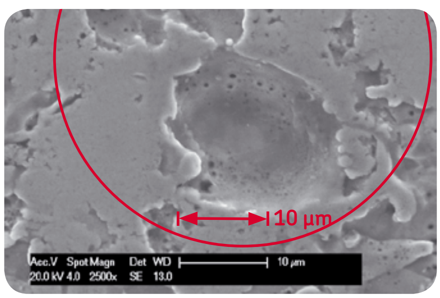
Fluting or washboarding in a raceway caused by the passage of damaging electrical current.
Outer ring raceway of a deep groove ball bearing

Fluting or washboarding in a raceway caused by the passage of damaging electrical current.

Single craters
Single crater damage is typically seen in DC applications. Due to increased use of frequency converters in variable speed drive applications, microcratering is a most common type of electrical damage seen in rolling bearings. When an electrical current continuously passes through the bearing in operation, the raceway surfaces become affected, as many thousands of craters are formed at the surface, which causes a dull/dark grey appearance.







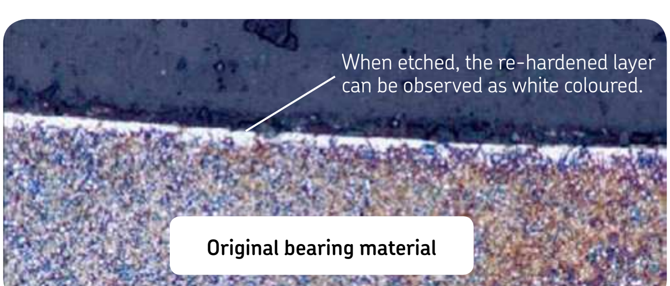
Lubricant degradation
Black discoloured grease on the cage bars caused by passage of current

Lubricant degradation

Local high temperatures cause the additives in the lubricant to char or burn the base oil. This causes the additives to be consumed more quickly. In case of grease lubrication, the grease turns black and hard. This rapid breakdown drastically shortens grease and bearing service life.

Re-hardened bearing steel
In addition, the crater material is re-hardened and much more brittle than the original bearing steel. Due to a continual current flow, the bearing surface layer will be re-hardened again and again. Finally, a re-hardened steel goes on covering the original bearing steel. When etched, the re-hardened layer can be observed as white coloured area in the cross section.

Be careful: The bearing steel is re-hardened due to high temperature which could be caused by a number of reasons, not only passage of electrical current.



Traction motor bearing insulation requirements

	Frequency converter AC traction motors	DC traction motors
Usage	Most commonly used	Requirements from some operators
Resistance requirements	Impedance[1)]	Ohmic resistance
Solution	Hybrid bearings INSOCOAT bearings depending on the specific application requirements	INSOCOAT bearings

1) Electrical impedance extends the concept of resistance to AC circuits, describing not only the relative amplitudes of the voltage and current, but also the relative phases. When the circuit is driven with DC, there is no distinction between impedance and resistance; the latter can be thought of as impedance with zero phase angle.

4

Electrical features

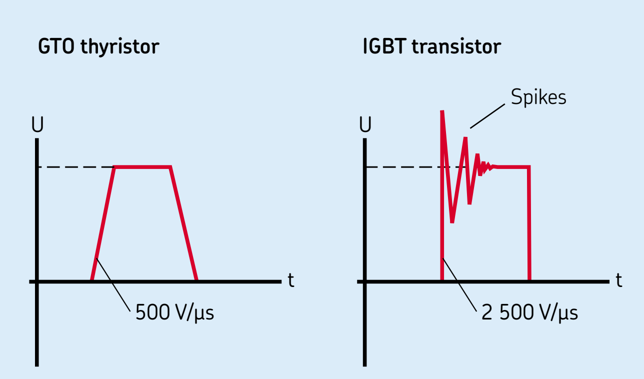
In recent decades, the demand for AC motors in railway and especially industrial applications has grown rapidly. The three-phase induction motor is the most commonly used type of traction motor in the railway industry. Classical DC traction motors are still in demand by some railway operators, but requests are continually decreasing.

Frequency converters

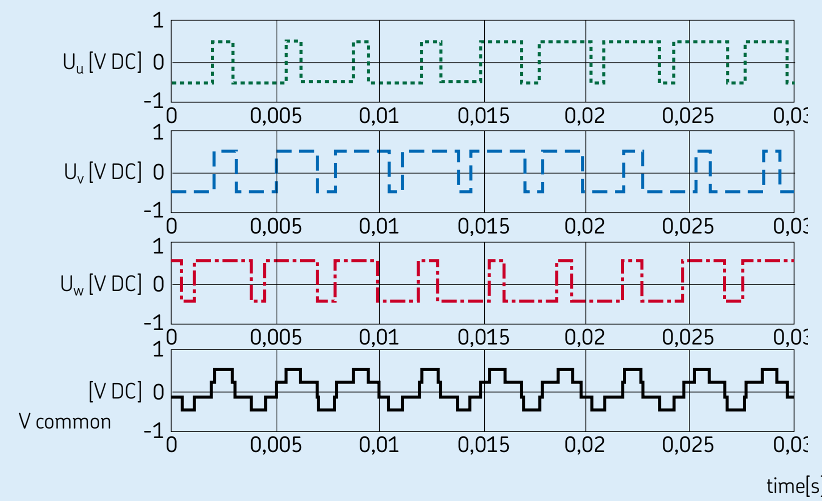
Power-switching semiconductor devices used in frequency converters have changed from thyristors to gate turn-off transistors (GTOs) and further to the insulated gate bipolar transistors (IGBTs). These IGBTs are used to create the pulse width modulated (PWM) output voltage waveform and thereby improve efficiency and dynamic performance of the drive. However, there is no advantage without compromise. So apart from the classic voltages and currents generated by the motor itself, new effects have been observed when the motor is supplied from a PWM converter (frequencies of 3 to 12 kHz, depending on the power range).

It now has been discovered that bearing damage is caused by a high frequency (5 kHz to 10 MHz) current flow that is induced by these fast-switching (100 ns) IGBT semiconductor devices. These IGBTs also cause a very rapid voltage rise (d_u/d_t) up to 2,5 to 8 kV/µs or even up to 10 kV/µs at the converter output.

Voltage pulse of a GTO thyristor compared to an IGBT transistor



Magnetic flux asymmetries in the motor:
The three phases and their sum is not zero but lead to the common mode voltage



The basic causes and sources for bearing currents are:

- magnetic flux asymmetries in the motor
- asymmetrical, non-shielded cabling
- fast-switching frequency converters and their common mode voltage

The first two sources are potential risks for all electrical motors, whether they are main-fed or converter-fed motors.

The last source only exists for converter-fed motors. Potential problems arise because of different parasitic currents:

- high frequency shaft grounding currents
- high frequency circulating currents
- capacitive discharge currents [23]

When a rolling bearing is operating correctly, an oil film separates the rolling elements from the raceways. From the electrical point of view, this film acts as a dielectric, which is charged by the rotor voltage. For high frequencies, it forms a capacitor in which the capacitance depends on various parameters such as the type of lubricant, temperature and viscosity, plus film thickness. If the voltage reaches a certain limit, called the breakdown or threshold voltage of the lubricant, the capacitor will be discharged and a high frequency capacitive discharge current occurs. In this case, the current is limited by the internal stray capacitances of the motor, but it will occur every time the converter switches.

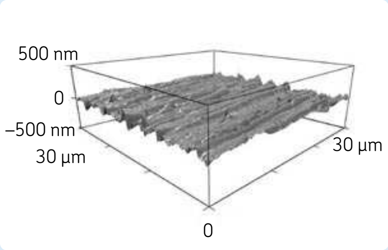
Obviously, an induction motor fed by a frequency converter is a very complex drive system, which is influenced by many parameters. The whole drive, including supply, DC link, switching elements, cables, motor and load, has to be regarded as a total system consisting of inductances and distributed capacitances.

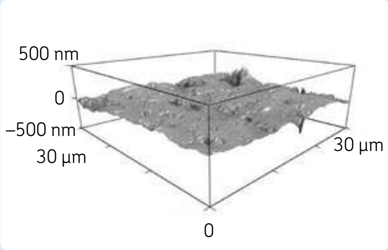
The basic three traction motor propulsion concepts and potential causes for electrical erosion

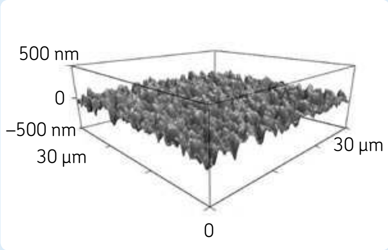
	Direct current propulsion system	Alternating current single phase propulsion system	AC frequency converter propulsion system
Magnetic flux asymmetries in the motor	yes	yes	yes
Asymmetrical, non-shielded cabling	no	no	yes
Common mode voltage	no	no	yes

Bearing raceway in very large magnification

Bearing raceway, no electrical current passage	Bearing raceway, damaged by electrical current passage	
	DC propulsion system	AC frequency converter propulsion system

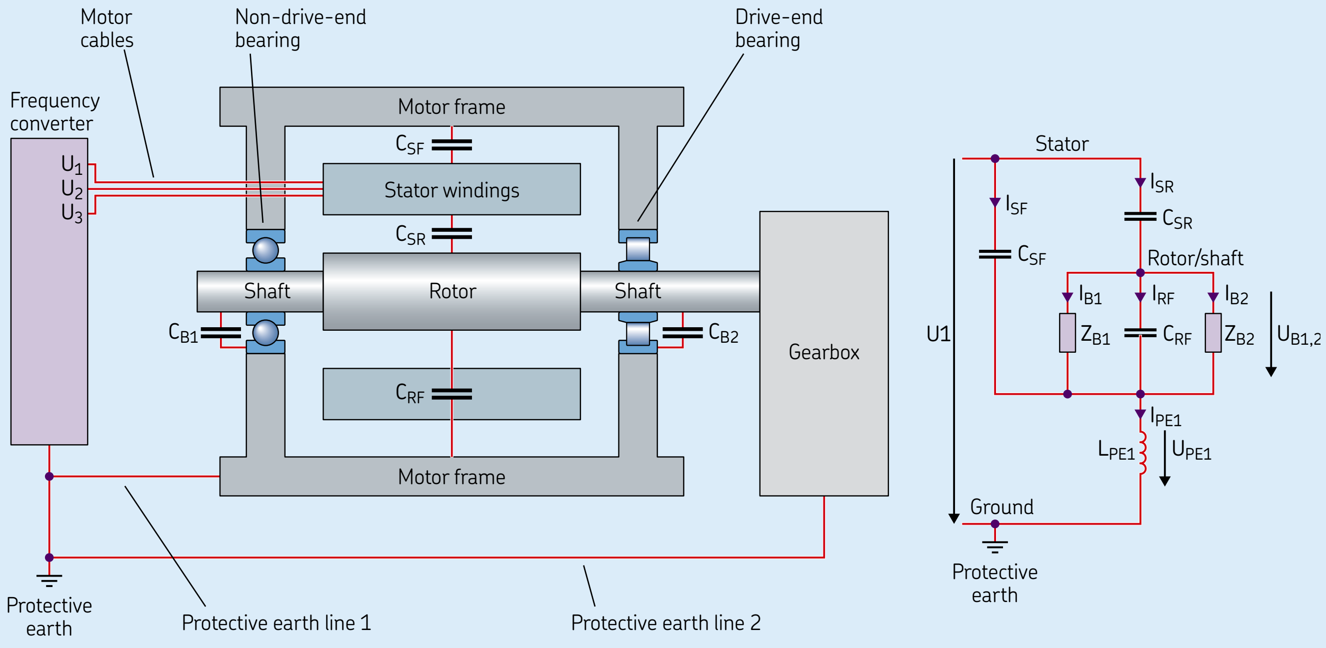




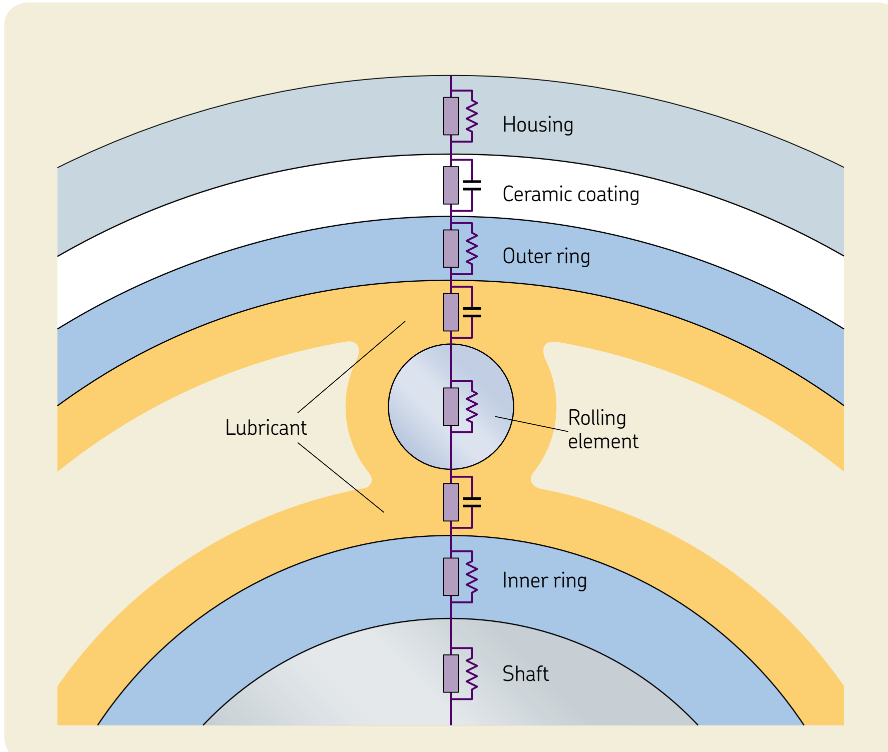


4

Traction motor principle with inherent stray capacitances [24]



Schematic electrical circuit model of a mounted INSOCOAT bearing



Influence of the electrical parameters

There is a distinction between DC and AC electrical regimes and the behaviour of INSOCOAT bearings in these applications.

In DC applications, an INSOCOAT bearing acts as a normal (pure ohmic) resistor. The aluminium oxide layer is an insulator and, therefore, only the ohmic resistance R of the layer is the important quantity. The breakdown voltage of the standard layer is stated as 1 000 V DC and the resistance is bigger than 50 MΩ, which provides efficient insulation of the bearing.

In AC applications, especially at high frequencies produced by PWM-converters, this is no longer valid. An equivalent electrical circuit diagram of the whole bearing that considers all elements of an INSOCOAT bearing, such as inner and outer ring, rolling elements, the cage, the lubricant and the contact surface area between rolling elements and raceways and the ceramic coating has to be developed. One possible approximation of the bearing equivalent electrical structure is shown in the illustration above.

It is difficult to create a precise equivalent circuit of the bearing as an electrical system. There are two main reasons for this:

- The massive metal elements in high frequency electrical fields have a very complicated three-dimensional structure. The possible presence of eddy currents within this structure has to be considered.
- The contacts between outer ring and rolling elements and between rolling elements and inner ring create capacitances. The values of these capacitances change stochastically according to the dynamics in bearings, for example, due to vibrations.

Modelling of electric insulation behaviour

An electrically insulating layer such as the aluminium oxide Al_2O_3 coating has to be modelled as a parallel connection of a resistor and a capacitor. Therefore, the impedance Z must be considered, which is described as

$$Z = \frac{R}{1 + j\,\omega\,R\,C}$$

where:

Z = impedance
j = imaginary unit
$\omega = 2\,\pi\,f$
R = DC (ohmic) resistance of the system [Ohm]
C = capacitance [F]
f = frequency [Hz]

The value of the impedance can be obtained from:

$$|Z| = \frac{1}{\sqrt{\frac{1}{R^2} + (2\pi f C)^2}}$$

This equation illustrates that with increasing frequency the term incorporating the capacitance becomes stronger and causes a decrease of the impedance. To increase the impedance of the bearing, the capacitance of the coating should be kept as small as possible. The capacitance of an INSOCOAT bearing depends on the size (coated surface area) of the bearing, on the thickness of the insulating coating and on the coating material, as indicated in the following equation [23]

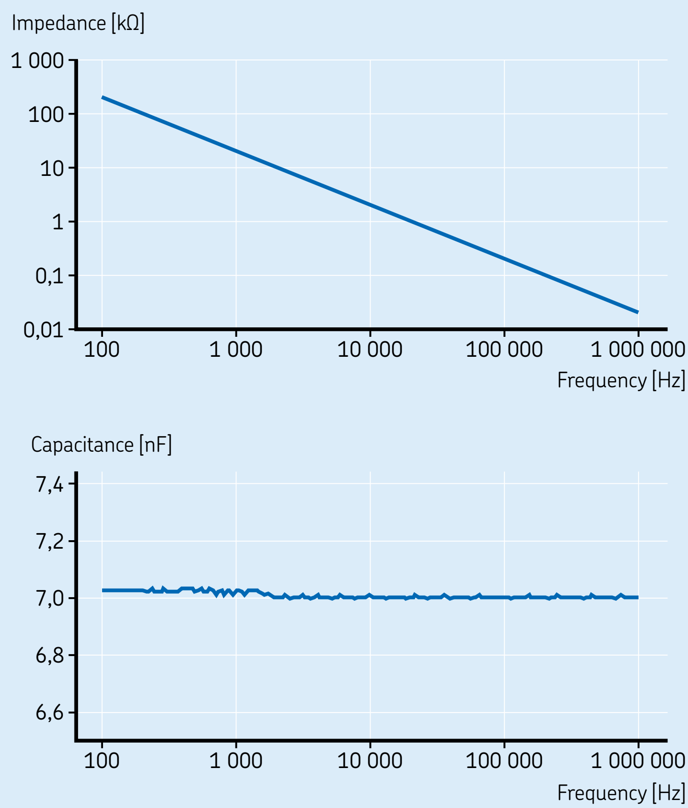
$$C = \varepsilon_0\,\varepsilon_r\,\frac{A}{s}$$

where:

ε_0 = dielectric constant in vacuum
ε_p = permittivity[1)] constant of the insulating coating
A = coated contact surface area
s = thickness of the ceramic coating

1) In electromagnetism, permittivity is the measure of how much resistance is encountered when forming an electric field in a medium.

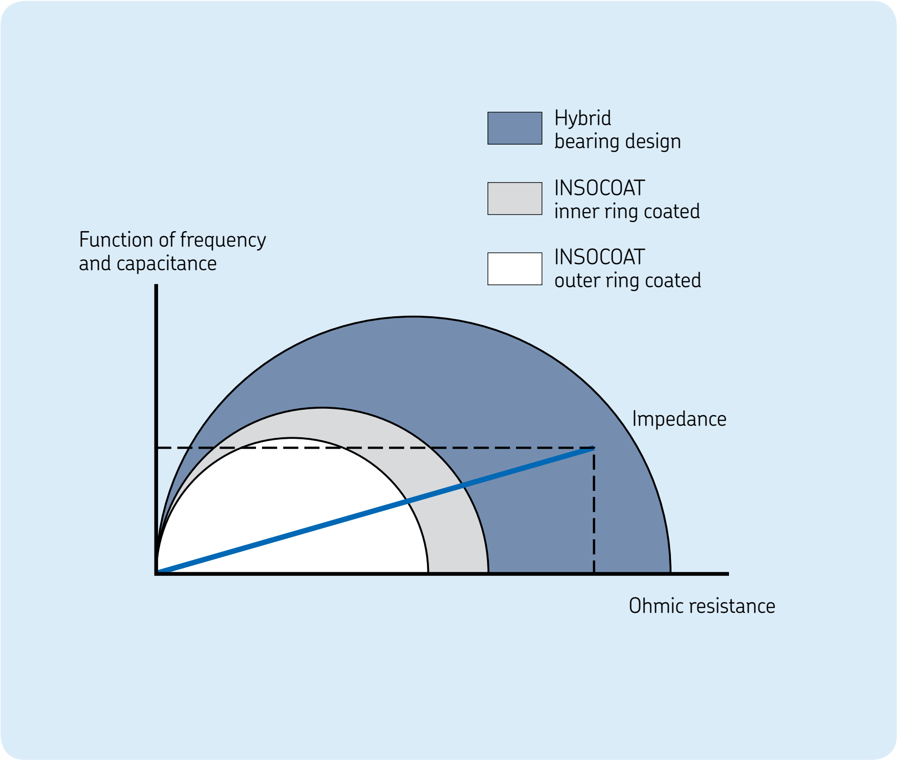
Measured impedance and capacitance of an INSOCOAT 6316/VL0241 deep groove ball bearing (outer ring coated)



Selection of electrical insulation

SKF offers three basic design solutions for electrical insulation of traction motor bearings, depending on the application requirements:

- Hybrid bearing designs
- INSOCOAT bearing designs with coated inner ring, which is mainly used for traction motor bearing units and industrial electrical machines
- INSOCOAT bearing designs with coated outer ring, which is used for traction motors and generators in railways



Bearing designs for different ohmic resistance, frequency and capacitance.
The electrical impedance is a vector function based on the ohmic resistance, frequency and capacitance. The capacitance is a measure of the amount of electric charge stored for a given electrical potential.

4

INSOCOAT bearings

INSOCOAT bearings are designed to prevent current from passing through the bearing. The bearings are a very cost-effective solution compared with other insulation methods. By integrating the insulating properties into the bearing, INSOCOAT bearings can improve reliability and increase machine uptime by virtually eliminating the problem of electrical erosion.

The standard assortment of INSOCOAT bearings listed in this handbook constitutes the most commonly used sizes and variants of:

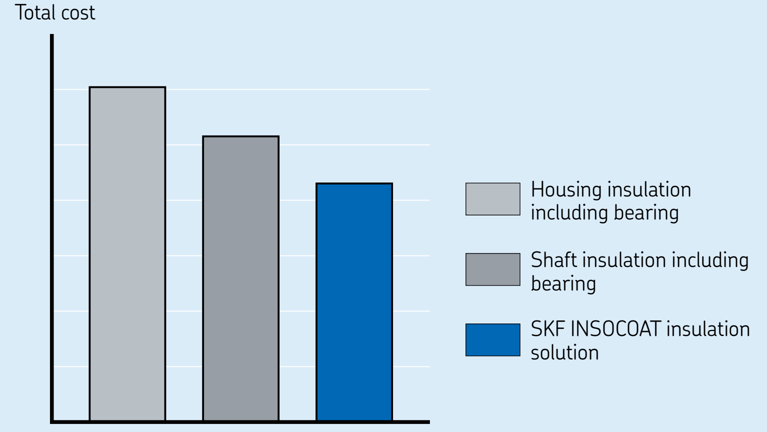
- single row deep groove ball bearings
- single row cylindrical roller bearings

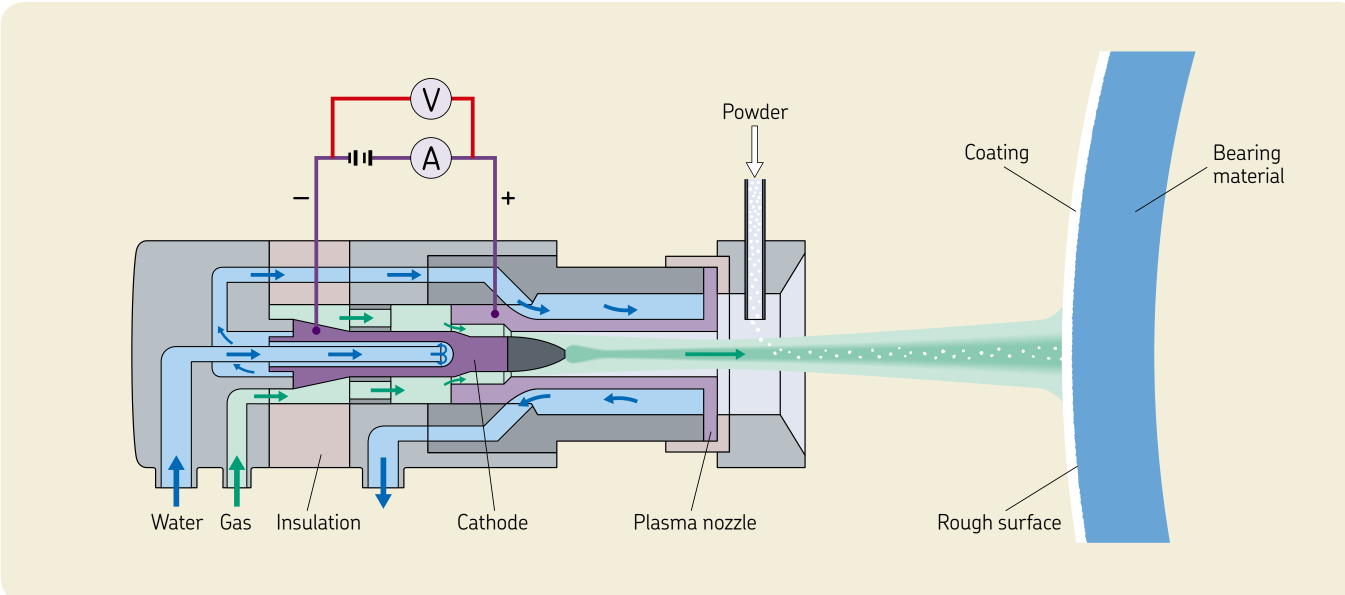
In railway applications, traction motor bearing units (TMBUs) can be designed with INSOCOAT coating (→ chapter 5).

For suspension tubes, special INSOCOAT tapered roller bearings with coated outer rings can be supplied.

INSOCOAT flanged tapered roller bearing for suspension tubes (→ chapter 2)

Total cost of SKF insulated bearing solution relative to other insulation approaches





Plasma spaying process principle

Design features

An INSOCOAT bearing is a standard bearing that has the outside surfaces of its inner ring (VL2071) or outer ring (VL0241), plasma-sprayed with an aluminium-oxide to form a coating. The coating is sealed with a resin to protect against the conductive effects of water and moisture.

In railway applications, INSOCOAT bearings typically have the outside diameter and side faces of the outer ring coated with aluminium-oxide [25]. These bearings are identified by the designation suffix VL0241.

The basic coating can withstand voltages up to 1 000 V DC. However, coating variants withstanding higher voltages can be supplied on request (→ table on page 117).

Cages

INSOCOAT bearings are fitted with one of the following cages:

- Deep groove ball bearings in electric traction motors and generators are mainly fitted with a riveted machined brass cage (→ pages 86 to **87**).
- Cylindrical roller bearings in electric traction motors and generators can be fitted with the same cage as used in comparable standard cylindrical roller bearings (→ page 79).

Implementation

Design of associated components

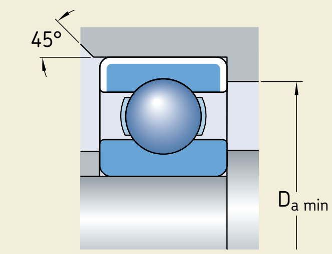
For insulation reasons, it is recommended that for bearings with a coated outer ring, designation suffix VL0241, the housing shoulder or spacer sleeve should not have a diameter that is smaller than the abutment dimension $\Delta_{\alpha\,\mu\text{lv}}$ listed in SKF catalogues.

Mounting and maintenance

During mounting, INSOCOAT bearings should be handled in the same way as standard bearings. Proper lubrication is important to fully utilize the service life of INSOCOAT bearings.

INSOCOAT design benefits

- virtually eliminates premature bearing failures caused by stray electric current
- economical solution compared to other insulation options
- higher reliability
- lower life cycle cost



Abutment dimensions for outer ring coated INSOCOAT bearings

Other design features

For additional information about minimum load, axial load carrying capacity, equivalent dynamic bearing load, equivalent static bearing load, temperature limits and speed limits, refer either to chapter *Traction motor bearing units* (→ chapter 5) or to SKF catalogues.

INSOCOAT bearing data

	Deep groove ball bearings and cylindrical roller bearings
Dimension standards	Boundary dimensions: ISO 15
Tolerances	Normal, higher accuracy on request Values: ISO 492, for additional information, refer to SKF catalogues. The aluminium-oxide layer on the external surfaces of either the outer or the inner ring does not influence the accuracy.
Internal clearance	Check suitable clearance class Values are valid for dismounted bearings under zero measuring load: ISO 5753-1, see SKF catalogues
Allowable misalignment	Identical to the comparable standard bearings
Electrical properties	The standard INSOCOAT layer provides protection against AC and DC currents. The minimum ohmic resistance is 50 MΩ at 1 000 V DC. Tests at SKF have shown that electrical breakdown of the insulating layer occurs above 3 000 V DC.

INSOCOAT specifications

SKF specification, designation suffix	No electrical breakdown up to operating voltage V DC	Electrical resistance min. MΩ
outer ring coated		
VL0241	1 000	50
VA3091[1]	1 000	50
VG2211[2]	1 000	50
VL0244	2 000	150
VL0246	3 000	150
inner ring coated		
VL0271	1 000	50

[1] VA3091: VL0241 plus VA301 special execution for bearings in traction motors
[2] VG2211: VL0241 plus special cage design

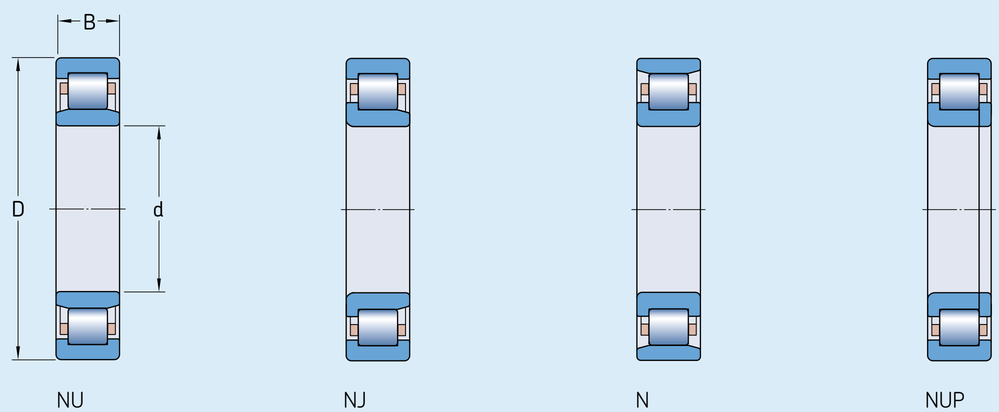
Preferred range

The preferred range is based on the assortment of September 2012. This range is a living collection and will be updated and published in future if needed.

The standard range of INSOCOAT bearings, as well as additional information about these bearings, can be found in SKF catalogues or online at skf.com/bearings, where further application relevant data can be obtained.

A complete listing of the designation prefixes and suffixes can be found on pages 94 to 96.

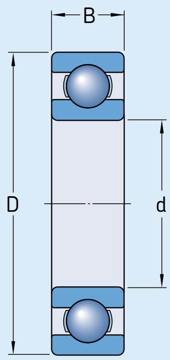
Traction motor – INSOCOAT cylindrical roller bearings



Principal dimensions			Designation
d	D	B	
mm			–
50	90	20	**NU 210 ECM/C3HVA3091**
65	120	23	**NU 213 ECM/C4VA3091**
70	125	24	**NU 214 ECM/C4VA3091**
	125	24	**NUP 214 ECM/C4VA3091**
75	130	25	**NU 215 ECM/C4HVA3091**
90	140	24	**NU 1018 M/C4VA3091**
95	170	32	**NU 219 ECM/C4VA3091**
100	215	47	**NJ 320 ECM/P64VA3091**[1)]
110	170	28	**NU 1022 M/C3VA3091**
	200	38	**NU 222 ECMR/P64VA3091**
	240	50	**NUP 322 ECML/C4VL0241**
120	260	55	**NU 324 ECM/C3VL0241**
130	280	58	**NU 326 ECML/C5VA3091**
160	290	48	**NU 232 ECM/C4HVA3091**
	340	68	**N 332 EMR/HB3L3BVA841**

1) In addition to NJ series cylindrical roller bearings, appropriate HJ series angle rings with suffix VA301 can be supplied.

Traction motor – INSOCOAT deep groove ball bearings



Principal dimensions			Designation
d	D	B	
mm			–
40	90	23	**6308 M/C4VL0241**
60	130	31	**6312 M/C3VL0241**
65	160	37	**6413 MC/C5HS2VL0241**
70	125	24	**6214 M/C4VL0241**
	150	35	**6314 M/C4VL0241**
75	130	25	**6215 M/C4VL0241**
	160	37	**6315 M/C4HVL0241**
80	125	22	**6016 M/P65HS0VG2211**
95	200	45	**6319 M/C4VL0241**
110	240	50	**6322 M/C4VL0241**
120	260	55	**6324 M/C3VL0241**
130	280	58	**6326 M/C3VL0241**
160	290	48	**6232 N1M/C5HS0VG2241**
	340	68	**6332 M/C3VL2071**
180	320	52	**6236 M/C5HS0VG2211**
240	360	56	**6048 M/C4S0VG2211**
260	400	65	**6052 M/C4S0VG2211**

Hybrid bearings

Hybrid bearings provide a further improvement of the electrical insulation properties, especially for modern high frequency converter system applications. These bearings are equipped with rolling elements made of bearing grade silicon nitride. Hybrid bearings have superior electrical insulation properties even at very high frequencies. Extended maintenance intervals can be based on the application of the new optimized grease life guidelines (→ **pages 132** to **135**).

The assortment of SKF hybrid bearings listed in this handbook comprises popular sizes for electric railway motors and generators. It includes:

- single row deep groove ball bearings
- single row cylindrical roller bearings

In addition, traction motor bearing units (TMBU) can be designed as hybrids (→ **chapter 5**).

Design features

Hybrid bearings have rings made of bearing steel and rolling elements made of bearing grade silicon nitride (Si_3N_4). Because silicon nitride is such an excellent electrical insulator, hybrid bearings can be used to effectively insulate the housing from the shaft in both AC and DC motors, as well as in generators.

In addition to being an excellent insulator, hybrid bearings have higher speed capabilities and provide longer bearing service life under the same operating conditions than a same sized all-steel bearing. Hybrid bearings also perform extremely well under vibrating or oscillating conditions. Often, it is not necessary to preload the bearing or apply special grease under these conditions.

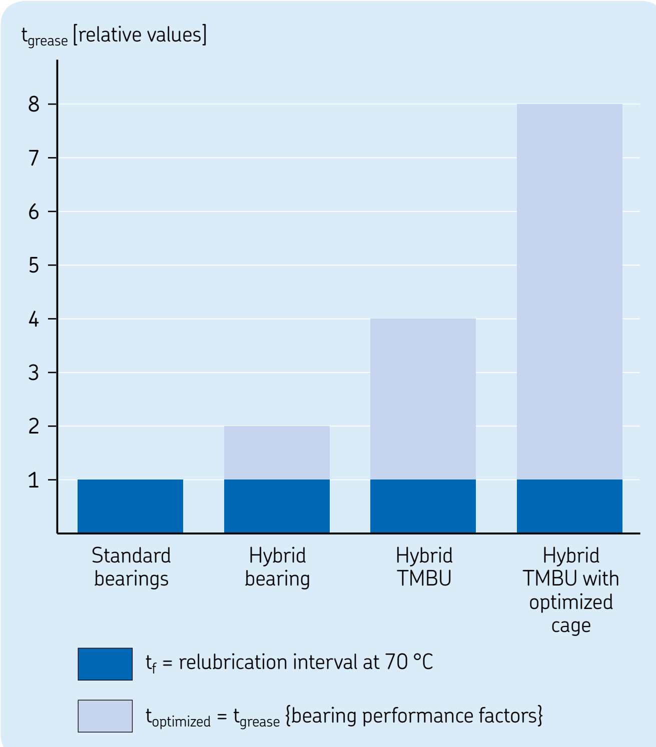
Bearing performance is not only determined by load or speed ratings. There are a number of other factors that contribute to bearing performance. Main factors that enhance SKF hybrid bearing performance, when compared to a same-sized all-steel bearing, include:

- **Insulating properties**
  As a non-conductive material, silicon nitride protects the rings from electric current damage and, therefore, can increase bearing service life in applications where otherwise damaging electrical currents shorten bearing service life, e.g. in AC and DC motors and generators.

- **Lower density**
  The density of a bearing grade silicon nitride rolling element is 60% lower than a same sized rolling element made of bearing steel. Lower weight means lower inertia – and that translates into superior performance during rapid starts and stops, as well as higher speed capabilities.

- **Lower friction**
  The lower density of a silicon nitride rolling element, combined with its low coefficient of friction, significantly reduces bearing temperature at high speeds. Cooler running increases the service life of both the bearing and the lubricant.

- **High hardness and high modulus of elasticity**
  The high degree of hardness of a silicon nitride rolling element means high wear-resistance, increased bearing stiffness and longer bearing service life in contaminated environments.



Applied SKF optimized grease life guidelines, for further information, see → pages 132 to 135

Hybrid bearing design benefits

- superior electrical insulation properties even at very high frequencies
- extended maintenance intervals due to longer grease life compared to all-steel bearings
- energy saving capabilities because of lower friction and higher precision
- extended maintenance intervals because of lower operating temperature

Resists false brinelling

If a stationary bearing is subjected to vibrations, there is a risk that "false brinelling" will occur. False brinelling is the formation of shallow depressions in the raceways that will eventually lead to spalling and premature bearing failure. In cases where steel rolling elements were replaced by ceramic rolling elements, the bearings were found to be significantly less susceptible to false brinelling.

Reduced risk of smearing between silicon nitride and steel surfaces

Even under inadequate lubrication conditions, there is reduced risk of smearing between silicon nitride and steel surfaces.

This enables hybrid bearings to operate much longer in applications where there are high speeds and fast accelerations, or applications where there is an insufficient hydrodynamic oil film to support undisturbed bearing operation (i.e. $\kappa < 1$, (→ **chapter 5**). For hybrid bearings, it is common to apply $\kappa = 1$ for bearing life calculations, also for conditions where $\kappa < 1$.

Runs faster, lasts longer

Combine the lower density of silicon nitride with its lower coefficient of friction, high hardness and the fact that silicon nitride does not smear the raceways under poor lubrication conditions, and the result is a bearing that will run faster and longer even under the most difficult operating conditions.

Low coefficient of thermal expansion

A silicon nitride rolling element has a lower coefficient of thermal expansion than a same-sized rolling element made of bearing steel. This means less sensitivity to temperature gradients within the bearing and more accurate preload/clearance control.

Speed capability

Typically, hybrid bearings have a higher speed capability than same-sized all-steel bearings, however, in some cases the cage execution may limit the permissible speed.

Benchmark of steel, silicon nitride and porcelain material properties

Material	Bearing steel grade	Bearing grade silicon nitride	Porcelain
Compressive strength (MPa)	2 300	3 000	950
Tensile strength (MPa)	1 900	800	150
Density (g/cm^3)	7,9	3,2	2,9
Hardness HV 10 (kg/mm^2)	700	1 600	800
Elastic modulus (GPa)	210	310	125
Thermal expansion (10^{-6}/K)	11,7	3	5
Electrical resistivity (Ω cm)	$0,4 \times 10^{-6}$ (conductor)	10^{12} (insulator)	10^{12} (insulator)
Dielectric strength (kV/mm)	–	15	–
Relative dielectric constant	–	8	–

Hybrid deep groove ball bearings

Deep groove ball bearings are the most widely used bearing type, especially in electric motors. These non-separable bearings are suitable for high speeds. The deep uninterrupted raceway grooves have a close osculation with the balls, enabling the bearings to accommodate radial loads and axial loads in both directions. For additional information, refer to SKF catalogues.

Hybrid cylindrical roller bearings

Hybrid cylindrical roller bearings are commonly used in electric motors, especially traction motors, and in applications running under severe operating conditions. They can accommodate heavy radial loads and high speeds. For additional information, refer to chapter *Bearing designs* (→ chapter 3).

Other design features

For additional information about minimum load, axial load carrying capacity, equivalent dynamic bearing load, equivalent static bearing load, temperature limits and speed limits, refer either to chapter *Traction motor bearing units* (→ chapter 5) or to SKF catalogues.

Hybrid bearing data

	Deep groove ball bearings	Cylindrical roller bearings
Dimension standards	Boundary dimensions: ISO 15 Normal, higher accuracy on request	 Normal, P6 running accuracy, higher accuracy on request
Tolerances	Values: ISO 492, for additional information, refer to SKF catalogues.	
Internal clearance	Check suitable clearance class (→ chapter 5) Values are valid for unmounted bearings under zero measuring load: ISO 5753-1	
Allowable misalignment	Identical to comparable standard bearings	
Electrical properties	Hybrid bearings provide protection against AC and DC currents. The impedance for a hybrid bearing is high, even for very high frequencies, providing excellent protection against high frequency current and voltage peaks. For additional information, contact the SKF application engineering service.	

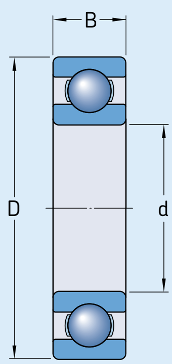
Preferred range

The preferred range is based on the assortment of September 2012. This range is a living collection and will be updated and published in future if needed.

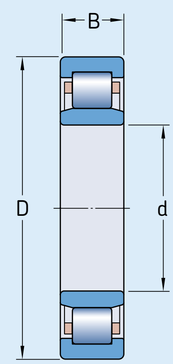
The standard range of hybrid bearings, as well as additional information about these bearings, can be found in SKF catalogues or online at skf.com/bearings, where further application relevant data can be obtained.

A complete listing of the designation prefixes and suffixes can be found on page 94 to 96.

Traction motor – Hybrid bearings



Deep groove ball bearing



Cylindrical roller bearing (NU design)

Principal dimensions			Designation
d	D	B	
mm			–
60	110	22	**6212 M/HC5C4S0VG319**
70	125	24	**6214 M/HC5C4S0VG319**
80	125	22	**6016 MC/HC5P65HS0**
85	150	28	**6217 M/HC5C5S0VG319**
90	160	30	**6218 M/HC5C4S0VG319**
110	170	28	**6022 M/HC5C4S0VG319**

Principal dimensions			Designation
d	D	B	
mm			–
40	68	15	**NU 1008 ML/HC5C5**
50	90	20	**NU 210 ECM/C3HVC498**
60	95	18	**NU 1012 MR/C4HVC498**
70	110	20	**NU 1014 MR/HC5C4**
75	115	20	**NU 1015 MR/HC5C4**
80	125	22	**NU 1016 MR/C4HVC498**

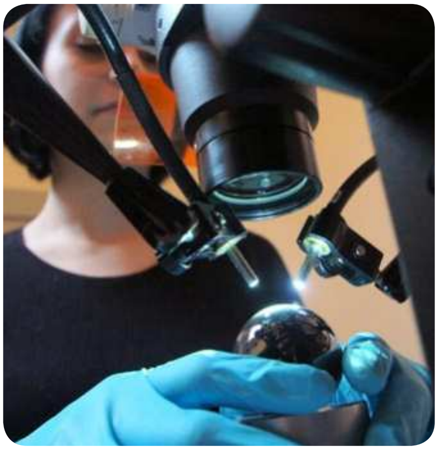
Hybrid bearing testing

To make sure that ceramic materials perform optimally in a bearing application, a careful assessment of the materials used for rolling elements is necessary. Test procedures have been established over time for this purpose.

In general, a first material assessment can be done by checking the macrostructure, microstructure and homogeneity on sectioned samples from blank or finished ball materials by sample mounting and polishing. Also, hardness and indentation fracture resistance for a possible bearing material candidate can be determined relatively quickly.

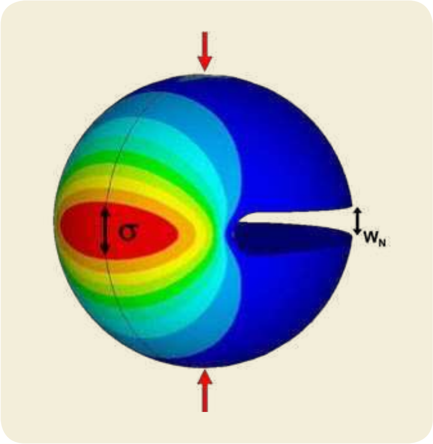
New methods for testing the strength of finished ceramic balls have been developed. Especially in high-strength materials, it has been seen that the surface quality has a significant influence on strength. And the surface quality of a bearing ball is much better than that of a reference sample bending bar. The "notched ball" test has the advantage that strength can be evaluated on real bearing balls and not on bending bars as specified at present in ISO 26602. The balls are notched and loaded vertically. They act in a similar way to bending bars [26].

Checking macrostructure, microstructure and homogeneity on sectioned samples



Optical testing of the ball surface

4



Principle of the notched ball test for bending strength evaluation of ceramic balls
σ = stress
W_N = width

Endurance life test rig with two sets of four axially loaded hybrid angular contact ball bearings

"Notched ball" test for ceramic balls

5 Traction motor bearing units

Traction motor bearing units

The traction motor bearing unit (TMBU) design offers a maintenance-free solution for an extended service interval. This solution is based on a very compact and space-saving design. The total motor length can be reduced or a given motor envelope iron length of rotor and stator can be increased to achieve a higher power rating. This subsystem design principle incorporates several features into one unit like grease, sealing and locating functions. The integrated flange design enables very easy mounting.

To develop and design a complete bearing arrangement and to handle the logistics of bearings and all surrounding parts like seals, washers, bolts and screws and to mount everything properly requires a lot of effort and time. Also, maintenance of traction motors to a traditional bearing arrangement design demand a lot of skills in workmanship and logistics. The overall cost for OEM customers and operators is a multiple of the bearing purchasing cost. These additional costs are partly obvious but also hidden in cost calculations from customers. On the other hand, unexpected potential risks can occur and severe failures can arise with such demanding and complex designs.

The traction motor bearing unit (TMBU) is a shielded and pre-lubricated bearing unit designed for flange mounting onto the housing. A special grease is selected to achieve extended grease life even at high operating temperatures. The bearing unit is equipped with non-contact labyrinth seals and do not wear. The bearing unit can be offered as a hybrid design with ceramic rolling elements to prevent damage caused by electric current passage, and sensors to detect operating conditions. Optional features are: electrical insulation and monitoring of operational data like temperature, speed and absolute positioning for propulsion system control.

Introduction

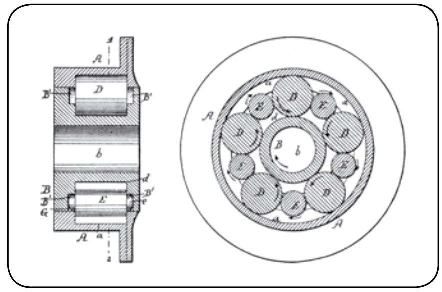
Early bearing designs

Bearing units

When industrial rolling bearings were first developed in the 19th century, designs were tailored to very specific applications. Some of these designs had already incorporated flanges for easier mounting and were equipped with a simple gap-type sealing.

Standardization

Later, the success of the rolling bearing industrialization was very much related to standardization of boundary dimensions with the aim to make these design elements interchangeable. Rolling bearings became a universal solution for a huge range of very different applications. The Deutsche Waffen- und Munitionsfabriken A.G. (DWF) Berlin, Germany1) in 1900 published the first bearing tables for series containing bearing dimensions and bearing load ratings. Some of these principal bearing boundary dimensions are even today most common and included in current ISO standards.



Example of an early design of a flanged bearing unit patented by L. W. Boyer in 1886. The rollers are guided by a set of inserted smaller rollers [12].

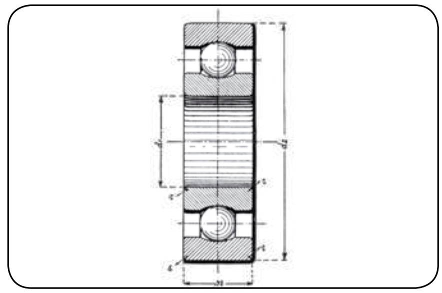


Illustration of a 322 series deep groove ball bearing from the DWF 1906 catalogue. Bearings with this design already had boundary dimensions as standardized by ISO later on: for example, a 6322 with 110 mm bore, 240 mm outside diameter, 50 mm width and a 3 mm chamfer [12].

Customization

Based on the daily communication with traction motor bearing customers and long term application engineering experience, a lot of application topics occur. These are mainly design, logistic, mounting and maintenance issues. This confirms that requirements of customers and their subcontractors on a proper bearing installation cannot always be easily fulfilled and are sometimes overly demanding.

In specialized industries like automotive and railways, standardized bearings were widely used in the first half of the 20th century. The introduction of customized bearing units started around 1950. In the SKF *Railway technical handbook, Volume 1* [1], the development and the current assortment of cylindrical and tapered roller bearing units for wheelsets is already presented in detail. These units are sealed and factory greased.

In 1991, the first SKF sensorized wheelset bearing units that could detect operating parameters like speed were introduced. In addition, incorporated vibration sensors detect bearing performance, which is observed by condition monitoring systems. The goal of these unit designs is to minimize the handling, mounting and maintenance of several components and to achieve the development of one subsystem that incorporates several functions.

Redesign

The aim is to achieve a customer focused traction motor bearing solution that has far lower demand on design, logistics, mounting and maintenance. The idea was born in the early 1990s by requestioning all conventional design principles used in the past several decades. The customer value of such a new design should be to achieve a much higher reliability and extended maintenance intervals and to end up with lower total cost, based on either life cycle or ownership. The development target was to tailor a special solution that was by far more application and customer oriented.

The investigation was based on the use of development tools like advanced design, calculation and testing tools as well as reinforced material and new production

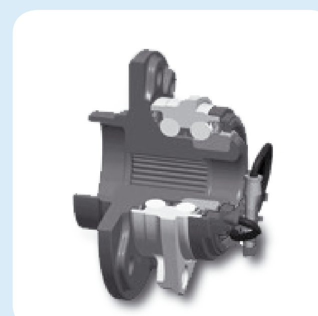
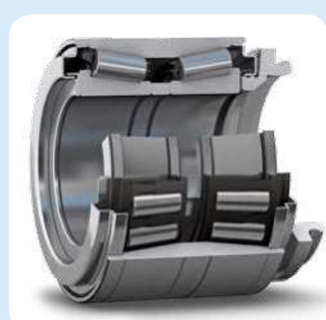
1) The Deutsche Waffen- und Munitionsfabriken A.G. (DWF) Berlin, Germany became later part of the Vereinigte Kugellagerfabriken (VKF), which in turn was acquired by SKF [12]

techniques. This completely new design is based on a labyrinth sealed and factory greased bearing unit with electric insulation and the option to integrate sensors to monitor operational data.

Customized bearing units

The applied design principle is in a way similar to automotive wheel bearing and axlebox bearing units. Single bearing arrangements were developed further so that they were pre-lubricated and sealed bearing units. Furthermore, integrated flanges offer a much easier design and logistic handling as well as easier mounting for customers. In addition, integrated sensors monitor operating parameters like speed and bearing temperature.

Developments in automotive, railway wheelset bearing and traction motor applications

	Single bearings	Sealed and pre-lubricated bearing	Sensorized bearing units
Car wheel			
Railway axlebox			
Railway traction motor			

Design features

Compactness

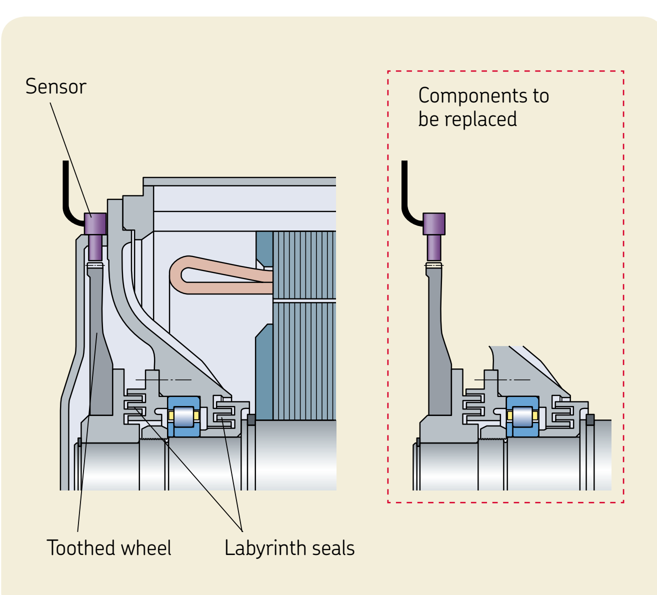
The principal TMBU idea [27] is based on a substitution of the conventional sensor and impulse ring that can have a larger diameter and need additional axial space. In addition, the complex labyrinth sealing which is not needed for a lot of applications, is substituted as well. The next step is the introduction of a labyrinth sealed, sensorized and flanged unit that is easy to handle and to mount.

As a consequence of the TMBU installation, space savings can be achieved for the complete traction motor arrangement. This helps to increase stator / rotor length, which results in increased power by a given geometrical motor envelope.

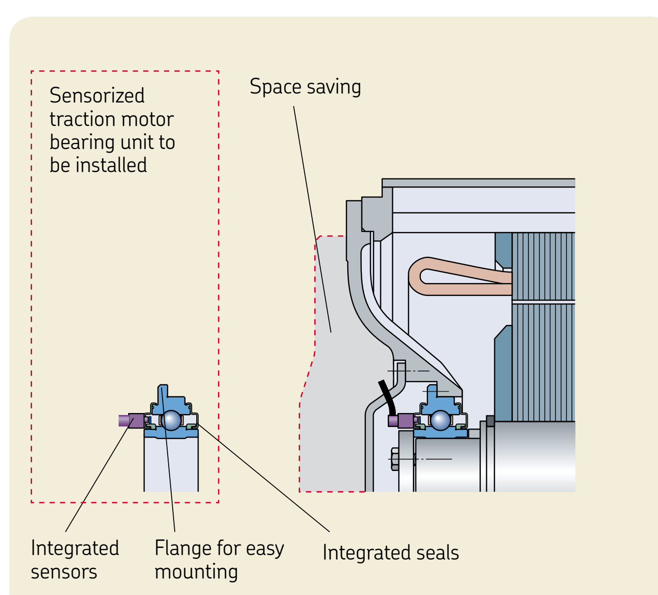
Internal design

The internal design is the set up of rolling elements. A design based on a ball bearing is used for the locating position, while a design based on a cylindrical roller bearing is used for the non-locating position. The pitch diameter depends mainly on the inner/outer ring dimensions. The advantage of the TMBU design principle is that it provides the possibility to select the optimum size and number of rolling elements to achieve a certain load rating. In some traction motor applications, especially with a coupling drive, the bearing loads are relatively small in comparison to the load ratings of standard bearings by a given bearing envelope. In these cases, the bearings are insufficiently loaded and during operation, additional wear occurs.

Conventional traction motor bearing installation on the non-drive side with impulse ring and sensor



Sensorized traction motor bearing unit installation on the non-drive side



Solutions and features

Features	All-steel bearing	INSOCOAT bearing	Hybrid bearing	Hybrid TMBU
				
Protection against electrical erosion	--	+	+++	+++
Heat generation	+	+	++	++
Speed capability	+	+	++	++
Grease life	+	+	+++	+++
Resistance against contaminated environment	+	+	++	+++
Minimum load capability	+	+	++	+++
Mounting simplification	+	+	+	++
Service and maintenance requirement savings	+	+	++	+++
Remanufacturing	possible	yes	yes	recommended
Integrated sensor option	--	--	--	yes

Symbols: +++ excellent, ++ good, + fair, -- unsuitable

Flange design

The TMBU design principle, incorporating an integrated flange, enables the manufacturer to achieve easier bearing installation. The TMBU flange can be directly bolted onto the housing shield. In addition to the TMBU sizes mentioned in the preferred range, customized bore and pitch diameters can be accommodated to provide an optimized traction motor bearing design. In addition, specially drilled and tapped holes in the flange can be provided to accommodate withdrawal bolts to facilitate dismounting.

Protection against contamination

Conventional traction motor bearings have an open design and need to be greased during installation. In some cases, the necessary cleanliness cannot easily be achieved and contaminants can enter the bearing, which will reduce the bearing life dramatically. The TMBU is a factory pre-lubricated bearing unit, which is protected with a labyrinth seal on both sides. This labyrinth seal operates without friction and does not wear, and can be used for many applications.

In some cases, such as when the TMBU is directly exposed to the environment, additional sealing devices might be necessary.

Electrical insulation

To increase the reliability, electrical insulation is realized by using either an INSOCOAT coating or a hybrid design with ceramic/silicon nitride rolling elements (→ **chapter 4**). Hybrid bearing design features help to upgrade the performance in electrical insulation and to achieve much longer maintenance intervals that help the operator to reduce life cycle cost.

Extended service life

As already mentioned on **page 15**, there is a growing trend to extend maintenance intervals for traction motors and the bearings that are incorporated.

Many in depth investigations have confirmed that longer maintenance intervals for grease lubricated traction motor bearings can be achieved in operation [15]. Depending on the application parameters, a number of different factors have to be considered.

Since the start of the first TMBU implementation in 1996, many different application parameters are covered. These concern mainly locomotives, multiple units, mass transport vehicles, tramcars and trolleybuses. Since several years a collection of field test results of TMBUs without relubrication is systematically documented.

One of several practical examples is mentioned on **page 168**. In this case, TMBUs were in service in locomotives for 12 years without any relubrication. They were in operation for more than 1,5 million km. There was almost no wear and the grease was found in very good condition. The bearings have been remanufactured and returned to the operator for further use.

This outstanding and broad experience was the basis for the development of a new optimized grease life model.

New optimized grease life guidelines for TMBUs

Based on this experience [4, 28], SKF developed new and optimized grease life guidelines. The basis of the grease life model is the consideration of several parameters:

- optimized bearing design, especially in regard to number and size of the rolling elements
- further improved cage design
- labyrinth seals to protect the bearing system against contaminants
- specific grease type and quantity applied
- high cleanliness during factory assembly and greasing

In addition, some application specific factors need to be considered:

- speed, speed cycles
- load, load patterns
- vibration
- temperature cycles
- humidity
- contamination etc.

The base for the new SKF optimized grease life model is the existing base grease life calculation that can be found in SKF catalogues or online at skf.com/bearings.

Grease performance factor

The suitable grease viscosity can be calculated by using SKF catalogues or the tools available online at skf.com/bearings. (→ **page 160**).

For non-sealed (open) traction motor bearings, the final grease selection (manufacturer and grease type) is initially made by the traction motor manufacturer. In some cases, the operator makes his own grease selection based on commercial or application specific reasons.

For pre-lubricated and sealed TMBUs, the grease selection is made by SKF.

Application specific factors

Further considerations are made in the new calculation model for the specific application parameters by the use of specific correction factors for:

- the bearing temperature
- vibration levels and shock loads during operation
- environmental effects like humidity
- airflow through the bearings
- vertical shaft applications
- outer ring rotation

Calculation principle considering application specific factors

The corrected grease life can be calculated:

$$t_{grease} = t_f \, L_a \, \{\text{corrective application factors}\}$$

where

t_{grease} = corrected grease life or relubrication interval

t_f = relubrication interval at 70 °C, or to be recalculated

L_a = life adjustment factor

5

Bearing related factors

In addition to the application specific factors, further bearing related performance factors are considered:

- a bearing unit factor: this can be a factor of 2 depending on the applied TMBU design
- a bearing material factor: this can be a factor of 2 when ceramic rolling elements are incorporated
- a cage performance: this can be a factor of 2 when specific roller or mixed guided brass cages are used. Mixed guided cages are centred by the roller and outer ring.

Calculation principle considering bearing related factors

The optimized grease life can be calculated by considering the bearing related performance factors:

$$t_{optimized} = t_{grease} \{\text{bearing performance factors}\}$$

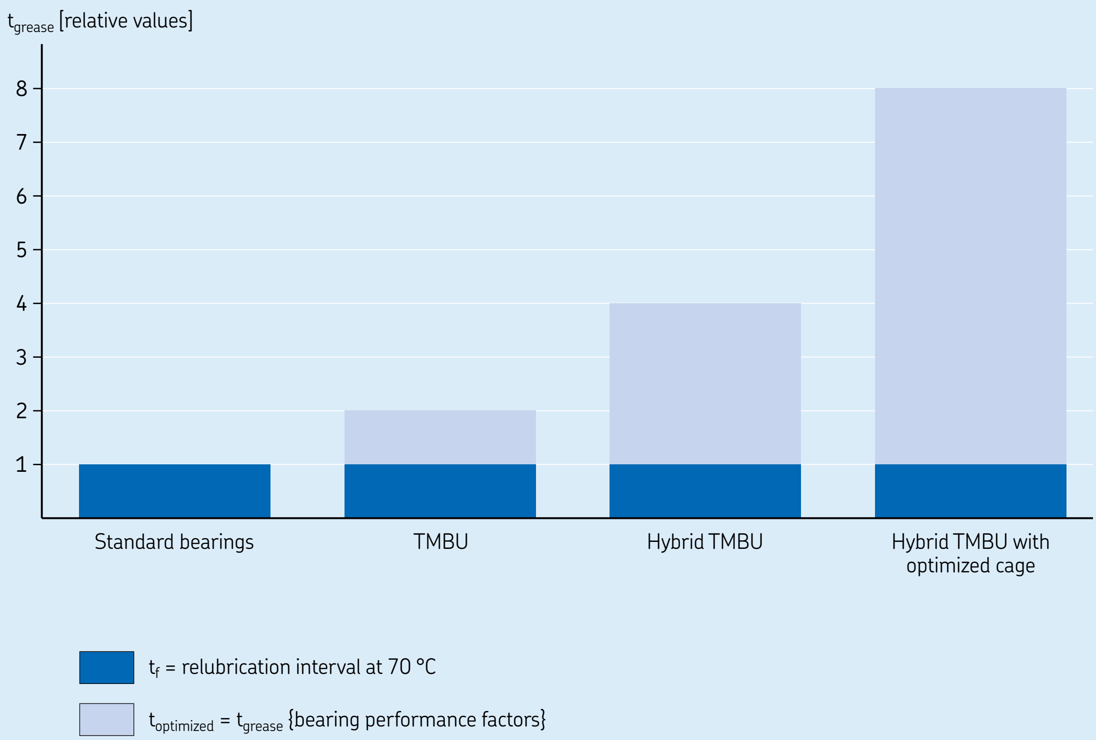
Calculation example

Based on a specific application where the specific bearing and grease related correction factors are already selected, the optimized grease life can be calculated for a TMBU application:

- by using the same grease and the same cage, the optimized grease life can be increased by a factor of 2 for a TMBU with all-steel material combination
- by using the same grease and the same cage, the optimized grease life can be increased by a factor of 4 for a hybrid TMBU design (steel bearing rings / ceramic rolling elements)
- by using the same grease and an optimized cage, the optimized grease life can be increased by a factor of 8 for a hybrid TMBU design (steel bearing rings / ceramic rolling elements). This factor can only be applied if an optimized cage design was not used before.

For additional information on specific customer applications, contact the SKF application engineering service.

Applied SKF optimized grease life guidelines



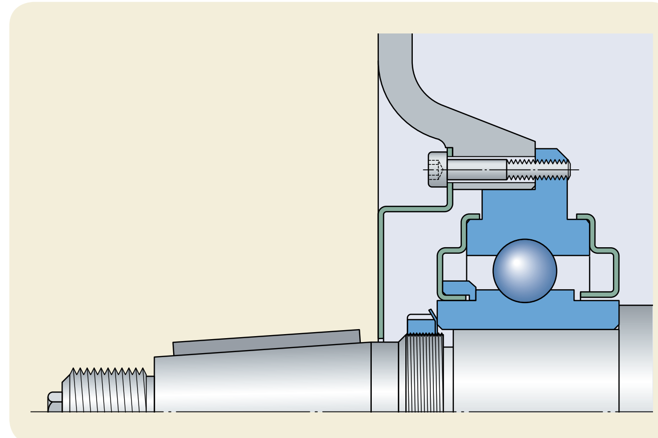
5

Designs for the locating position

The traction motor bearing unit (TMBU) design for locating bearing arrangements is based on a deep groove ball bearing design. This shielded and pre-lubricated bearing unit has an integrated flange on the outer ring to be bolted onto the traction motor shield. To accommodate the TMBU, the seat in the motor shield typically is machined to a H7 tolerance class.

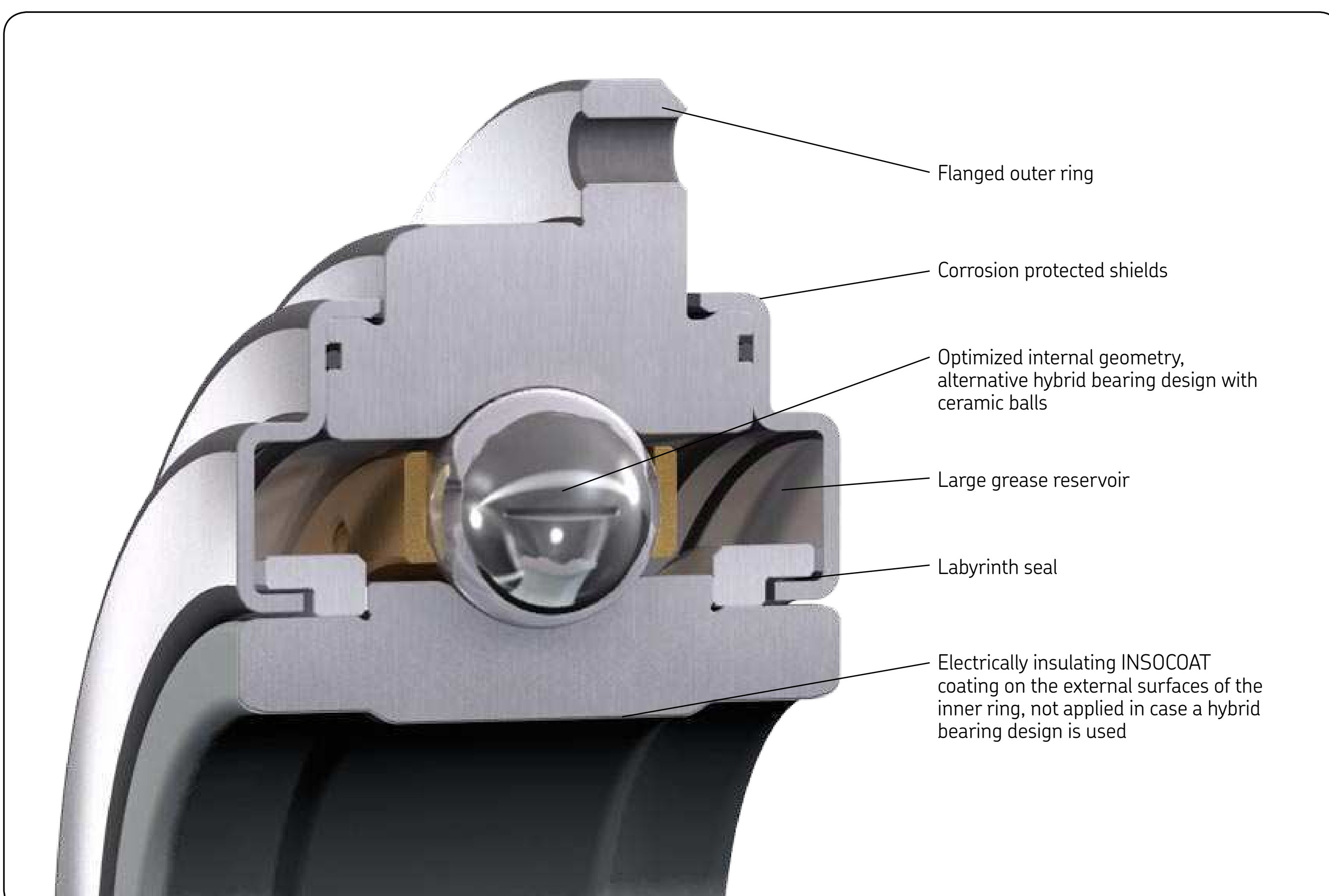
Electrical insulation can be provided either by applying a hybrid bearing design based on ceramic balls or by an electric insulating INSOCOAT layer on the external surfaces of the inner ring.

These TMBUs are customized designs, which can be further tailored to meet specific requests.



Application example of a traction motor bearing unit for the locating position
The complete traction motor drawing is shown on ***page 212****, for further applications see* ***pages 42***, ***46***, *and* ***54***.

All-steel TMBU for locating bearing arrangements based on a deep groove ball bearing design



Preferred range

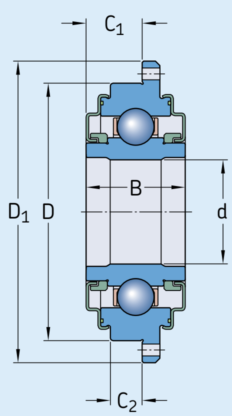
The preferred range is based on the assortment of September 2012. This range is a living collection and will be updated and published in future if needed.

Features and benefits of the TMBU design for the locating position

- space saving, fewer parts
- unit concept enables very easy mounting
- labyrinth seals
- greased for extended maintenance intervals

5

Traction motor bearing units for the locating position



Principal dimensions						Designation
d	D	B	C_1	C_2	D_1	
mm						–
65	170	68	38,5	22	200	**BB1-7024**
80	145	60	25	10	175	**BB1-7116**
90	190	88	47,5	28	230	**BB1-7141**
110	180	62	31	22	220	**BB1-7330**
120	182	48	17,5	7	230	**BB1-7348**
208	280	65,5	18	15	320	**BMB-7509**

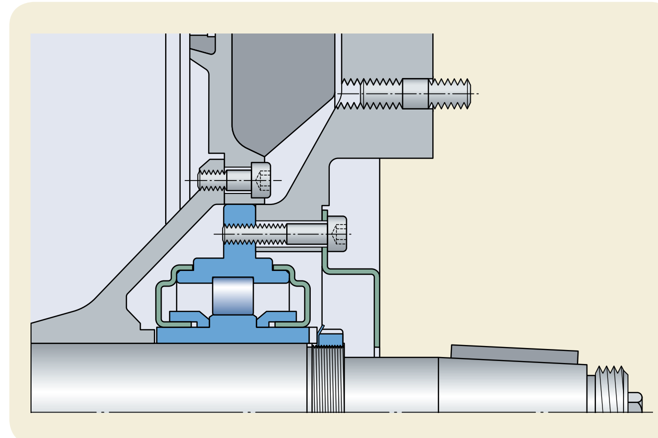
These figures are for information only. For detailed product specifications, contact the SKF application engineering service.

Designs for the non-locating position

The traction motor bearing unit (TMBU) design for non-locating bearing arrangements is based on a cylindrical roller bearing design. This sealed and pre-lubricated bearing unit has an integrated flange on the outer ring to be bolted on to the traction motor shield.

Electrical insulation can be provided either by applying an electric insulating INSOCOAT coating on the external surfaces of the inner ring, or by using a hybrid bearing equipped with silicon nitride rollers.

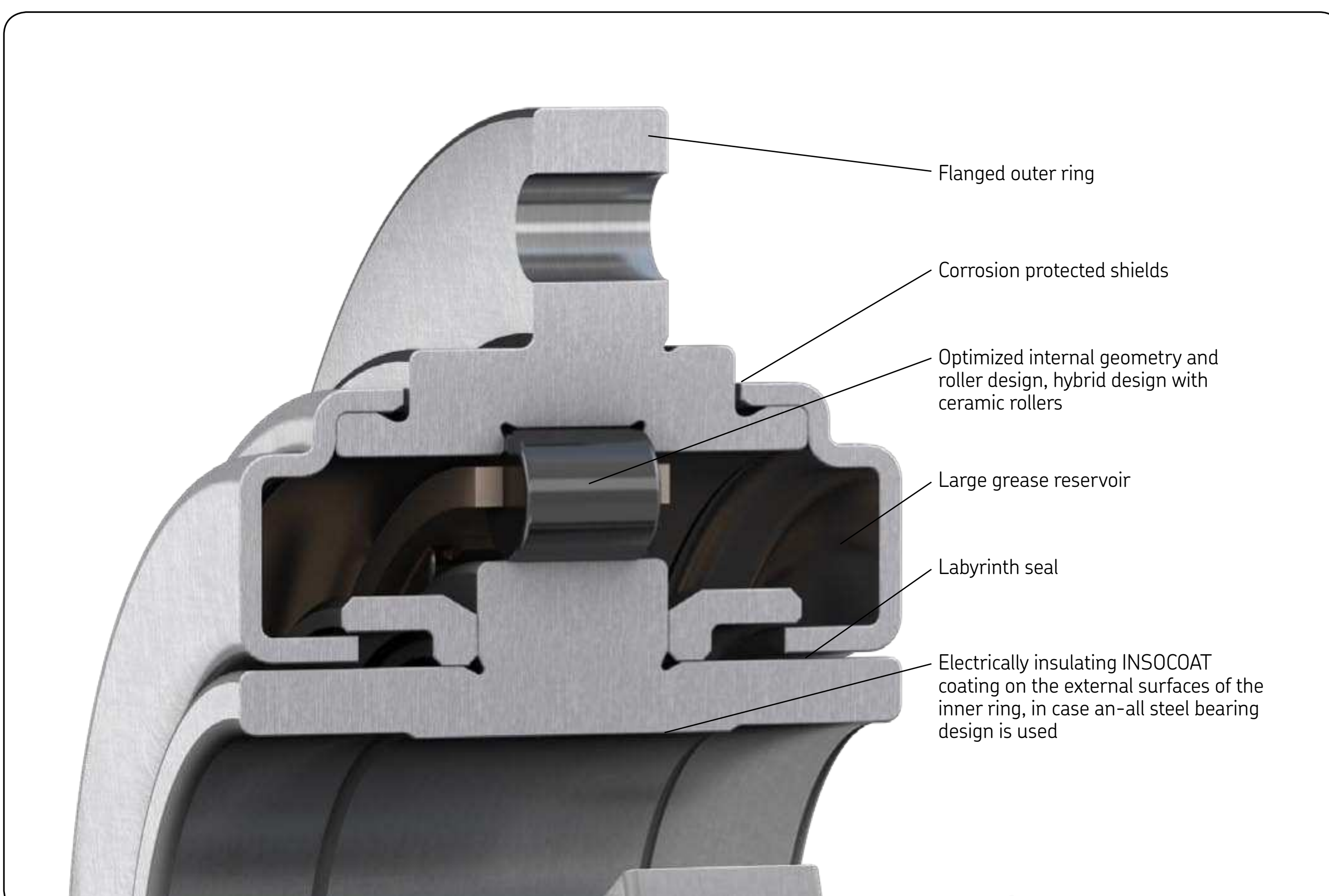
These TMBUs are customized designs, which can be further tailored to meet specific requests.



Application example of a traction motor bearing unit for the non-locating position

The complete traction motor drawing is shown on ***page 212****, for further application see* ***page 54****.*

Hybrid TMBU for non-locating bearing arrangements based on a cylindrical roller bearing design



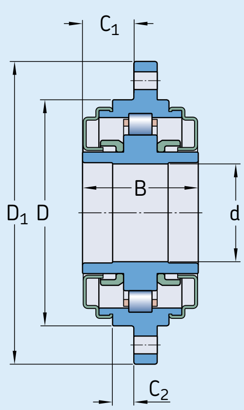
Preferred range

The preferred range is based on the assortment of September 2012. This range is a living collection and will be updated and published in future if needed.

Features and benefits of the TMBU design for the non-locating position

- space saving, fewer parts
- unit concept enables very easy mounting
- labyrinth seals
- greased for extended maintenance intervals

Traction motor bearing units for the non-locating position



Principal dimensions						Designation
d	D	B	C_1	C_2	D_1	
mm						–
50	115	59	21	6	155	**BC1-7229**
80	145	59	21	6	185	**BC1-7273**
120	220	56	30	30	268	**BC1-7292**
	220	74	54	54	262	**BC1-7293**
210	280	50	29	26	320	**BC1-7308**

These figures are for information only. For detailed product specifications, contact the SKF application engineering service.

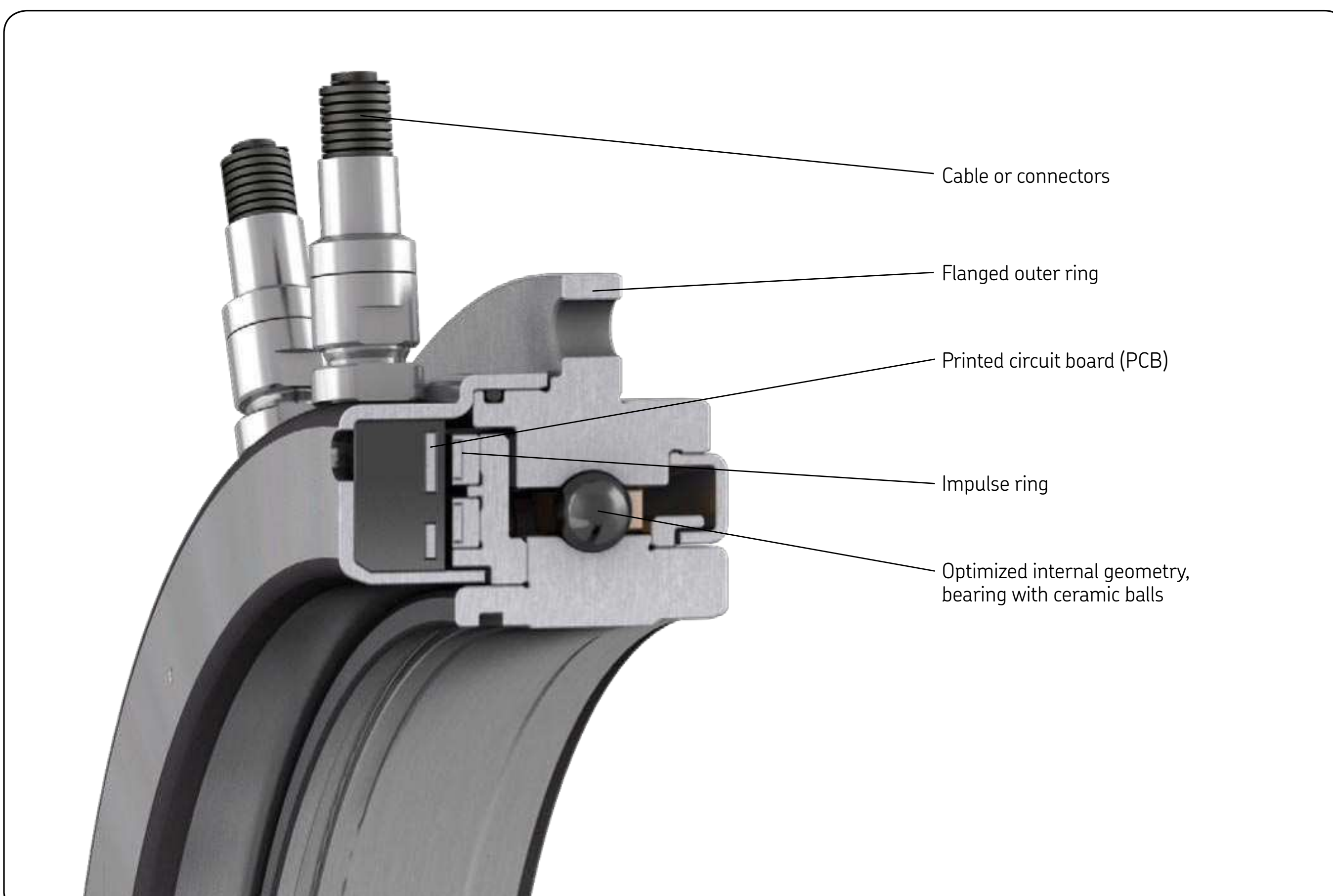
Sensorized designs

The sensorized TMBU concept offers several detection and measurement opportunities (→ chapter 9). The incremental sensor unit is integrated into the labyrinth sealing system of the outer ring of the bearing unit. This design is very space-saving, especially in the axial direction, compared with conventional sensor devices. The space saving design with fewer parts provides high resolution and accuracy, as well as a robust design for a long bearing unit life.

Sensorized design options

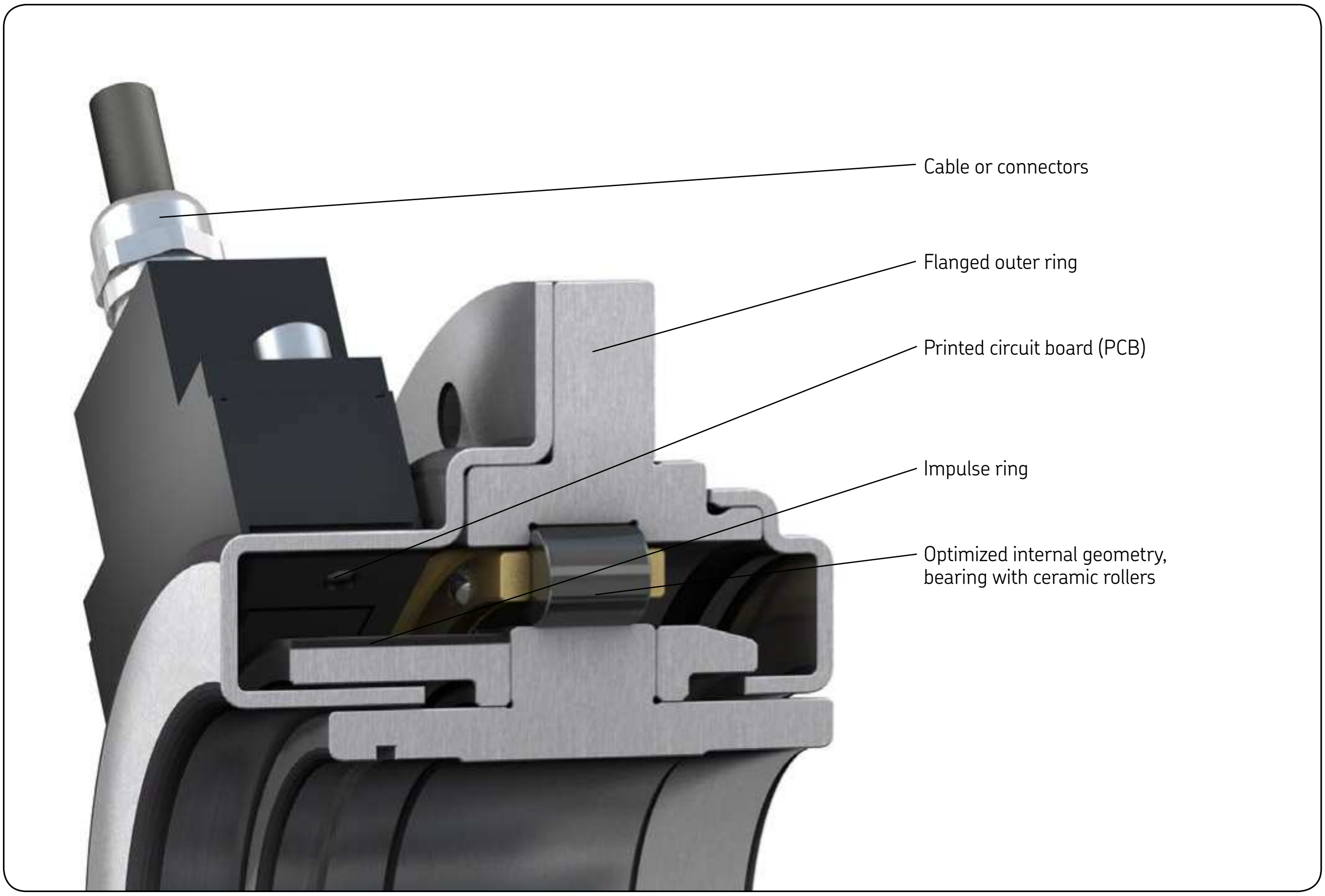
- absolute positioning detection for traction motor control devices
- detection of direction of rotation
- speed measurement for brake control systems
- temperature measurement to monitor operating conditions

Sensorized TMBU design for locating bearing arrangements

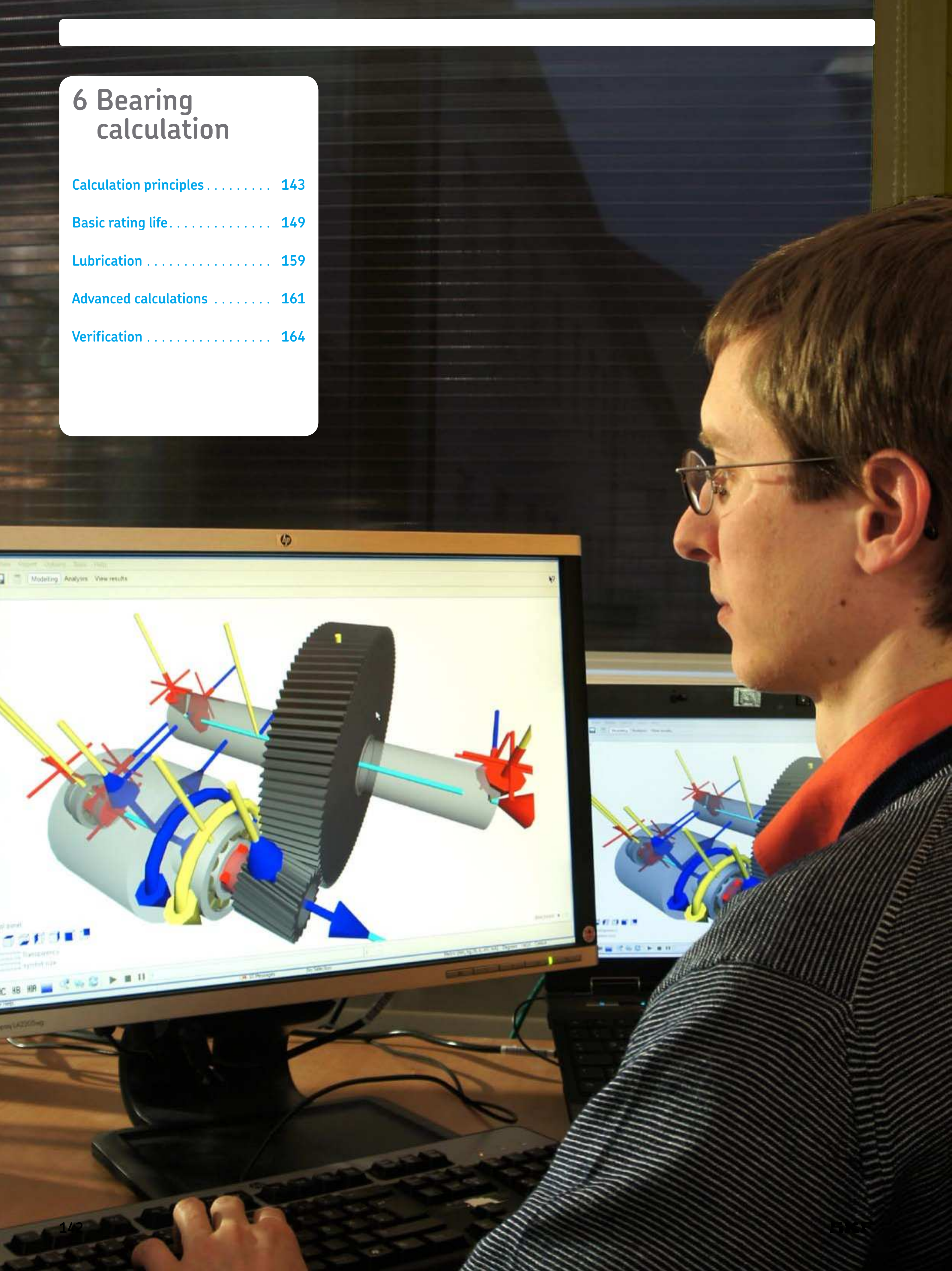


5

TMBU design for non-locating bearing arrangements



6 Bearing calculation



Bearing calculation

SKF provides a portfolio of different calculation methods to optimize bearing selection for traction motor and gearbox applications. Basic calculation principles are mentioned in SKF catalogues. In this chapter, an overview of the state of the art methods and more advanced calculation tools that are used by SKF application and development engineers are described. Depending on the individual specification requirements and experience, the most suitable calculation package has to be selected to provide a reliable design that requires a low need of maintenance. For assistance with more complex calculations, consult SKF railway application engineering assistance.

Calculation principles

In the following sections, basic calculation information is presented in the order it is generally required. More generic information can be found in SKF catalogues or online at skf.com/bearings. Obviously, it is impossible to include here all of the information needed to cover every drive system design configuration.

In addition to the bearing rating life calculation, other design elements should be considered as well. The lubricant is also a very important component of the bearing arrangement, because it has to minimize wear and protect against corrosion, so that the bearing can reach its full performance potential. Seal performance is of vital importance to the cleanliness of the lubricant. Cleanliness has a profound effect on bearing service life, which is why traction motor bearing units are used more and more frequently. Another reason is that they are factory lubricated and have integrated sealing systems (→ **chapter 5**).

How much calculation needs to be done depends on whether there is experience data already available with similar arrangements. When specific experience is lacking and extraordinary demands in the specification are made, then much more work is needed including, for example, more accurate calculations and/or testing.

Function and bearing life

The bearing function depends on the rating life, which can be calculated by using the basic rating life model and further advanced calculations. Obviously, bearing life is related to speed and forces.

There are, however, other important factors that influence the bearing function. These are considered in the SKF rating life calculation, such as lubrication and operating temperature (viscosity), and cleanliness, which depends very much on the sealing system (contamination factor).

Especially for grease lubricated traction motor and suspension bearings, the grease life and the contamination level has to be considered when evaluating the maintenance intervals.

Advanced calculations are based on the influence of additional operating conditions like influence of shaft and housing fits, elasticity and deformation as well as adjustment.

The bearing life depends on the bearing function which can be modelled by several calculations. In addition, the application environment such as machine design, installation and usage has a direct impact on the bearing life and required maintenance.

The calculated bearing life should be verified by field results. This can be done by:

- taking lubricant samples for analysing (→ **chapter 10**, **page 222**)
- investigating bearing condition when components can be easily dismounted and disassembled (→ **chapter 7**)
- applying condition monitoring tools (→ **chapter 9**)

For additional information about extended service life for traction motor bearing units, hybrid designs etc., refer to **page 122** and **pages 132** to **135**.

Factors for bearing function and rated bearing life

- **Component quality**
  - bearing / seal / lubricant
- **Machine design**
  - bearing selection
  - lubrication selection
  - housing design
  - seal design
  - electric current flow
- **Machine installation**
  - bearing mounting (fits, etc.)
  - initial lubrication
  - cleanliness
- **Machine usage**
  - speed, load
  - cooling / heating
  - lubrication
- **Machine maintenance**
  - bearing / lubrication function

Bearing service life

Bearing life is only partly covered by the standard calculation models. Further, and advanced calculations can take more factors into considerations, such as life of the components separately:

- inner ring raceway
- outer ring raceway
- rolling elements
- cage
- lubricant
- seals

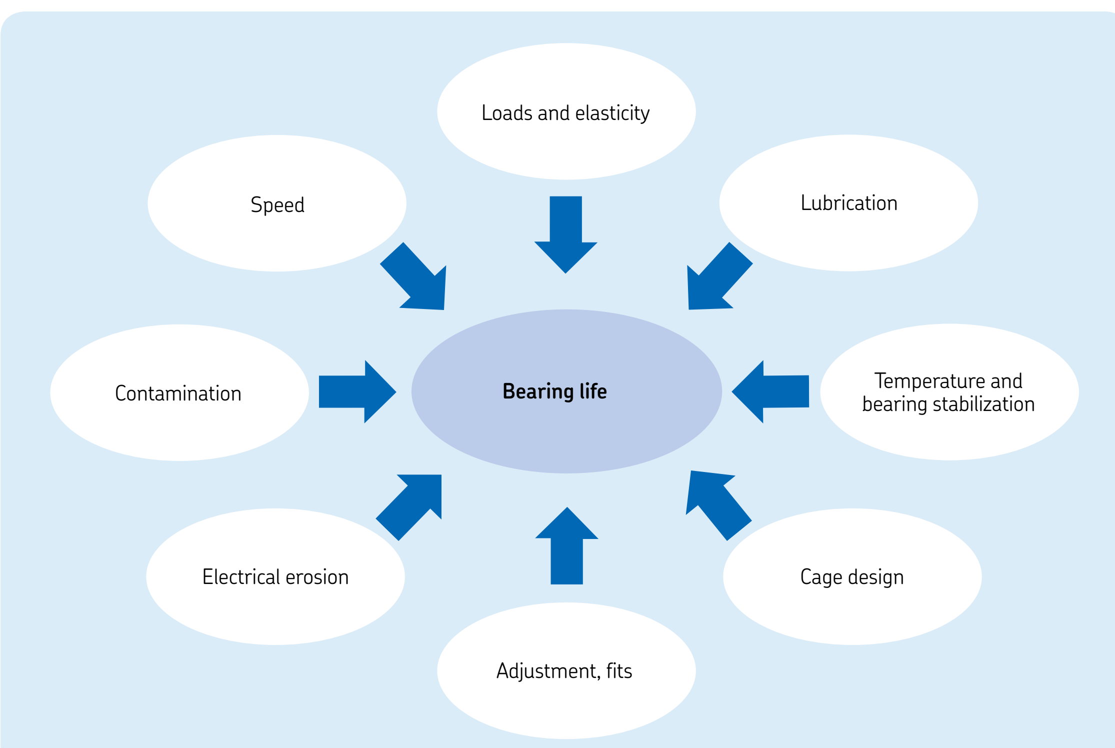
This can be mathematically expressed as

$$L_{\text{bearing}} = f\,(L_{\text{raceways}}, L_{\text{rolling elements}}, L_{\text{cages}}, L_{\text{lubricant}}, L_{\text{seals}})$$

In the sub-chapter advanced calculations (→ **page 161**), some calculation models and examples are explained.

Although, these calculations come close to the life in real operating conditions, the bearing service life can finally only be defined by field experience.

The bearing service life can be extended by remanufacturing (→ **page 218**).



Main factors influencing rated bearing life

Specifications

The basis for all calculations and application advice are customer's specifications. These have to be as detailed as possible. In addition, experience with similar previous designs can help to define which calculation and application engineering efforts are needed.

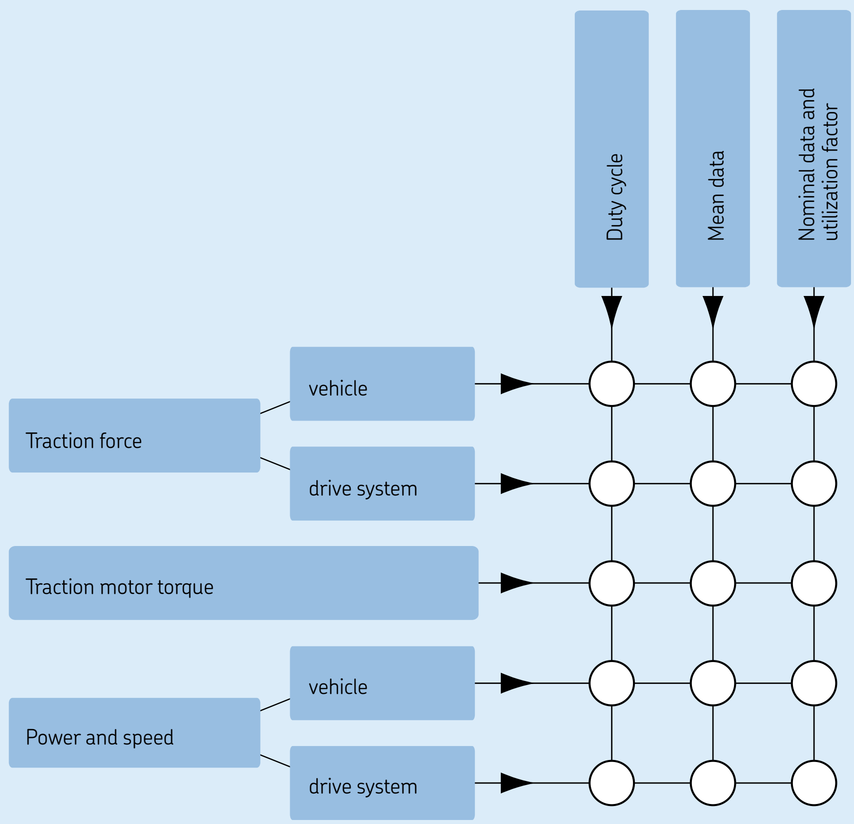
For basic calculations, main input data and other information, like description of the operational parameters and drawings, are needed. Based on this information, it has to be decided if, in addition to the basic rating life calculation, additional and more advanced calculations are needed.

The bearing loads can be defined based on the tractive effort of the vehicle, motor torque or power and speed rating of the traction motor. These data should be provided as a collective, based on different utilization regimes or calculated mean values. Nominal data provide results which can be used for a first estimation.

Specification example

- vehicle manufacturer
- bogie manufacturer
- gearbox manufacturer
- traction motor manufacturer
- operator name and country
- vehicle type
- project name
- maximum speed
- wheel diameters: new/mean/worn
- expected mileage per year
- required maintenance regime in mileage and in time
- climatic condition, min/max temperature and humidity
- track condition
- gearbox design, geometric data like distances, gear wheel data
- housing and shaft design details and materials used
- application design, geometric data like distances, rotor and coupling weight
- power and speed, average data or load cases, this can be expressed in torque or traction force data as well as those listed in the following table.
- bearing loads if already known
- preferred bearing/unit design and size
- experience with similar designs used before
- field test results if available
- electric current passage and request of bearing insulation
- monitoring: temperature, speed and vibration

Different drives input data options to calculate the bearing loads [15]



6

Installed power and utilization

Because of different specification requirements, there is widespread installed power relative to the train mass to be hauled. One example is a survey based on 50 different light rail vehicle designs produced between 1993 and 2008 for urban transport [29]. The specific power is related to the total vehicle mass including seating passengers and standing passengers, based on 4 people/m^2. Even if the operating conditions of these light rail vehicles are comparable, there is a wide spread of installed power related to the total vehicle mass.

Operational condition variation can be caused by the utilization of installed power in the daily service of different operators. Same vehicle designs can be operated with quite different accelerations, speeds and on different track conditions. Sometimes, for example, light rail vehicles are lengthened after several years in operation by adding an additional unpowered section to increase capacity and/or low-floor passenger access. In these cases, the original calculation specification cannot be valid anymore. The calculation result can only as good as the real operating conditions that are specified in the very beginning.

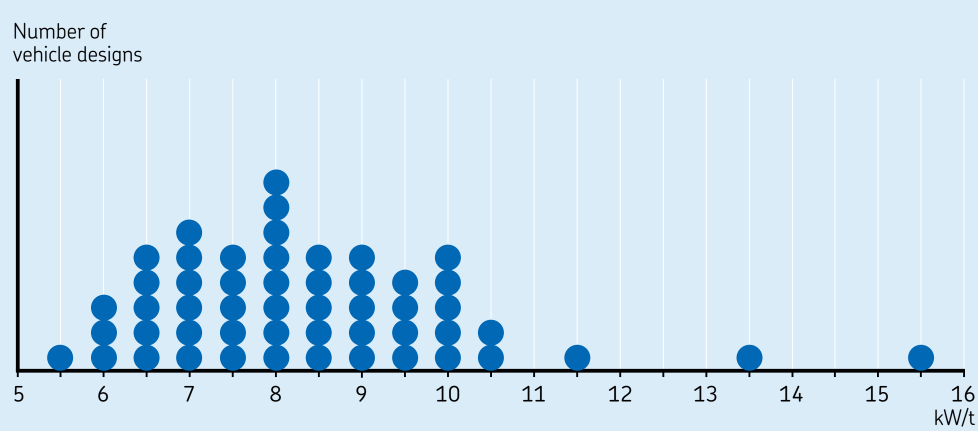
On page 164 the results for a multi-purpose locomotive field test are mentioned. There is a wide variation of acting forces and bearing operating temperatures related to different usage during the test run.

Analytical process

Based on the specification and the decision about what and how has to be calculated and investigated, an analytical process has to be started which contains in principle several steps:

1 determine bearing loads
2 calculate bearing life
3 consider appropriate temperature, lubrication and clearance
4 verify the results in regard to the selected bearing design

Variation of specific power installed relative to the total mass of a light rail vehicle



SKF

Basic rating life

For simplified calculations and to obtain an approximate value of the bearing life, the so-called “handbook method” is used to calculate the basic rating life. The basic rating life of a bearing according to ISO 281 is

$$L_{10} = \left(\frac{C}{P}\right)^p$$

where

L_{10} = basic rating life (at 90% reliability), [million revolutions]

C = basic dynamic load rating [kN]

P = equivalent dynamic bearing load [kN]

p = exponent for the life equation

= 3 for ball bearings

= 10/3 for roller bearings, as used typically in axlebox applications

The basic rating life for a specific bearing is based on the basic dynamic load rating according to ISO 281. The equivalent bearing load has to be calculated based on the bearing loads acting on the bearing via the wheelset journal and the axlebox housing.

For railway applications, it is preferable to calculate the life expressed in operating mileage, in million km

$$L_{10s} = \frac{\pi D_w}{1\,000}\left(\frac{C}{P}\right)^p$$

where

L_{10s} = basic rating life (at 90% reliability), [million km]

D_w = mean wheel diameter [m]

When determining bearing size and life, it is suitable to verify and compare the C/P value and basic rating life with those of existing, similar applications where long term field experience is already available.

For traction motor and gearbox applications, the gearbox ratio relative to the gearbox shaft has to be considered.

Typical basic rating life values

Mass transit vehicles and shunting locomotives	Multiple units and locomotives
600 000 – 1 500 000 km	1 000 000 – 3 000 000 km

Note: There can be different customer requirements for specific applications

$$L_{10sg} = \frac{L_{10s}}{i}$$

where

L_{10sg} = basic rating life (at 90% reliability), million km in regard to the applied gearbox ratio

i = gearbox ratio

6

Equivalent dynamic bearing load

If the calculated bearing load F is constant in magnitude and direction, and acts radially on a radial bearing or axially and centrically on a thrust bearing, then P = F and the load may be inserted directly in the life equations. In all other cases, it is first necessary to calculate the equivalent dynamic bearing load. This is defined as that hypothetical load, constant in magnitude and direction, acting radially on radial bearings or axially and centrically on a thrust bearing which, if applied, would have the same influence on bearing life as the actual loads to which the bearing is subjected.

Radial bearings are often subjected to simultaneously acting radial and axial loads. If the resultant load is constant in magnitude and direction, the equivalent dynamic bearing load P can be obtained from the general equation

$$P = X\,F_r + Y\,F_a$$

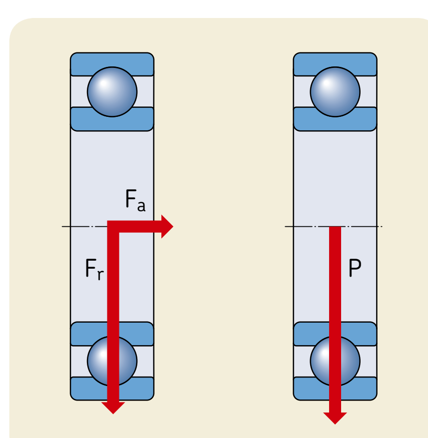
where
P = equivalent dynamic bearing load [kN]
F_r = actual radial bearing load [kN]
F_a = actual axial bearing load [kN]
X = radial load factor for the bearing
Y = axial load factor for the bearing

An additional axial load only influences the equivalent dynamic load P for a single row radial bearing if the ratio F_a/F_r exceeds a certain limiting factor e. With double row bearings, even light axial loads are generally significant.

For thrust bearings that can accommodate only purely axial loads, e.g. thrust ball bearings and cylindrical, needle and tapered roller thrust bearings, the equation can be simplified, provided the load acts centrically, to

$$P = F_a$$

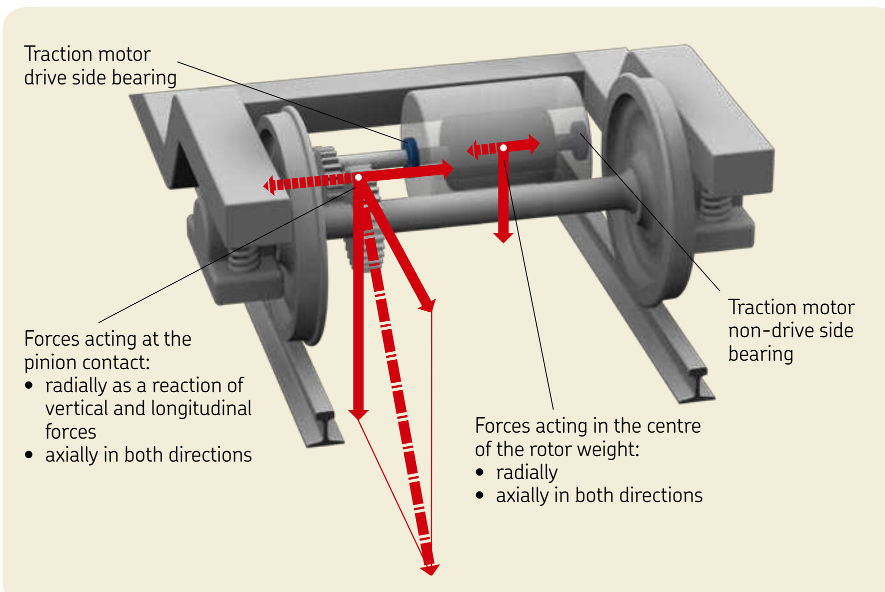
Information and data required for calculating the equivalent dynamic bearing load can be found in SKF catalogues, also available online at skf.com/bearings, or in specific SKF customer drawings.



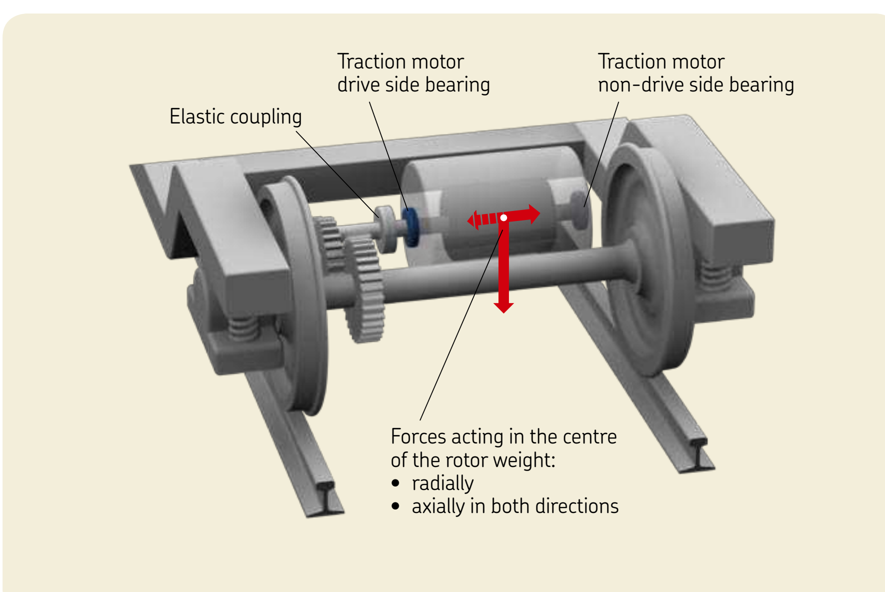
The radial load F_r and the axial load F_a are represented by the radially acting equivalent dynamic bearing load P

Calculation of dynamic bearing loads

The loads acting on a bearing can be calculated according to the laws of mechanics [15] if the external forces (e.g. forces from power transmission, work forces or inertia forces) are known or can be calculated. When calculating the load components for a single bearing, the shaft is considered as a beam resting on rigid, moment-free supports for the sake of simplification. Elastic deformations in the bearing, the housing or the machine frame are not considered, nor are the moments produced in the bearing as a result of shaft deflection.



Application example of acting traction motor forces in the pinion contact and the centre of gravity of the rotor, in case of the traction motor shaft accommodating the pinion



Application example of acting traction motor forces in the centre of gravity of the rotor, in case of an elastic coupling between the traction motor and the gearbox

6

These simplifications are necessary if a bearing arrangement is to be calculated using readily available aids such as a pocket calculator. The standardized methods for calculating basic load ratings and equivalent bearing loads are based on similar assumptions.

It is possible to calculate bearing loads based on the theory of elasticity without making the above assumptions but this requires the use of complex computer programs. In these programs, the bearings, shaft and housing are considered as resilient components of a system.

External forces that arise, for example, from the inherent weight of the shaft and the components that it carries, or from the weight of a vehicle, and the other inertia forces are either known or can be calculated. However, when determining the work forces like shock forces and additional dynamic forces, e.g. as a result of unbalance, it is often necessary to rely on estimates based on experience with similar machines or bearing arrangements.

Gear trains

With gear trains, the theoretical tooth forces can be calculated from the power transmitted and the design characteristics of the gear teeth. However, there are additional dynamic forces, produced either in the gear itself or by the input drive or power take-off. Additional dynamic forces in gears result from form errors of the teeth and from unbalanced rotating components. Because of the requirements for quiet running, gears are made to high standards of accuracy and these forces are generally so small that they can be neglected when making bearing calculations.

Additional forces arising from the type and mode of operation of the machines coupled to the gear can only be determined when the operating conditions are known. Their influence on the rating life of the bearings is considered using an “operation” factor that takes shock loads and the efficiency of the gear into account. Values of this factor for different operating conditions can usually be found in information published by the gear manufacturer.

Life calculation with variable operating conditions

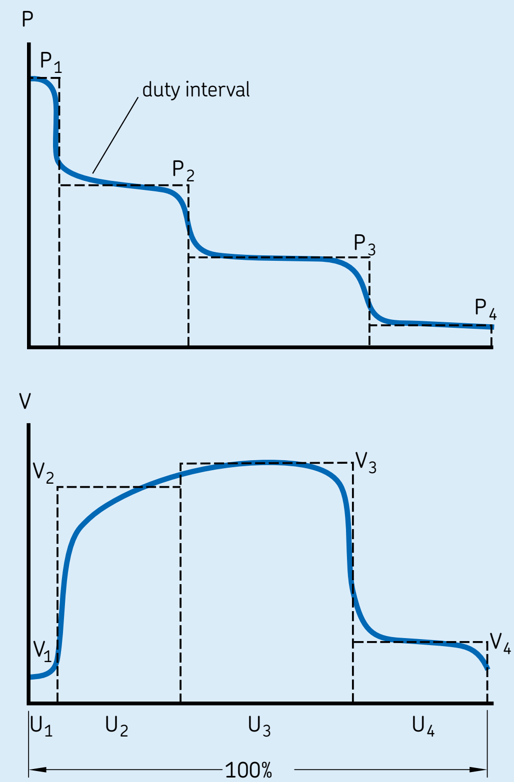
In applications where bearing load varies over time, both in magnitude and direction with changes of speed, temperature, lubrication conditions and level of contamination, the bearing life cannot be calculated directly without the need of the intermediate calculation step of an equivalent load related to the variable load conditions.

Given the complexity of the system, however, this intermediate parameter would not be easy to determine and would not simplify the calculation.

Therefore, in the case of fluctuating operating conditions, it is necessary to reduce the load spectrum or duty cycle of the application to a limited number of simpler load cases.

In case of continuously variable load, each different load level can be accumulated and the load spectrum reduced to a histogram of constant load blocks, each characterizing a given percentage or time-fraction of the operation of the application.

Example of variable operating conditions



6

Note

Heavy and medium loads consume bearing life at a faster rate than lighter loads.

Therefore, it is important to have shock and peak loads well represented in the load diagram, even if the occurrence of these loads is relatively rare and limited to a few revolutions.

Within each duty interval or “bin”, the bearing load and operating conditions can be averaged to some constant value. Furthermore, the number of operating hours or revolutions expected from each duty interval shows the life required by that particular load condition. Thus, for instance denoting with N_1 the number of revolutions required under the load condition P_1, and with N the total life cycle of the application, then life cycle fraction $U_1 = N_1/N$ will be used by the load condition P_1, which has a calculated life of L_{10m1}. Under variable operating conditions, bearing life can be predicted, see table below.

The use of this calculation method depends very much on the availability of representative load diagrams (→ page 153) for the application.

For calculation of the bearing life, considering load cycles, see the program “SKF Bearing Select”.

Note

Load history can also be derived from typical operating conditions or standard duty cycles required from that type of application.

An excelent tool for evaluation of loads under real operating condition is field testing (→ pages 164 to **165**).

Life calculation with variable operating conditions

$$L_{10m} = \frac{1}{\dfrac{U_1}{L_{10m1}} + \dfrac{U_2}{L_{10m2}} + \dfrac{U_3}{L_{10m3}} + \cdots}$$

where

L_{10m}	= SKF rating life (at 90% reliability) [million revolutions]
L_{10m1}, L_{10m2}, ...	= SKF rating lives (at 90% reliability) under constant conditions 1, 2,... [million revolutions]
U_1, U_2, ...	= life cycle fraction under the conditions 1, 2,... Note: $U_1 + U_2 + \ldots\ldots U_n = 1$

Load cycle reduction – binning method

Binning is a pre-processing technique used to reduce the number of load cases in large duty cycles. The original data values that fall in a given small interval – a bin, are replaced by a value representative of that interval, often the central value.

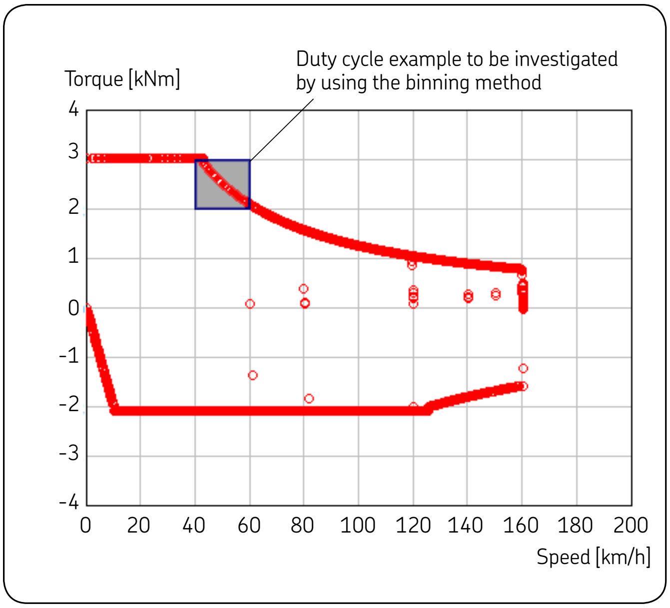
Some customer specifications are expressed through a large number of load cycles, usually speed, torque and duration. The purpose of the binning method is to reduce for example a 7 000-step load cycle to a 50-step one. This makes it possible to reduce calculation time when the performance of the gearbox is predicted.

Verification and experience is needed to define the minimum number of bins for a given application.

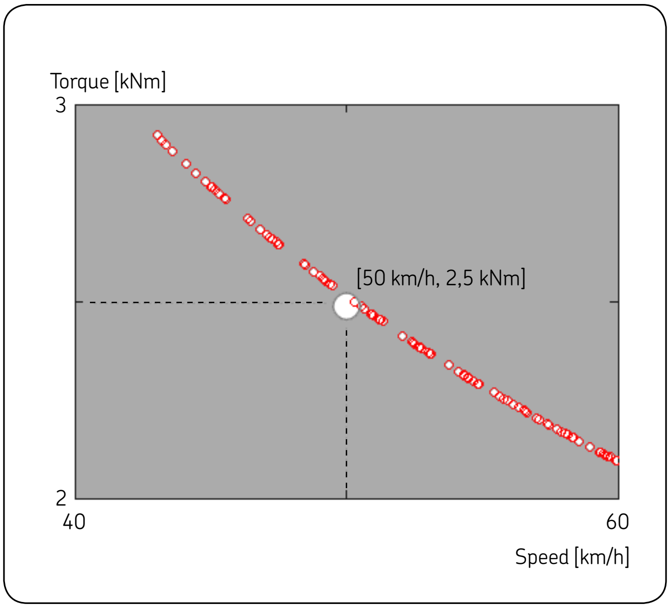
The graph to the left shows a duty cycle of a train consisting of 7 000 load steps. Each step is a combination of speed and torque with a duration of one second. The small square in the left graph, highlighted grey, represents a bin with 325 load cycles shown in magnification in the graph to the right. In this example the 325 load cycles in this bin can be reduced to one load cycle with a value of 50 km/h and 2,5 kNm for 325 seconds.

6

Drive system duty cycle



Binning method example



SKF rating life

For more sophisticated bearing calculations, the basic rating calculation method can be further improved. The reason is that the service life of the bearing can deviate significantly from the calculated basic rating life. There is a variety of influencing factors like lubrication, degree of contamination, misalignment, proper installation and environmental conditions.

Therefore, ISO 281 contains a modified life equation to supplement the basic rating life. This life calculation makes use of a modification factor to account for the lubrication and contamination condition of the bearing and the fatigue load limit of the material.

This ISO 281 standard enables bearing manufacturers to recommend a suitable method for calculating the life modification factor to be applied to the bearing based on operating conditions. The SKF life modification factor a_{SKF} applies the concept of a fatigue load limit P_u analogous to that used when calculating other machine components.

The SKF life modification factor a_{SKF} makes use of the lubrication conditions (viscosity ratio κ) and a factor η_c for the contamination level, to reflect the real application operating conditions.

The equation for the SKF rating life is in accordance with ISO 281

$$L_{nm} = a_1 \, a_{SKF} \, L_{10} = a_1 \, a_{SKF} \left(\frac{C}{P}\right)^p$$

where

L_{nm} = SKF rating life (at 100 – n[1])% reliability) [million revolutions]

a_1 = life adjustment factor for reliability

a_{SKF} = SKF life modification factor

Calculations described here can be easily performed using the tools available online at skf.com/bearings. Additional information about SKF rating life can be found in SKF catalogues.

Reliability

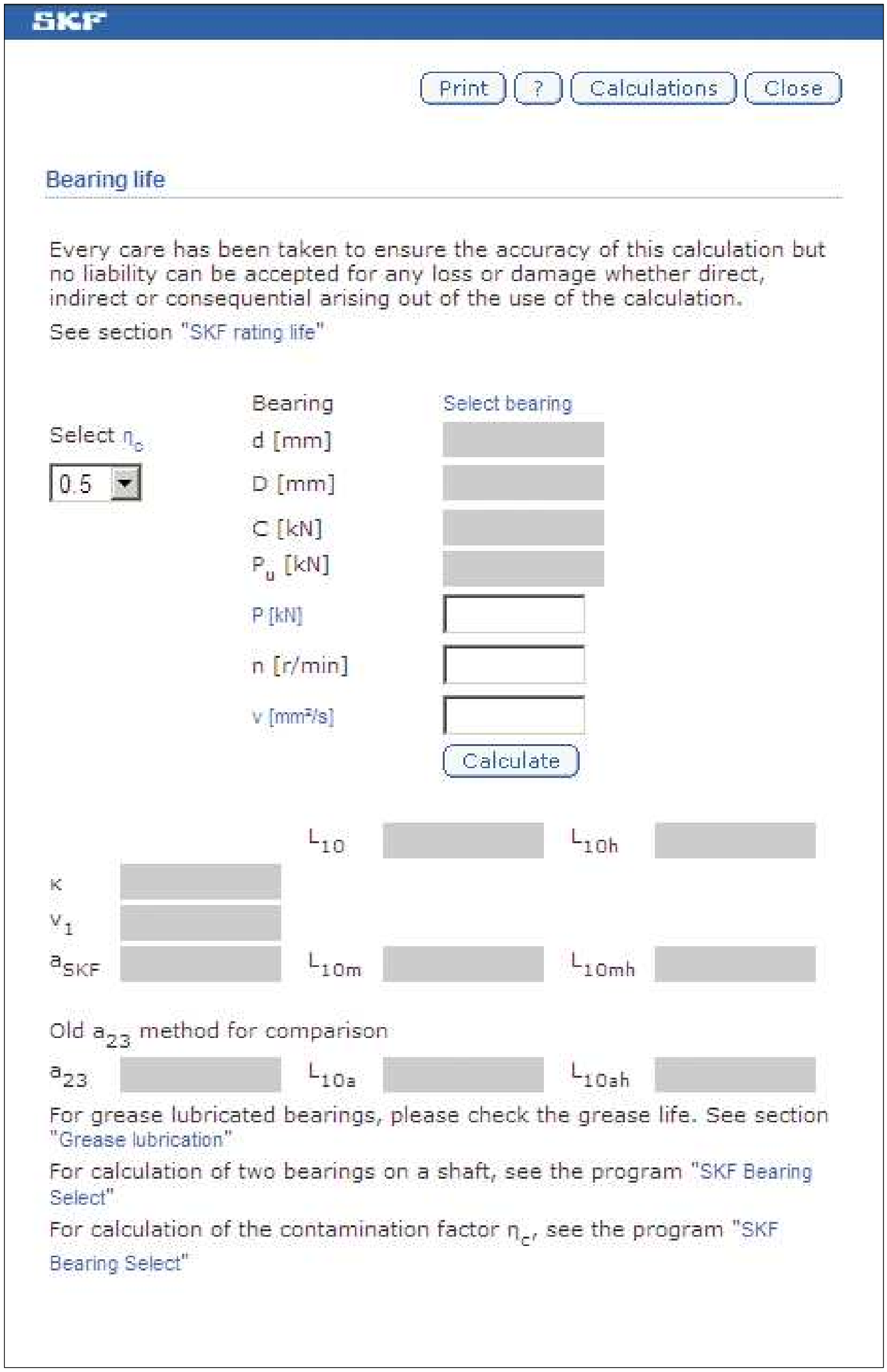
The SKF basic rating life L_{10} is based on 90% reliability. This calculation model is widely used for bearings in railway traction motors and gearboxes.

For higher reliability requests, the SKF rating life can be calculated by using the life adjustment factor a_1.

Values for life adjustment factor a_1

Reliability %	Failure probability n %	SKF rating life L_{nm}	Factor a_1
90	10	L_{10m}	1
95	5	L_{5m}	0,62
96	4	L_{4m}	0,53
97	3	L_{3m}	0,44
98	2	L_{2m}	0,33
99	1	L_{1m}	0,21

[1] The factor n represents the failure probability, i.e. the difference between the requisite reliability and 100%


SKF
Print
?
Calculations
Close
Bearing life
Every care has been taken to ensure the accuracy of this calculation but no liability can be accepted for any loss or damage whether direct, indirect or consequential arising out of the use of the calculation.
See section "SKF rating life"
Bearing
Select bearing
Select η_c
0.5
d [mm]
D [mm]
C [kN]
P_u [kN]
P [kN]
n [r/min]
ν [mm²/s]
Calculate
L_{10}
L_{10h}
κ
ν_1
a_{SKF}
L_{10m}
L_{10mh}
Old a_{23} method for comparison
a_{23}
L_{10a}
L_{10ah}
For grease lubricated bearings, please check the grease life. See section "Grease lubrication"
For calculation of two bearings on a shaft, see the program "SKF Bearing Select"
For calculation of the contamination factor η_c, see the program "SKF Bearing Select"

6

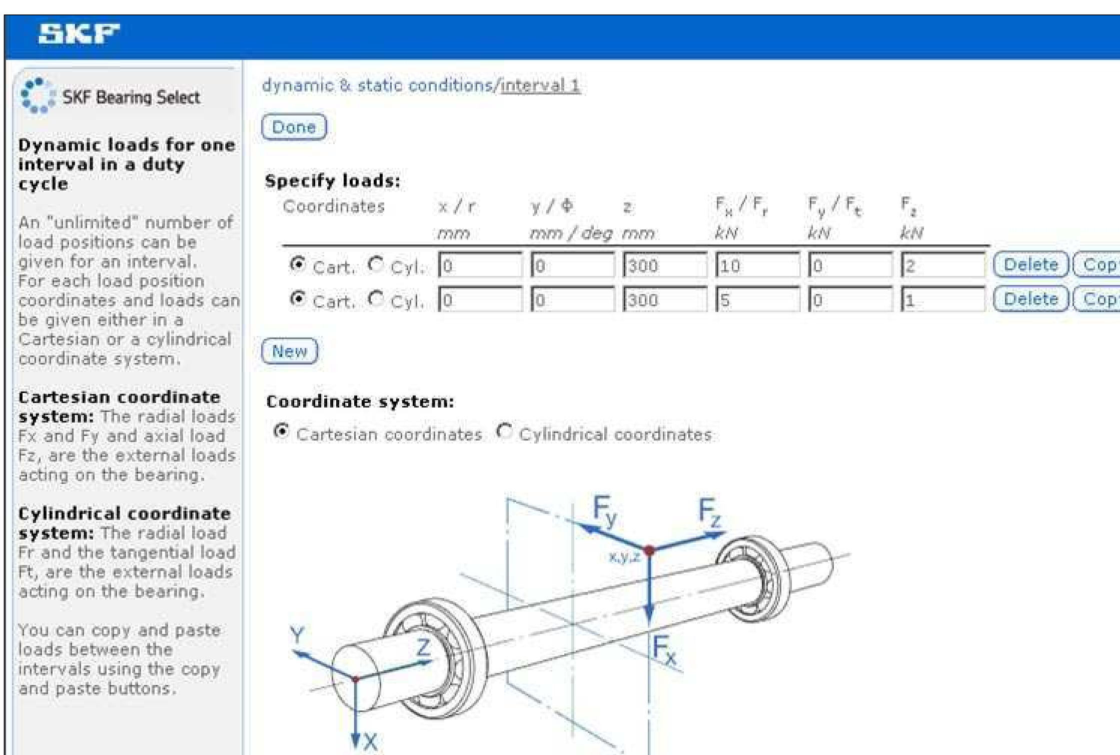
SKF Bearing Select

SKF Bearing Select is a web-based bearing selection tool that calculates the fatigue life of rolling bearings.

The calculations are based on the theories presented in SKF catalogues and compliant with ISO 281.

SKF Bearing Select is based on its well known predecessor – SKF CADalog and has the following features:

- calculation of rolling bearing fatigue life for a single bearing or two bearings on a shaft
- easy access through the Internet
- no installation of software necessary
- integrated report generator for quick documentation
- aligned with the latest version of SKF catalogues
- updated bearing database containing the latest product data including SKF Explorer bearings
- possibility to store input files on the server or locally on your own computer
- compatible with its predecessor – the SKF CADalog



Calculation of the bearing loads and selection of applicable bearing types with the tools available online at skf.com/bearings

Lubrication

If rolling bearings are to operate reliably, they must be adequately lubricated to prevent direct metal-to-metal contact between the rolling elements, raceways and cages. The lubricant also inhibits wear and protects the bearing surfaces against corrosion. The choice of a suitable lubricant and lubrication method for each individual bearing application is therefore important, as is proper maintenance.

A wide assortment of greases and oils is available to lubricate rolling bearings. Selecting a lubricant depends primarily on the operating conditions, i.e. the temperature range and speeds as well as the influence of the surroundings.

Generally, the most favourable operating temperatures can be obtained when the minimum amount of lubricant needed to reliably lubricate a bearing is provided. However, when the lubricant has additional functions, such as sealing or removing heat, additional amounts of lubricant may be required.

The lubricant in a bearing arrangement gradually loses its lubricating properties as a result of mechanical working, ageing and the build-up of contaminants. It is therefore necessary for grease to be replenished or renewed and for oil to be filtered and changed at regular intervals.

The information and recommendations in this section relate to bearings without integral seals or shields. SKF bearings and bearing units with an integral shield or seal on both sides are supplied greased. Information about the greases used are provided on customer request.

Note

Differences can exist in the lubricating properties of seemingly identical lubricants – particularly grease – produced at different locations.

Therefore, SKF cannot accept liability for any lubricant or its performance. The user is therefore advised to specify lubricant properties in detail so as to obtain the most suitable lubricant for the application.

Viscosity ratio κ

The effectiveness of a lubricant is primarily determined by the degree of surface separation of the rolling contact surfaces. If an adequate lubricant film is to be formed, the lubricant must have a given minimum viscosity when the application has reached its normal operating temperature. The condition of the lubricant is described by the viscosity ratio κ as the ratio of the actual viscosity ν to the rated viscosity ν_1 for adequate lubrication, both values being considered when the lubricant is at normal operating temperature, refer to SKF catalogues.

$$\kappa = \frac{\nu}{\nu_1}$$

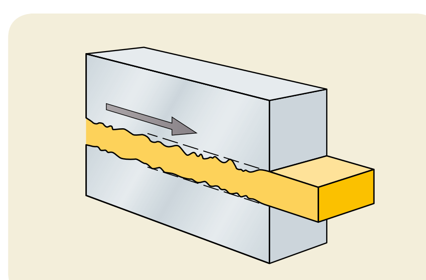
where

κ = viscosity ratio

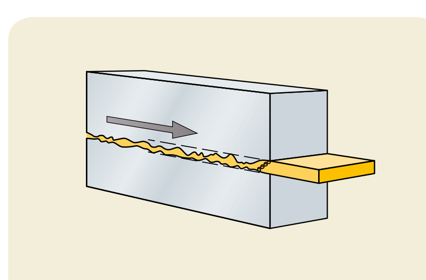
ν = operating viscosity of the lubricant [mm^2/s]

ν_1 = rated viscosity depending on the bearing mean diameter and rotational speed [mm^2/s]

The rated viscosity ν_1 required for adequate lubrication can be obtained from the graphs in SKF catalogues or with the information online at skf.com/bearings.



Full film lubrication, hydrodynamic lubrication which means a complete separation of rolling contact surfaces by the lubricant film viscosity ratio $\kappa \geq 1$



Mixed lubrication which means an incomplete separation of rolling contact surfaces by the lubricant film viscosity ratio $\kappa < 1$

6

Grease lubrication

The majority of rolling bearings are grease lubricated.

Compared to oil, the advantage of grease is that it is more easily retained in the bearing arrangement, particularly where shafts are inclined or vertical. Grease also contributes to sealing the arrangement against solid and liquid contaminants as well as moisture.

Excessive amounts of grease cause the operating temperature within the bearing to rise rapidly, particularly when running at high speeds. As a general rule, when starting up, only the bearing should be completely filled, while the free space in the housing should be partly filled with grease. Before operating at full speed, the excess grease in the bearing must be allowed to settle or escape during a running-in period. At the end of the running-in period, the operating temperature will drop considerably, indicating that the grease has been distributed in the bearing arrangement.

Grease lubrication is mostly used for traction motor and suspension tube designs. If possible at all, oil lubrication should be applied.

Oil lubrication

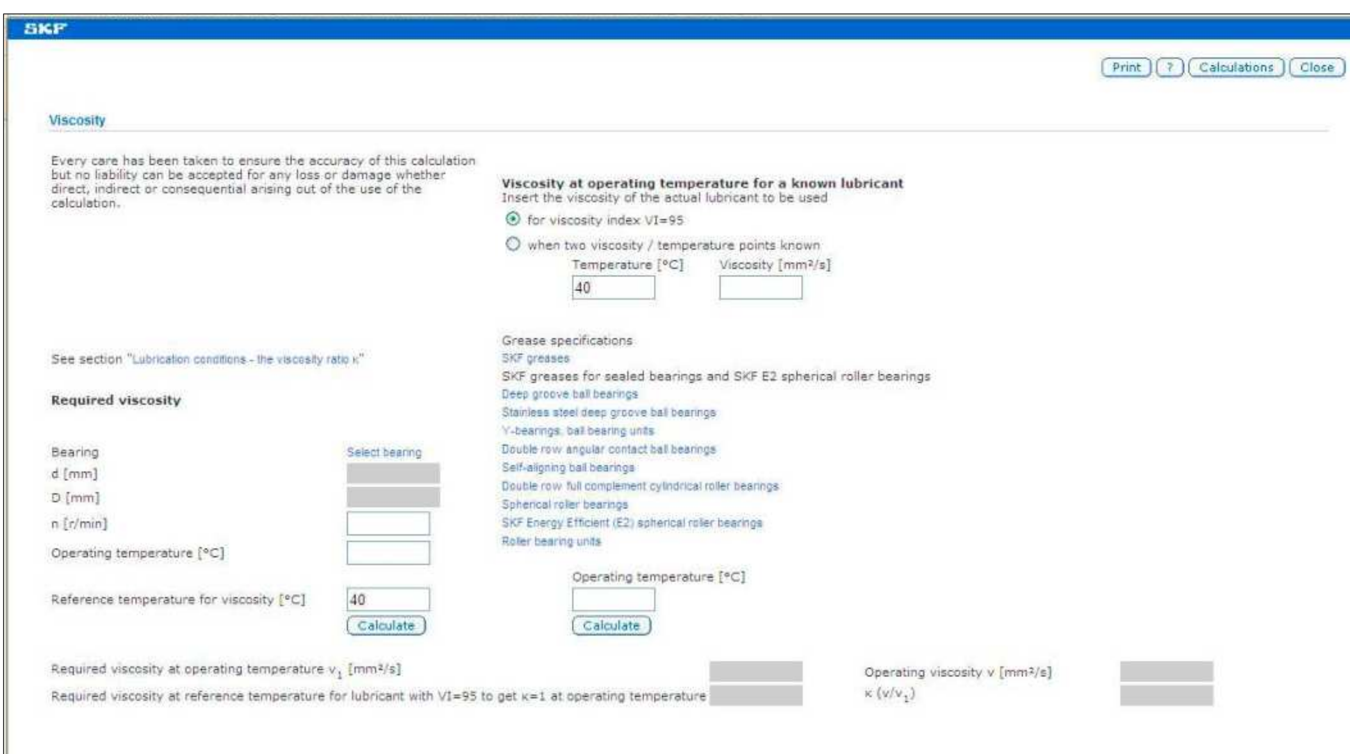
Oil is generally used for rolling bearing lubrication when high speeds or operating temperatures preclude the use of grease, when frictional or applied heat has to be removed from the bearing position, or when adjacent components (gears etc.) are already lubricated with oil.

In order to extend bearing service life, all methods of bearing lubrication that use clean oil are preferred, i.e. well filtered circulating oil lubrication, oil jet method and the oil-spot method with filtered air and oil.

When using the circulating oil and oil-spot methods, adequately dimensioned ducts must be provided so that the oil flowing from the bearing can leave the arrangement.

Oil lubrication is used mainly for gearbox bearings and drive side traction motor and suspension tube bearings.

Calculation of the viscosity with the tools available online at skf.com/bearings



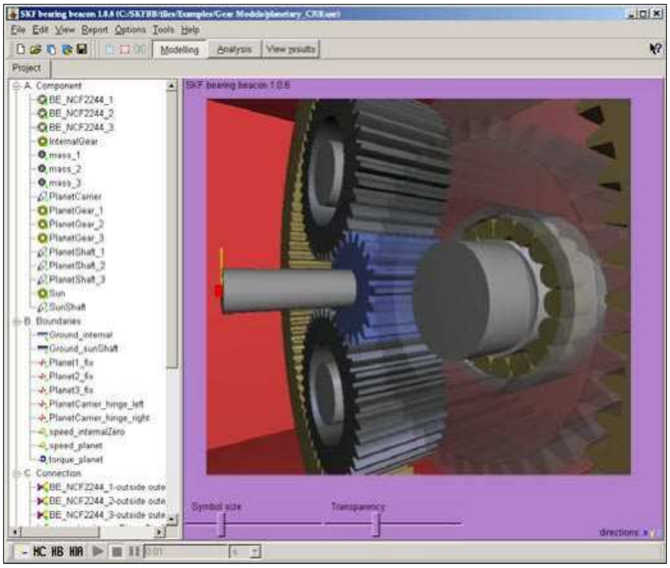
Advanced calculations

SKF possesses one of the most comprehensive and powerful sets of modelling and simulation packages in the bearing industry. They range from easy-to-use tools based on SKF catalogue formulae to the most sophisticated calculation and simulation systems running on parallel computers. One of the most used tools at SKF for advanced life calculations is SKF bearing beacon.

SKF bearing beacon

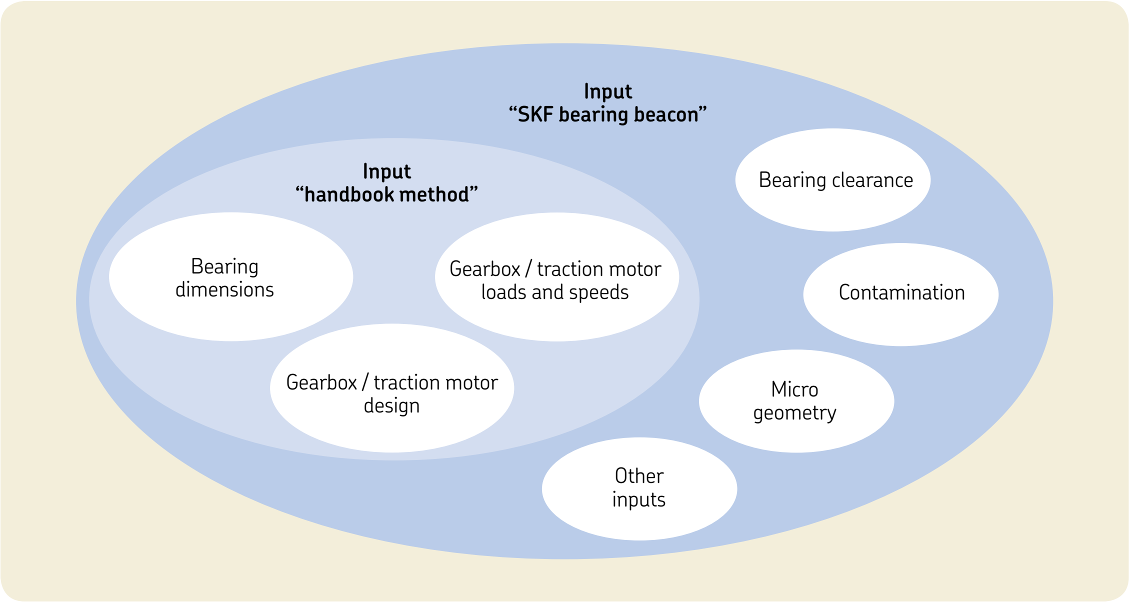
The SKF bearing beacon is the mainstream bearing application program used by SKF engineers to find the best solution for a customer's bearing system. Working in a virtual environment, SKF engineers combine mechanical systems containing shafts, gears and housings with a precise bearing model for an in-depth analysis of the system's behaviour. The program can also analyze rolling fatigue in a bearing using the SKF rating life method. SKF bearing beacon is the result of years of research and development within SKF.

For SKF drive system calculations, SKF bearing beacon is mainly used for investigating the load distribution on rollers and inner/outer ring raceways for specific applications with load offset, Hertzian stresses, truncation, axle journal bending, extreme temperature conditions and advanced bearing fatigue calculations.



SKF bearing beacon 3-dimensional calculation model

6



Comparison of input data requirements for a handbook calculation with those for the SKF bearing beacon calculation

The most advanced one is called SKF AFC (Advanced Fatigue Calculation). This method is based on a full integration of rolling element contact stress. It evaluates the number of stress cycles until life in the entire loaded volume is consumed.

The advantages of the advanced fatigue calculation are

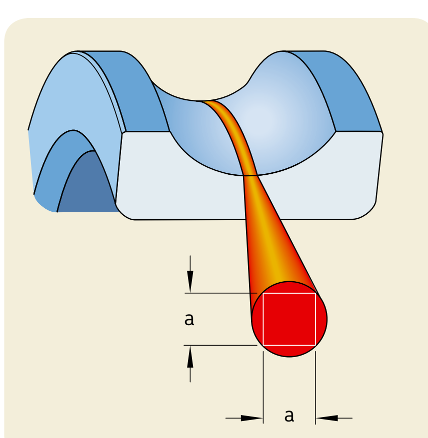
- more exact than any other model
- full stress integration (evaluation of actual stresses)
- adjustment factors for lubrication and contamination
- fatigue of the steel is considered
- all possible loads and misalignments are taking into account

The numerical SKF bearing beacon tool is further used to study and optimize the dynamic behaviour of noise and vibration-critical bearing applications (e.g. electric motors, gearboxes). The program is also used to solve the complete non-linear equations of motion for a bearing arrangement and the surrounding components, including gears, shafts and housings.

This method can provide profound understanding of and advice on the dynamic behaviour of an application, including the bearings, accounting for form deviations (waviness) and mounting errors (misalignment). This enables SKF engineers to determine the most suitable bearing type and size as well as the corresponding mounting and pre-load conditions for a given application.

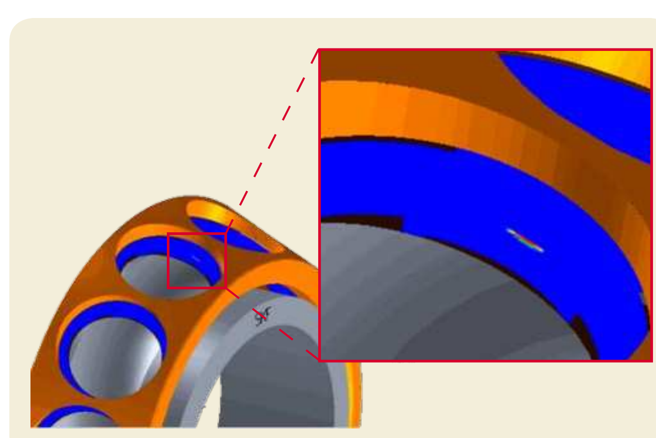
BEAST

BEAST is a simulation program that enables SKF engineers to simulate the detailed dynamics inside a bearing. It can be seen as a virtual test rig performing detailed studies of forces, moments etc. inside a bearing under virtually any load condition. This enables the “testing” of new concepts and designs in a shorter time and with more information gained compared with traditional physical testing.



SKF bearing beacon method AFC calculation is based on a full integration of rolling element contact stress

BEAST calculation results of the cage pocket deformation and contact stresses in an angular contact bearing



FEM calculation

Finite element method (FEM) calculation is a tool for modal analysis in structural mechanics to determine natural mode shapes. These calculations are made to find approximate solutions of partial differential equations, as well as of integral equations.

The solution approach is based either on eliminating the differential equation completely (steady state problems), or rendering them into an approximating system of ordinary differential equations, which are then numerically integrated using standard techniques such as Euler's method, Runge- Kutta method, etc. [1].

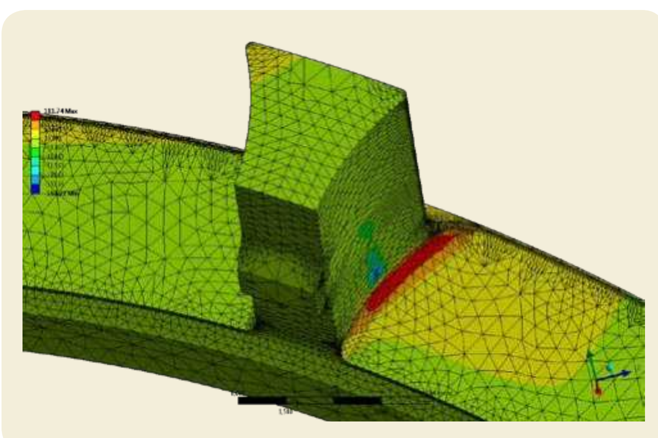
The FEM results can be provided as max. values based on von Mises[2] or principal stresses.

Other programs

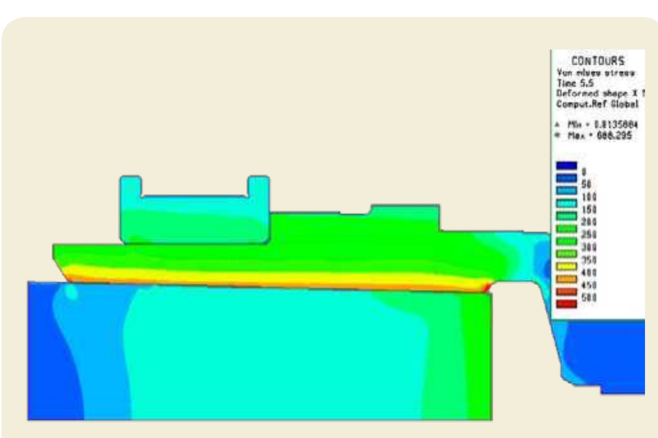
In addition to the mentioned programs, SKF has developed dedicated computer programs that enable SKF scientists to provide customers with bearings having an optimized bearing surface finish to extend bearing life under severe operating conditions. These programs can calculate the lubricant film thickness in elasto-hydrodynamically lubricated contacts. In addition, the local film thickness resulting from the deformation of the three dimensional surface topography inside such contacts is calculated in detail and the consequent reduction of bearing fatigue life.

In order to complete the necessary capabilities for their tasks, SKF engineers use commercial packages to perform tests such as finite element or generic system dynamics analyses. These tools are integrated with the SKF proprietary systems enabling a faster and more robust connection with customer data and models.

FEM calculation result of the maximum principal stress of a cylindrical roller bearing brass cage



FEM stress calculation result based on von Mises principle of a drive side inner ring of a N design cylindrical roller bearing, with the pinion pressed onto the tapered shaft.



[1] named after Leonhard Euler (1707 – 1783), Carl David Tolmé Runge (1856 – 1927), Martin Wilhelm Kutta (1867 – 1944)
[2] named after Richard Edler von Mises (1883 – 1953)

Verification

As mentioned on **page 148**, the application analytical process should be validated by a verification process. Some typical evaluations are

- static safety
- bearing life
- minimum load
- speed limit
- re-lubrication interval
- temperature stability
- lubricant compatibility

For high-demand applications, SKF can make further verification such as

- bearing contact pressure
- operating clearance
- truncation
- misalignment
- stiffness
- ring hoop stresses

In addition, field test results can help to validate calculation results and application engineering advice.

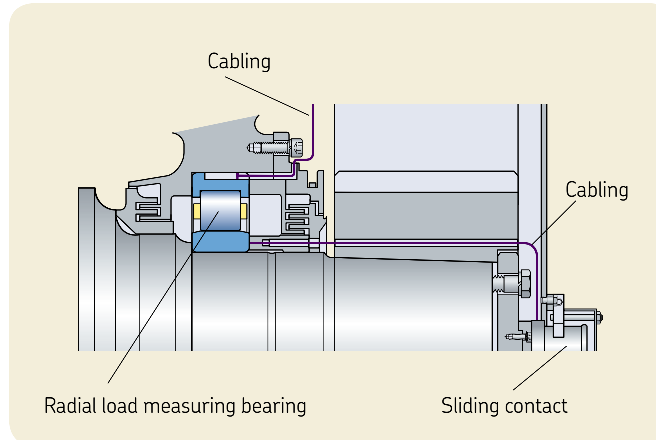
Field testing

In cooperation with a railway operator, a field test was done [30]. The multipurpose electric locomotive is used for long distance passenger trains with speeds up to 140 km/h and 950 t freight trains operating on ramps in the alpine region. The operational maximum speed was 160 km/h. In addition, a special short trial was made with a test speed of 175 km/h. The focus of the field test was to measure radial and axial bearing loads on the drive and non-drive side of the traction motor under different operational conditions. The total field test run covered 8 different operational sections with around 800 km total mileage, during a time of around 14 travelling hours spread over two working days.

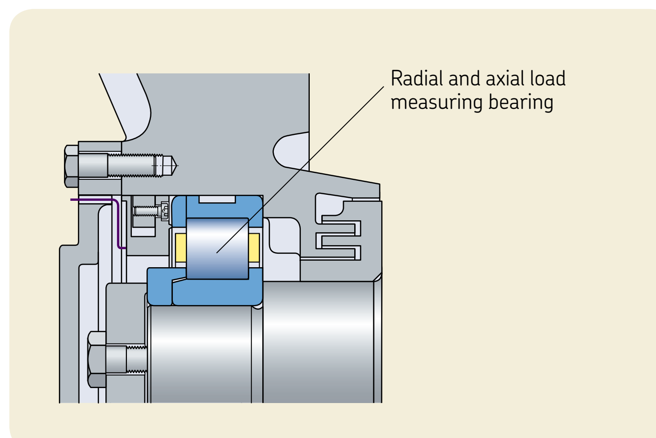
The measured maximum drive side radial load is around 3,5 times the mean load over the complete field test. There was a very good correlation between the measured loads and the traction motor current.

The temperature difference of the drive side bearing during operation was 26 °C measured on the outer ring and 30 °C measured on the inner ring. The measured largest temperature difference between the inner and outer ring of the drive side bearing was 11 °C. The ambient temperature during the test trip was very moderate at around 20 °C.

The temperature difference of the non-drive side bearing during operation was 37 °C.



Drive end side traction motor bearing equipped with sensors



Non-drive end side traction motor bearing equipped with sensors

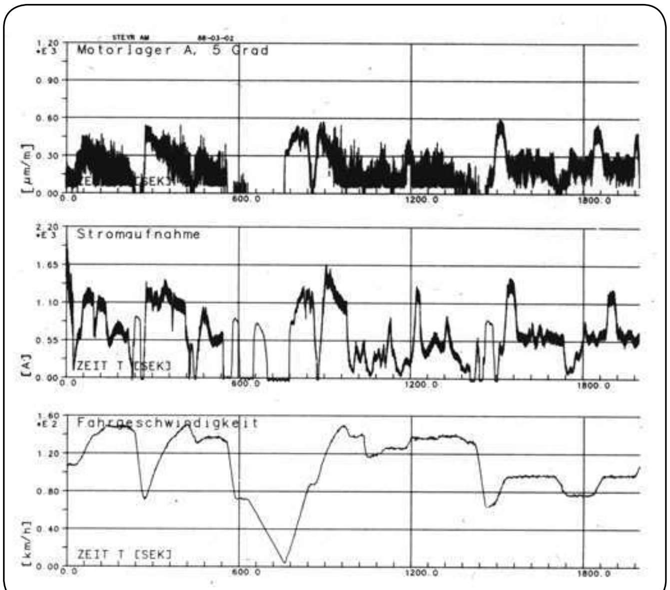
Summary of the field test: radial maximal and medium loads acting on the drive side and non-drive side traction motor bearings

	Max. radial load F_{max} [kN]	Mean radial load F_m [kN]	Location
Drive side traction motor bearing	168,0 140,0	52,4 37,4	5° 147°
Non-drive side traction motor bearing	(13,0) (15,0) 29,0	(3,6) (4,6) 8,4	42° 77° 175°

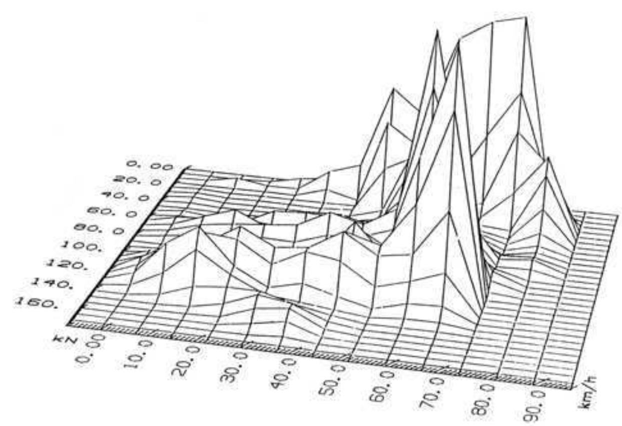
The values in brackets refer to two measured test sections only

Summary of the field test: maximal and medium temperatures on the drive side and non-drive side traction motor bearings

	Max. operating temperature δ [°C]	Mean operating temperature δ [°C]	Location
Drive side traction motor bearing	30 … 56 33 … 63	26 … 52 28 … 52	outer ring
Non-drive side traction motor bearing	36 … 73	30 … 65	outer ring

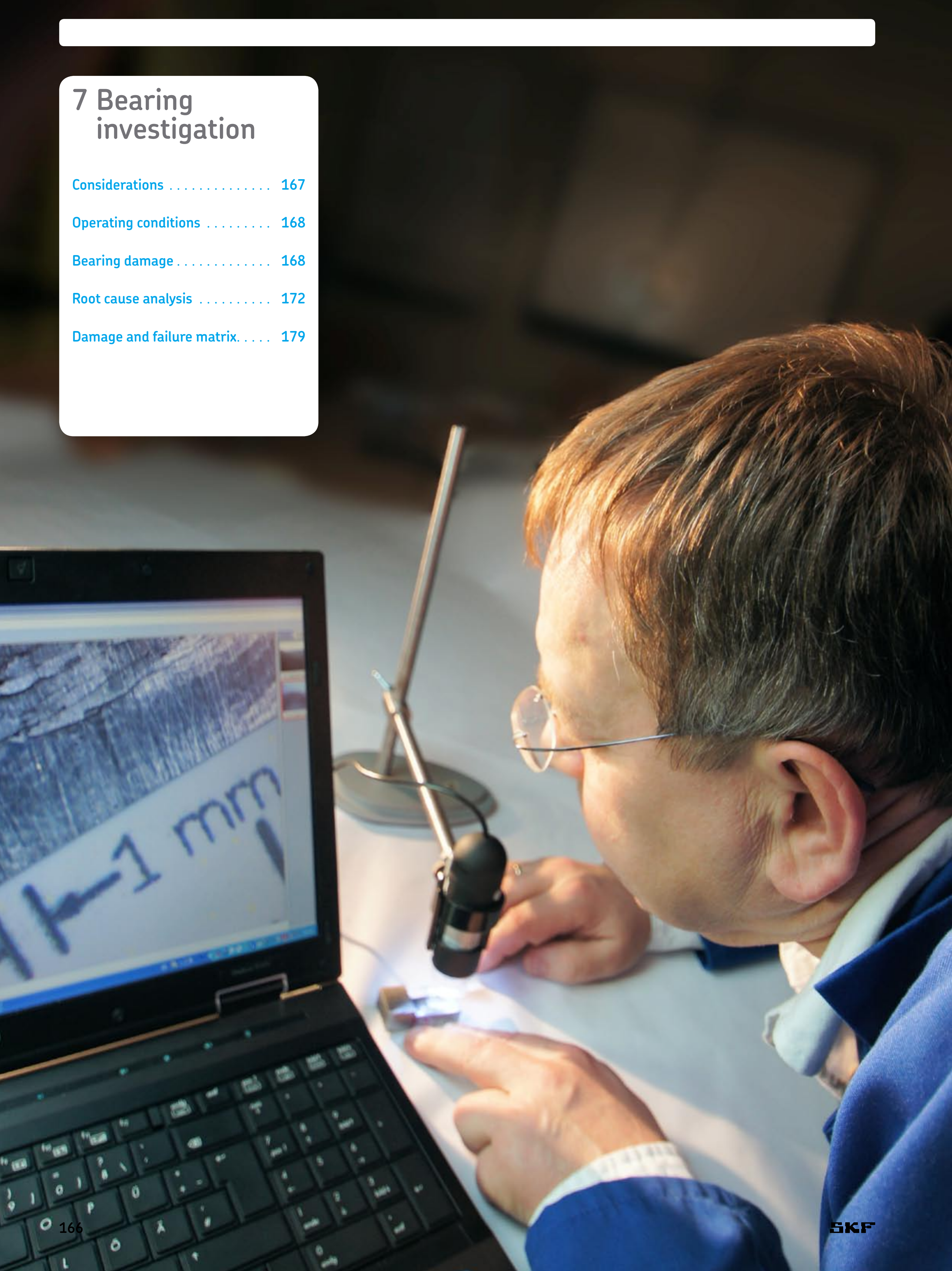


Example of measured parameters
- *First graph: traction motor bearing drive side radial forces 5° position*
- *Second graph: traction motor current [A]*
- *Third graph: locomotive speed [km/h]*



Example of measured speed and radial loads action on the drive side bearing

7 Bearing investigation



Bearing investigation

There is an ever increasing demand for higher reliability and extended safety intervals for traction motors and gearboxes. To validate bearing conditions in the field, condition monitoring should be applied (→ chapter 9). A complementary method is bearing investigation undertaken by railway maintenance personnel or by the bearing manufacturer. In most cases, an intermediate investigation on the condition of the grease or oil can more easily be done than a complete dismounting and investigation of the bearings (→ page 222). This can help to establish the bearing condition indirectly with limited efforts. All three methods complement each other with the aim to enhance reliability, to improve the scheduled maintenance interval and to implement corrective actions where needed.

Considerations

Rolling bearings are extremely vital components in traction motors and gearboxes of railway vehicles. A large number of factors need to be considered to select the appropriate bearing for an application. But, complete information is not always available. Real operating conditions might differ from the specifications (→ **page 146**).

Wear and tear might change the operating conditions. Also, use of the vehicle might change over time.

All of these can influence rolling bearing service life. Damage to bearings might occur earlier than foreseen. Poor lubrication and damaged bearings can lead to catastrophic failures like damaged rotors and stators of traction motors or gearwheels in gearboxes. In this case, train operational service has to be interrupted and powered vehicles have to be specially hauled to the maintenance shop for repairs. This unplanned action may cause transportation standstills and require a lot of effort to get the needed spare parts and repair.

With the introduction of AC propulsion systems, collectors and brushes for former DC traction motors are not needed. Usually, these components had a much shorter service life than lubrication grease and bearings. Today, traction motor maintenance intervals are more focused on required grease life and bearing condition and service life. In the future, it will become even more important to ensure high reliability resulting in a long maintenance interval. In comparison, oil lubricated gearbox bearings are less demanding on maintenance. Intermediate oil investigations and eventual replacement can be done in a relatively cost-effective way without the need to dismount the propulsion system.

Operating conditions

Calculating bearing life is dealt with in the different chapters. However, to select the final bearing, a large number of factors need to be considered. The following main factors influence this selection:

- type
- dimensions
- precision
- fit
- clearance
- cage
- heat treatment
- lubrication
- sealing
- electric current passage
- mounting/dismounting

Selecting the appropriate bearing for the application (→ chapter 3 to 6) is only the first step in achieving reliable equipment performance.

If all the needs relative to the above factors are satisfactorily met, it would be expected that a bearing will reach its calculated life. Unfortunately, in a number of cases this is quite hypothetical. There is often something that occurs that prevents "ideal" operating conditions. Bearings might get damaged and their life impaired [31, 32].

Calculated life expectancy of any bearing is based on eight assumptions:

1. The bearing is appropriate for the application.
2. The bearing is of highest quality and has no inherent defects.
3. Dimensions of associated components, such as shaft and housing seats, are appropriate.
4. The bearing is mounted correctly.
5. The appropriate lubricant, in the required quantity, is always available to the bearing.
6. The bearing arrangement is properly protected (sealed).
7. The bearing arrangement is matched to the operating conditions.
8. Recommended maintenance is performed.

Bearing damage

Theoretically, it would be an advantage to classify bearing damage based on the primary root cause of the failure. In practice, however, there is most often an overlay of different failure causes, which in combination can lead to significant bearing damage such as:

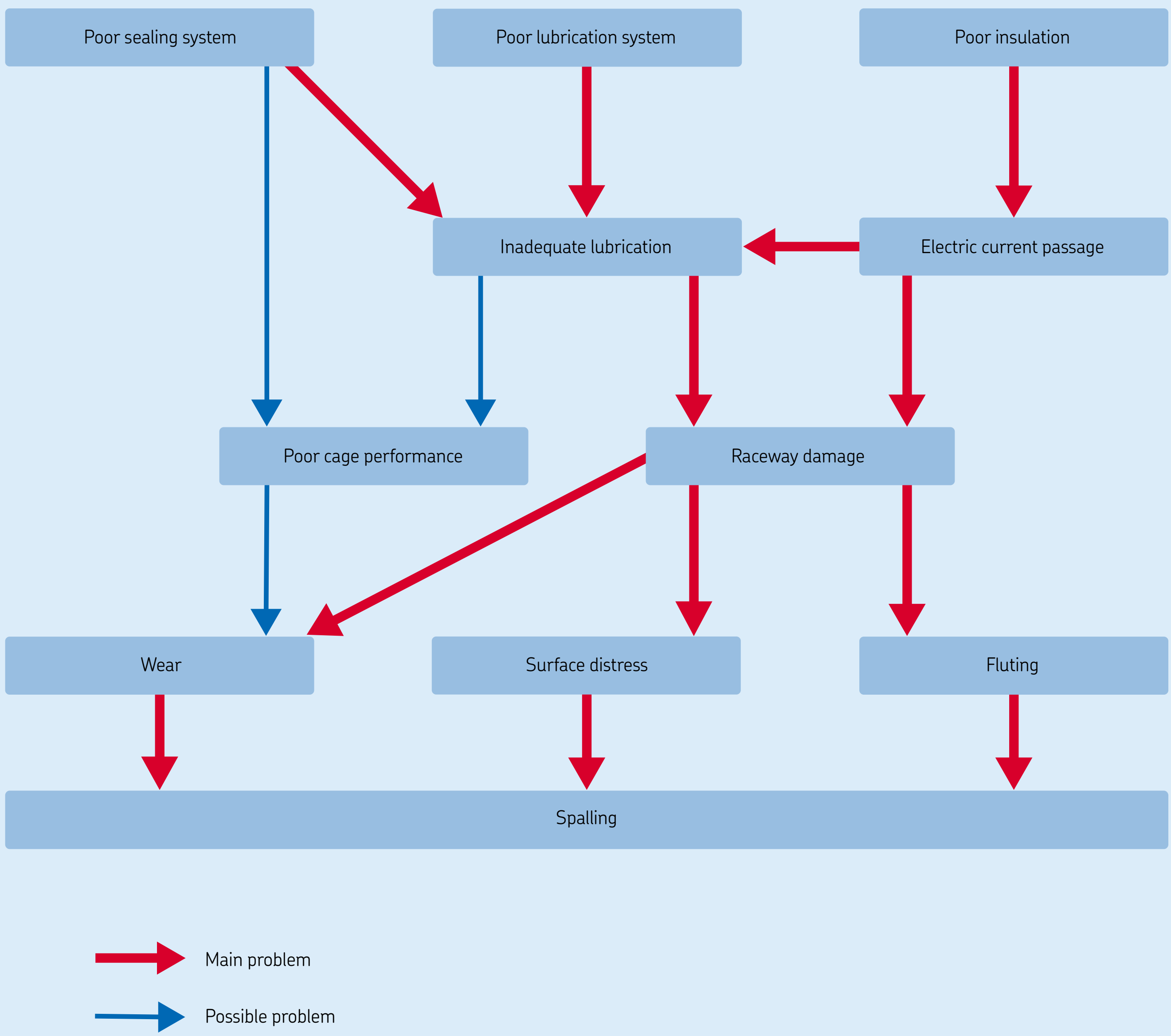
- excessive wear (e.g. caused by contaminated lubricant[1)] because of inadequate sealing performance)
- early fatigue (e.g. small spalls) which can end up as large spalling and cause severe traction motor failures in operation (e.g. cracked rings and/or rolling elements)

Because of the possibility that there are multiple causes of the failure, bearing damage investigation can be quite complex and difficult.

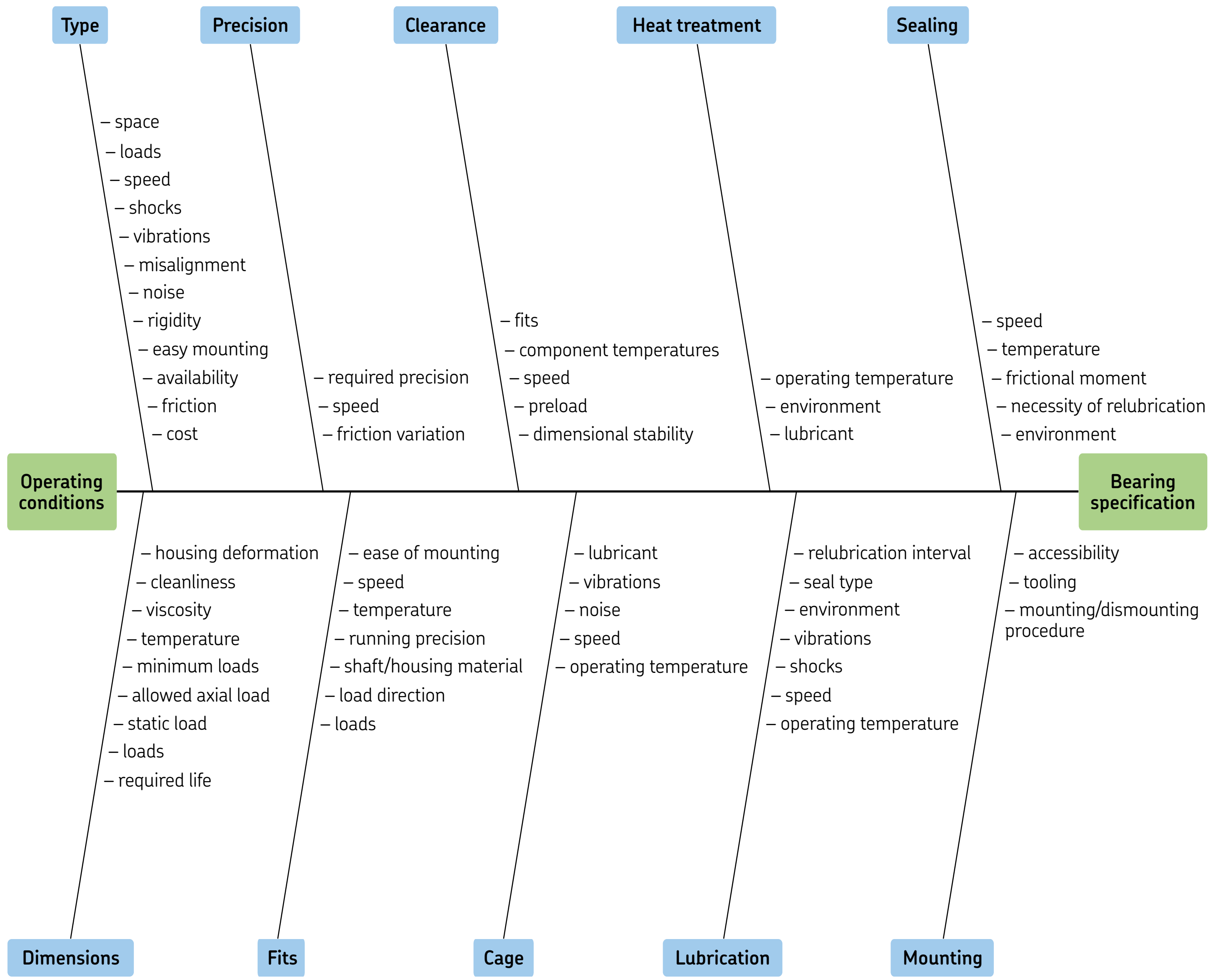
A detailed inspection of a traction motor bearing unit is the first step in the remanufacturing process. This traction motor bearing unit was in service for 12 years and has covered 1,5 million km in heavy locomotive service. The wear is very minor and all parts can be reused after remanufacturing.

1) For detailed lubrication investigation, the SKF Grease Test Kit TKGT 1 helps to get a better understanding of the grease condition (→ page 222)

Design problems – Simplified example of interactions



7



A large number of operating conditions influence the bearing specification

Cylindrical roller bearing used in a traction motor that was only 10 km in operation.
This is an example of where two overlapping reasons caused the damage: too little radial clearance and wrong cage design for the application.

Failure of a cage and roller assembly of a deep groove ball bearing of a traction motor.

Progressive stages of damage

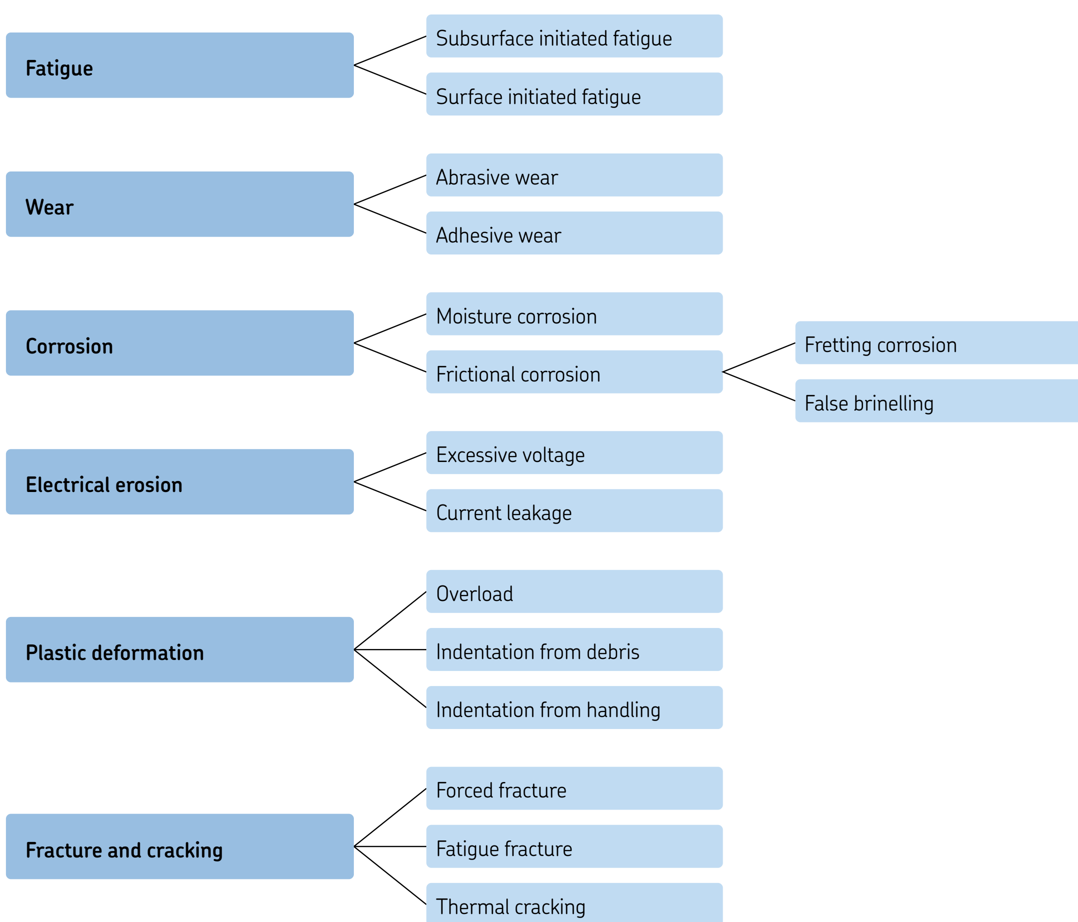
Initial damage may cause surface fatigue and wear. Subsequently, fracture and cracking of the bearing can occur. Often, drive bearings run hot and block the motor, the gearbox and the wheelset. The rotor and stator can be seriously damaged and require extensive repairs. In this case, expensive actions are necessary to move the railway vehicle from the track to the next depot, which will delay operation.

A practical example

Here is a practical example from the field: A traction motor bearing failure occurred during heavy operation on a ramp in the alpine region. The stranded locomotive blocked the single track and had to be rescued with a special transport to the next depot, which was difficult and time consuming. It delayed several trains for half a day.

Later on, the traction motor was rebuilt in the railway maintenance shop. It required a new rotor shaft, new stator and rotor windings. In fact, only the traction motor housing remained. In most cases, unfortunately, damage of this kind cannot be repaired. Condition monitoring can help to detect damage at a very early stage (→ chapter 9).

In the following pages, some typical traction motor and gearbox bearing investigations are described. More cases can be found in the SKF *Railway technical handbook*, *Volume 1*, **chapter 6**, or in ISO 15243.



ISO 15243: Bearing damage classification – showing 6 primary failure modes and their sub-modes.

Root cause analysis

It is commonly understood that:

- A cause of damage (failure) results in a certain characteristic form of change.
- A certain failure mechanism results in a certain failure mode (pattern).
- From the damage observed, one can possibly determine the root cause of failure.

Much work has been done by ISO to define the different failure modes and to classify them. This has resulted in the ISO 15243 standard, first published in 2004. When looking at bearing failures, a total of six main failure modes can be observed, which can be further classified into a number of sub modes [32].

The classification is based on three major factors:

- damage and changes that occurred during service (as soon as a bearing has left the factory)
- characteristic forms of change in appearance that can be attributed to a particular cause
- classified by visible features (including the use of non-destructive equipment for magnifying, such as microscopes).

Fatigue

Subsurface initiated fatigue

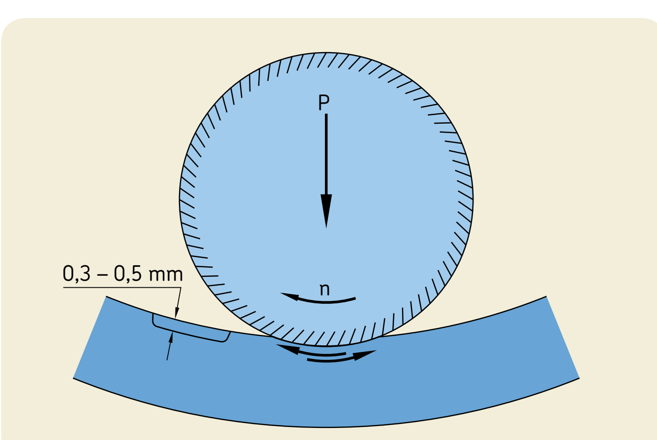
The deterioration of the material is caused by cyclic loading and the built-up of stresses just underneath the raceway surface, ultimately resulting in decay of the material. Cracks are initiated and propagate underneath the surface, and when they come to the surface, spalling occurs.

Surface initiated fatigue

This results from inadequate lubrication conditions. The role of the lubricant is to build up an oil film that separates the moving parts.

Under poor lubrication conditions, for example due to contamination or inadequate viscosity, metal-to-metal contact occurs. The surface asperities (peaks) shear over each other, resulting in stresses that lead to material fatigue, and finally resulting in microspalls. Initially, there might be a shiny surface, because the surface roughness is reduced, but the process continues and the surface becomes dull and breaks up.

Spalling caused by fatigue



Subsurface initiated fatigue
Subsurface initiated fatigue on a bearing outer ring raceway

Surface initiated fatigue
Surface initiated fatigue in the outer ring of a spherical roller bearing.
There is surface distress on part of the outer ring raceway. In one place, spalling has already occurred.

Wear

Wear is typical damage that occurs in the contact zones of moving bodies. Wear most often is unavoidable. However, circumstances may cause wear to occur at an early stage of bearing operation. Two variants of wear can occur. These are "abrasive" and "adhesive" wear. They occur due to differences in the speed of the working contact surfaces. The cause of the speed differences can be kinematic slip, acceleration and/or deceleration.

Abrasive wear

This occurs due to abrasive particles in the lubricant. These can be contaminant particles coming from the outside or inside – for example, wear particles from gears. The abrasive particles wear out the surfaces of the raceways, rolling elements and also metal cages. This normally results in dull surfaces.

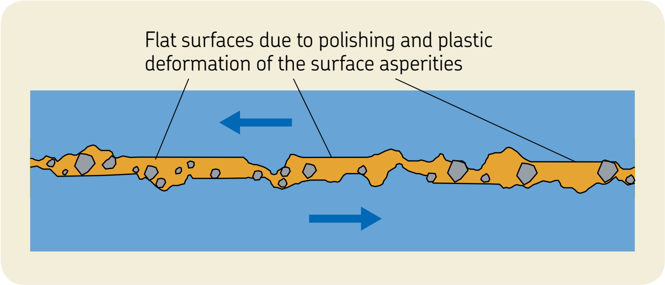
However, if the abrasive particles are very fine and hard, such as cement dust, a polishing effect might occur and mirror-like surfaces appear. Often, inadequate (or the absence of) sealing arrangements result in contaminants entering the bearing cavity. A lubricant analysis might reveal the origin of the contamination, which can help in finding a solution for the problem.

Adhesive wear

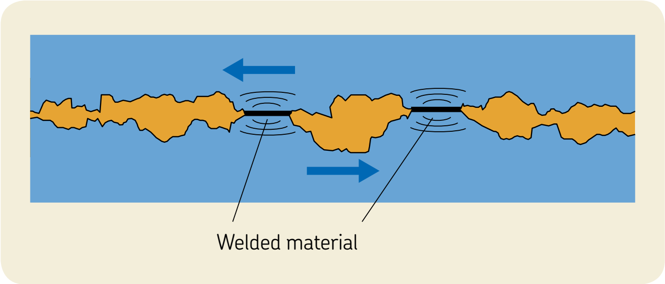
Adhesive wear occurs mainly in contact surfaces subjected to light loads, poor lubrication conditions and with important speed differences, resulting in sliding of the rolling elements.

One example is the passage of rolling elements from the unloaded zone into the loaded zone. The rolling elements can lose speed in the unloaded zone and accelerate when returning to the loaded zone. This can result in breakthrough of the lubrication film, sliding, heat development and possibly material transfer from the rolling element to the raceway or vice versa. In an early stage, the appearance is shiny surfaces, but quickly it turns into a dull surface with (more or less) smeared material.

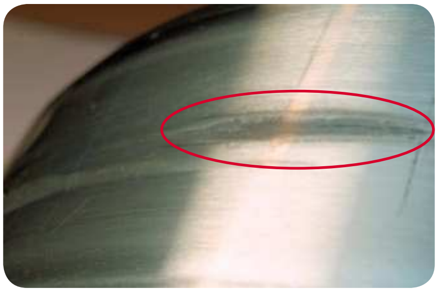
Abrasive wear
Abrasive wear on a steel cage of a tapered roller bearing



Abrasive wear
Polishing wear causes mirror-like surfaces

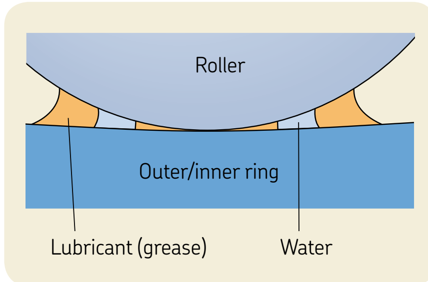


Adhesive wear
Important speed differences and too light loads can cause sliding, resulting in very high temperatures and smearing



Adhesive wear
Adhesive wear on the inner ring raceway of a cylindrical roller bearing

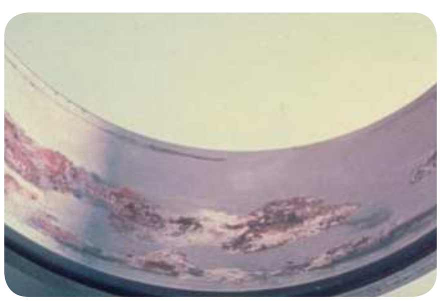
Moisture corrosion principle



Moisture corrosion
Moisture corrosion on the inner ring of a spherical roller bearing

Fretting corrosion
Fretting corrosion in the bore of a bearing

Fretting corrosion
Fretting corrosion in the bore of a bearing, resulting from an inadequate fit



Corrosion

Moisture corrosion

In contrast to other damage processes, corrosion can occur quickly and penetrate deeply into the material. This can cause serious bearing damage. Corrosion occurs in the presence of water, corrosive liquids or moisture. Also, high humidity in the air and touching raceways with fingers can lead to this type of corrosion.

It is therefore important to have good protection. Corrosion often happens during standstill and is then visible by corrosion marks at rolling element distance. Deep-seated rust leads to early bearing damage.

Fretting corrosion

The root cause for it to occur is micro-movements between two loaded surfaces. Mostly, this frictional corrosion occurs between the bearing outside diameter and housing and/or between the bearing bore and shaft.

The micro-movements are mainly caused by the cyclic loads when rolling elements are passing by. Inadequate fit, shaft bending and/or imperfections in the contact surfaces can be the cause and/or accelerate the occurrence. Air can come into the unprotected surfaces, and accelerate the progression of corrosion.

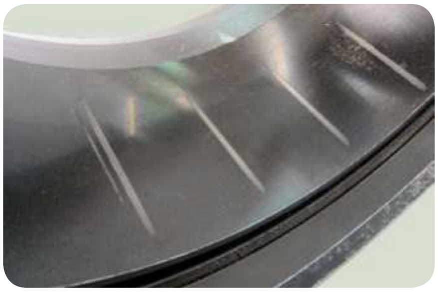
The formed iron oxide has a larger volume than pure steel. This can develop material growth and high stresses, even to the bearing raceway and can lead to premature fatigue. Fretting corrosion can easily lead to ring cracking.

False brinelling

False brinelling, also frictional corrosion damage, occurs in rolling element/raceway contact areas due to micro movements and resilience of the elastic contact under cyclic vibrations. Since it occurs when the bearing is stationary and loaded, the damage appears at rolling element pitch.

Depending on the intensity of the vibrations, the lubrication condition and load, a combination of corrosion and wear occurs, forming shallow depressions in the raceways.

Normally, the vibration results in a local break-through of the (protective) lubricant film, metal-to-metal contact, corrosion of the surfaces and abrasive wear. The appearance is therefore usually dull, often discoloured and sometimes reddish due to occurrence of the corrosion. Occasionally, the depressions can be shiny. False brinelling damage results in spherical cavities for ball bearings and lines for roller bearings.



False brinelling damage in the outer ring of a tapered roller bearing
False brinelling damage occurs at standstill and is characterized by damage at rolling element distance.

7

Electrical erosion

Electrical features, electrical erosion process, electric current prevention and insulated bearing solutions such as INSOCOAT and hybrid bearings are mentioned in **chapter 4** (→ **pages 104** to **106**).

Here, a few illustrations of electrical erosion damage are shown.

Excessive voltage
Raceway of an outer ring of a deep groove ball bearing.
1 *Craters in a bead-like procession*
2 *Zig-zag pattern in the outer ring and on the ball*

Excessive voltage
Ball bearing raceway with large spalls

Fluting or washboarding in a raceway caused by the passage of damaging electrical current.
Outer ring raceway of a deep groove ball bearing

Fluting or washboarding in a raceway caused by the passage of damaging electrical current.

Plastic deformation

Permanent deformation occurs whenever the yield strength of the material is exceeded.

Overload

Overload results from static or shock loads and leads to plastic deformation. This can be recognized by depressions at rolling element distance. Often, wrong mounting procedures are the reason for the problem, i.e., applying the mounting force to the wrong ring thereby producing a shock load over the rolling elements.

Indentation from debris

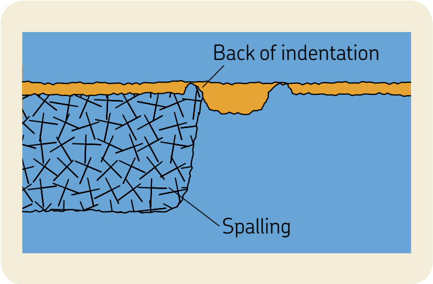
This results from foreign particles (contaminants) that have gained entry into the bearing and are rolled into the raceways by the rolling elements. The size and shape of the dents depend on the nature of the particles. The raceway geometry at the dent is destroyed and lubrication is impaired. Stresses arise at the surface and fatigue leads to premature spalling of the surface.

Indentation from handling

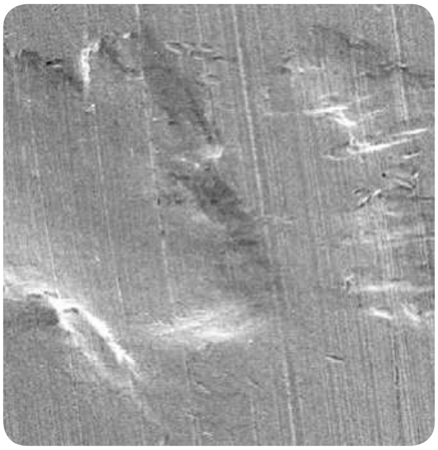
Indentation from handling can occur when bearing surfaces are gouged by hard, sharp objects. Also, bearings must always be handled with care. Although made of highest-quality steel, localized overloads, e.g., from dropping a bearing, might dent the surfaces and make the bearing unserviceable.

Overload
Mounting force was transmitted over the rolling elements, resulting in dents at rolling element distance, axially displaced.

Overload
The dents, resulting from wrong mounting, are overrolled and quickly lead to spalls.

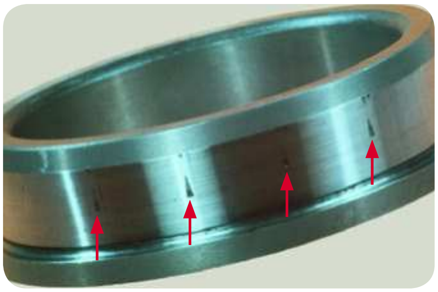


Indentation from debris
Dents destroy the geometry and lead to surface initiated fatigue in the area behind the spall



Indentation from debris
of soft particles

Indentation from debris
of hard particles



Indentation from handling
damage to inner ring of a cylindrical roller bearing due to wrong assembly

7

Forced fracture
Cracked flanges of a cylindrical roller bearing inner ring due to impact load

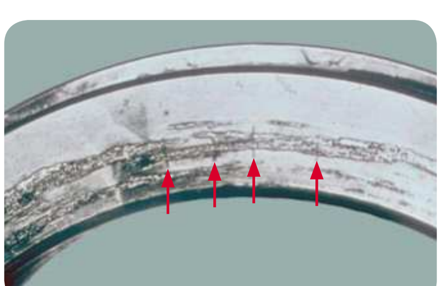
Forced fracture
Cracked inner ring of a cylindrical roller bearing

Forced fracture
Bad housing seat, finally resulting in a cracked outer ring

Forced fracture
Forced fracture through excessive drive-up

Fatigue fracture
Fatigue fracture of a spherical roller bearing outer ring

Thermal cracking
Very heavy smearing on the side face of a bearing inner ring. The heat resulted in cracks (transverse). finally the ring will crack through



Fracture and cracking

Fracture (or cracking) occurs when the ultimate tensile strength of the material is exceeded.

Forced fracture

Forced fracture is caused by stress concentration in excess of the material tensile strength by local impact or by over-stressing. Two common causes are:

- rough treatment (impact) when a bearing is being mounted or dismounted. Hammer blows applied to a hardened chisel directly against the ring may cause the formation of fine cracks with the result that pieces of the ring break off when the bearing is put into service.
- excessive drive-up on a tapered seat or sleeve. As a result, the tensile stresses (hoop stresses) arising in the rings produce cracks when the bearing is put into operation .

Fatigue fracture

This starts when the fatigue strength is exceeded under bending. A crack is initiated and will then propagate. Finally, the whole ring or cage cracks through. Fatigue fracture can occur when a tight fit has been used, leading to high hoop stresses. Then, the combined Hertzian and hoop stresses can lead to premature fatigue and through cracking of the ring.

Thermal cracking

Thermal cracking can occur when two surfaces slide heavily against each other. The frictional heat that is developed causes cracks, generally at right angles to the sliding direction.

Damage and failure matrix

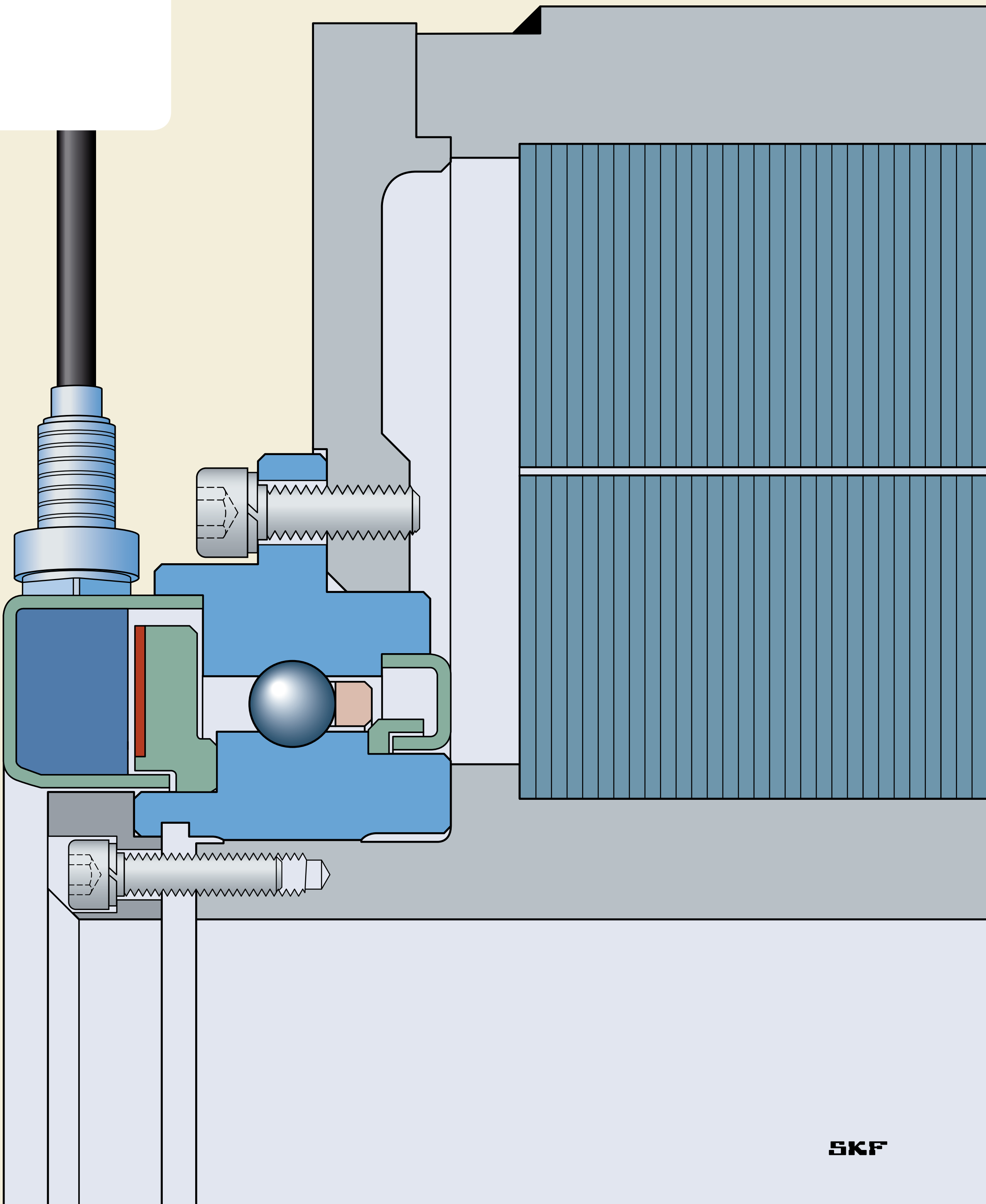
When looking at a damaged bearing, often the damage can be classified as one of the ISO damage modes.

The difficulty, however, might be to determine the root cause of the damage. The damage and failure matrix shown below can help. It shows the links between the damage (sub-)modes and operating conditions and whether or not one of the operating conditions might be a root cause. The table also shows where the damage can be found.

Damage and failure matrix

Failure modes with characteristics		Operating conditions						Environmental factors				Lubrication					Mounting							Other					
	Possible causes	Excessive load	Excessive speed	Frequent load or speed fluctuations	Excessive acceleration	Vibration	Shaft/housing deflections	Temperature too high/low	Solid contaminants ingress	Water ingress	Electrical current	Incorrect viscosity	Wrong consistency or additives	Insufficient lubricant	Excessive lubricant	Contaminated	Incorrect handling (impact)	Mounting procedure	Fit too tight	Fit too loose	Misalignment / tilting	Incorrect setting (preload)	Incorrect clamping	Incorrect storage	Vibration (transportation)	Bearing selection	Equipment design	Manufacturing concerns	Material concerns
Fatigue	Subsurface spalling, flaking	•					•	•				•	•						•		•	•	•			•	•	•	•
	Surface spalling		•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•		•	•		•	•	•	•	•	•
Wear	Abrasive wear		•	•	•	•	•	•	•	•	•	•	•	•	•	•			•	•	•	•	•			•	•	•	•
	Scratches, scores								•				•			•	•	•							•				
	Adhesive, smearing			•	•		•	•				•	•	•	•			•	•	•	•					•	•	•	•
	Hot runners	•	•	•	•		•	•				•	•	•	•			•	•		•	•	•			•	•	•	•
Corrosion	Moisture corrosion									•			•			•		•						•	•		•		
	Fretting corrosion	•		•		•	•													•	•	•	•			•	•	•	
	False brinelling					•							•							•				•	•	•			
Electrical erosion	Craters										•																•		
	Fluting										•																•		
Plastic deformation	Depressions	•					•								•		•	•	•		•	•	•	•	•	•	•		•
	Debris indentation								•							•	•	•						•			•	•	
	Nicks, gouges																•	•						•	•			•	
Fracture & cracking	Forced fracture	•	•					•									•	•	•		•	•	•			•	•	•	•
	Fatigue fracture	•	•	•	•	•	•													•	•	•	•			•	•	•	•
	Thermal cracking	•	•	•				•				•		•	•			•	•			•					•		•
Damage area	Raceways	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•		•		•	•	•	•	•	•
	Seats radial	•					•										•	•		•							•	•	•
	Seats axial (abutments)	•					•										•	•		•			•				•	•	•

8 Sensors



Sensors

The sensorized traction motor bearing unit (TMBU) concept offers several detection and measurement opportunities: absolute positioning detection for traction motor control devices, detection of direction of rotation, speed measurement for brake control systems and temperature measurement to monitor operating conditions.

Design principles

The integrated sensor concept offers several detection and measurement opportunities, such as absolute positioning detection for traction motor control devices, detection of direction and rotational speed measurement for brake control systems and, if needed, a temperature measurement to monitor reliability.

In most cases, both sensors are integrated into the sealing system of the outer ring of the bearing unit. This design offers several opportunities such as space and parts savings.

Sensor design benefits

- compact solution: space saving, especially in the axial direction, compared to conventional sensor devices
- robust design: fewer parts, no toothed impulse wheel
- high resolution and accuracy
- easy sensor replacement
- designed for long-life

Integration example

Classical design

In many applications, the classical traction motor design on the non-drive side is based on cylindrical roller bearings. To achieve the locating function, either a NUP design cylindrical roller bearing, or a NJ design cylindrical roller bearing with an HJ angle ring is used. The application of either of these cylindrical roller bearings enables easy mounting in comparison to a deep groove ball bearing. Usually, the load rating of a deep groove ball bearing is sufficient. On the other hand, a cylindrical roller bearing is often oversized.

For implementation of the AC three phase technique, motor speed detection is needed for the propulsion system. For conventional designs, this is realized by applying a toothed wheel that is fixed on the rotor shaft.

In many cases, the sealing function of the cylindrical roller bearing is based on a labyrinth seal on both sides of the bearing.

Substitution

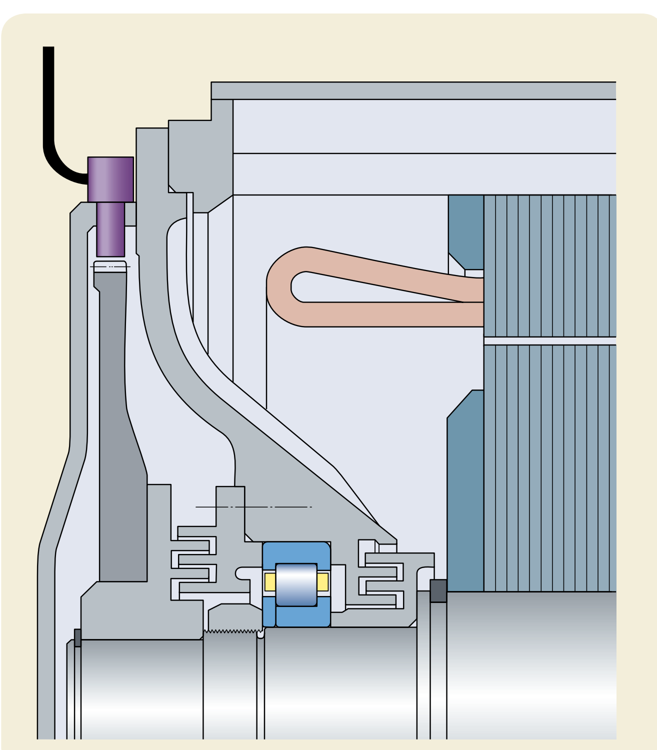
This conventional design principle requires a lot of space, especially in the axial direction. In this area, the wheel flange is nearby. The total length of the traction motor plus the gearbox is limited by the gauge and the wheel flange.

This design limits the active rotor length, which is, in principle, close to a linear function of the total traction motor power.

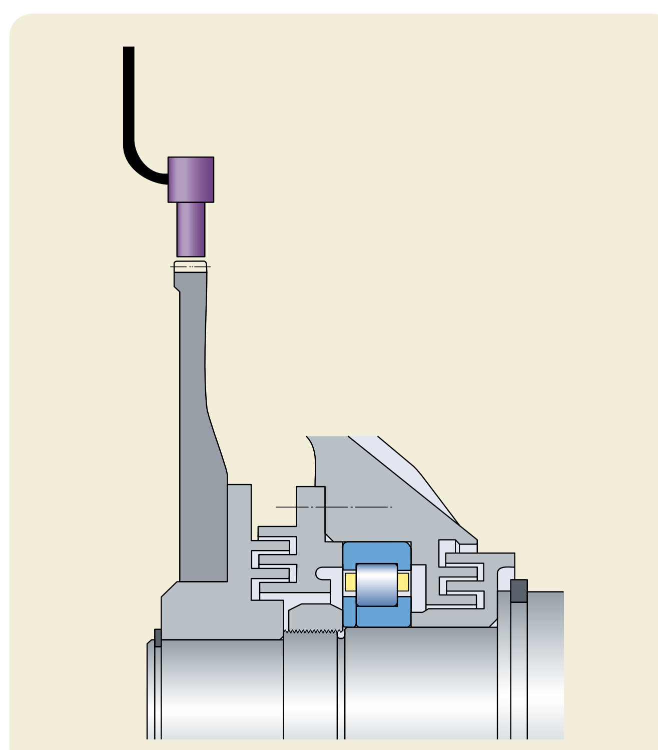
The basic idea for the implementation of a sensorized TMBU is to substitute:

- the toothed wheel mounted on the traction motor shaft and the sensor mounted into the intermediate housing of the traction motor
- the cylindrical roller bearing, which often is oversized
- the labyrinth seal on both sides of the cylindrical roller bearing

Classical design of a non-drive side arrangement of a traction motor



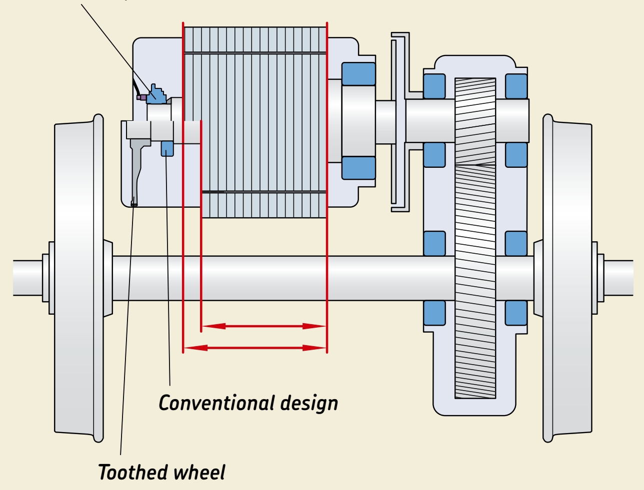
Substituted parts of a classical design when incorporating a TMBU: impulse ring sensor, cylindrical roller bearing and two sealing systems



TMBU concept

The TMBU concept includes a pre-lubricated and sealed bearing unit based on a deep groove ball bearing design. This is used for the non-drive side of the traction motor (→ chapter 5).

The rotating impulse ring is directly flanged on the TMBU and the sensor is fixed on the outer ring.



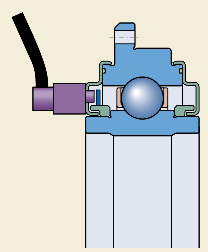
Comparison of the active rotor length

Implementation

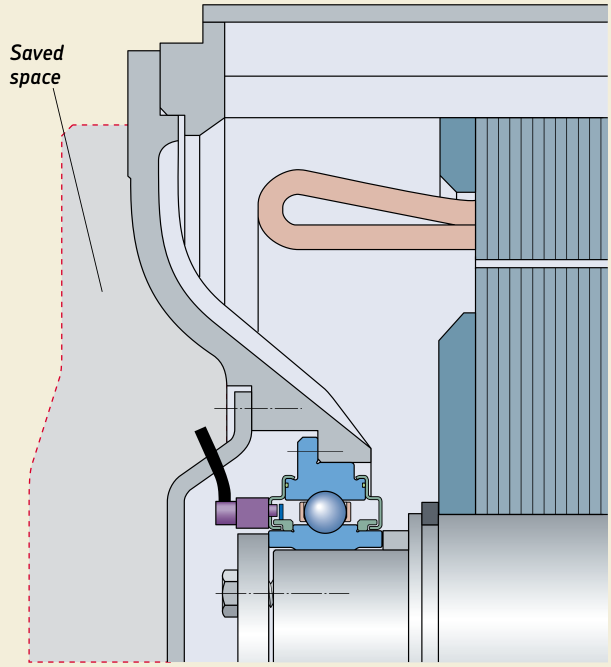
The TMBU is incorporated into the traction motor design, which enables the manufacturer to save space in the axial direction. Therefore, the total length of the traction motor, including the active rotor length, can be increased and a higher power rating achieved.

The TMBU is fitted onto the rotor shaft and then the intermediate traction motor housing is fitted on the flanged outer ring. The pre-mounted assembly is axially moved into the traction motor stator. For further details, see chapter 10.

Traction motor bearing unit (TMBU)



Implementation example



8

Hybrid traction motor bearing unit equipped with a speed sensor

Speed sensors

The sensor unit includes a code ring, which is linked with the rotating inner ring of the bearing. This code ring is magnetized with a sequence of north and south magnetic poles. Magnetic field sensors inside the sensor body detect a change in the magnetic field and convert this into digital signals.

Each rotation of the shaft produces a predefined number of pulses. The sensor also provides rotational speed and incremental output.

Speed sensor – technical data

Mechanical data

	Min.	Typical	Max.	Unit
Cable lengths	–	Customized	–	m
Mounting position		Radial[1]		
Connector		Open end as standard, customization possible		

[1] axial on request

Electrical data

	Min.	Typical	Max.	Unit
Supply voltage	4,75	12	30	V
Supply current	15	28	40	mA
Push-pull output[1]	0		0,8	V
(load = 20 mA)	V_b –2,5 V		V_b	V
Sensor accuracy over speed and temperature range	–0,1		+0,1	°
Sensor resolution	122	[2]	7 808[3]	ppr
Permissible rotational speed	0		10 000	r/min
Measuring range	0		360	°

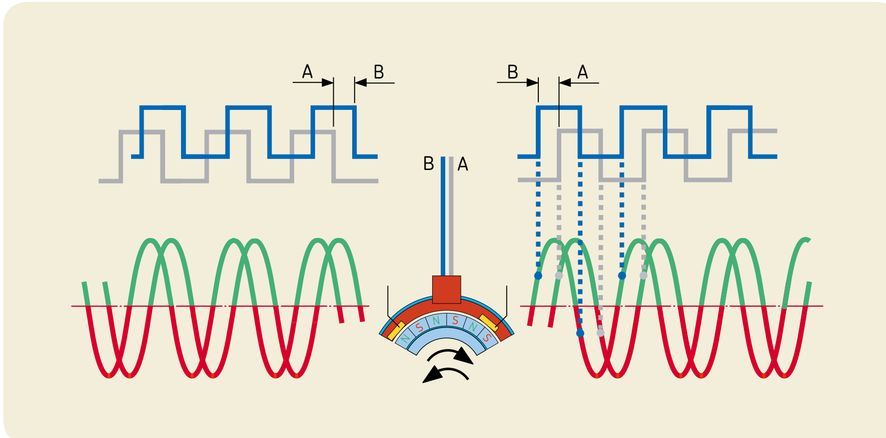
[1] Output like RS485 also available
[2] Depends on bearing size
[3] Valid for bearing size with a bore of 65 mm. Bigger sizes enable higher resolution.

Environmental data

	Min.	Typical	Max.	Unit
Operating temperature	–40	20	+125	°C
CE/EMC	According to EMC directive 2004/108/EC, harmonized standard EN 50121-3-2 (2006) Railway			
Protection class		IP 67		
Shock and vibration	According to EN 61373 class 2			

8

The output from the speed sensor is two square pulse signals with a 90° phase difference, which enables the direction of rotation to be determined.



Direction of rotation detection

The speed sensor has 2 outputs: A and B. Due to the phase shift between the A and B outputs, the direction of rotation can be defined as well. The absolute position sensor has a serial data output that provides the angle in a binary format. Other output is available on request.

SKF integrated sensors provide speed and incremental or absolute position information. Due to the integration of the sensor into the bearing, it is a very robust solution. Both the electronics and mechanics are well protected from the harsh environment.

SKF sensor bearings and units incorporate bearing functions and sensor electronics. The integrated incremental sensor is capable of detecting shaft speed and direction of rotation with high resolution and accuracy.

The number of output pulses is up to 64 times the number of code ring poles. The number of poles depends on bearing diameter, e.g. 122 for a deep groove ball bearing 6213. Additionally, an option reference position as well as temperature or redundancy of the speed and direction sensor are possible. It is a non-contact sensing principle that helps to ensure a long operational life. The SKF integrated incremental sensor is highly resistant to electromagnetic disturbances and thus generates reliable output.

Integration with rolling bearings starting with a bore size of 65 mm offers a number of benefits for many industrial applications such as traction motors, electrical motors, and gears.

Speed and absolute position sensors

For more sophisticated AC propulsion systems used for traction motors, absolute position detection of the rotor with a very high accuracy is required. SKF has developed a completely new sensor technology to achieve a position accuracy of ±0,075% over a 360° circumference. The resolution can be, for example, 5 632 pulses per revolution. This sensor system can be used for through-shaft applications as well as for end-of-shaft applications. The complete sensor unit is tested according to the railway standard, EN 61 373, to validate its shock and vibration performance. Electromagnetic compatibility is in accordance with the international standard. The sensors are CE marked to indicate conformity with the essential health and safety requirements set out in European directives.

SKF sensor bearings and units incorporate bearing functions and sensor electronics.

The integrated absolute position sensor HAPS (high resolution absolute positioning sensor) is capable of detecting shaft position with high resolution and accuracy.

The sensor is optimized for motor encoding applications and provides the absolute rotor position within a rotor pole. This sensor unit can be customized for an optimal fit to meet the customer needs [33].

Options are temperature sensor, speed sensor IIS (integrated incremental sensor) or redundancy of the position, speed and direction sensor. Since it is a non-contact sensing design, this helps to provide a long operational life. The SKF integrated incremental sensor is highly resistant to electromagnetic disturbances and generates reliable output. Integration with rolling bearings offers a number of benefits for many industrial applications such as traction motors, electrical motors, gears, etc.

The position sensors are calibrated by SKF and ready for installation – zero setting.

Hybrid traction motor bearing unit equipped with a speed sensor and absolute position sensor

8

Speed and absolute position sensors – technical data

Mechanical data

	Min.	Typical	Max.	Unit
Cable lengths	–	Customized	–	m
Mounting position		Axial		
Connector		Open end		

Electrical data

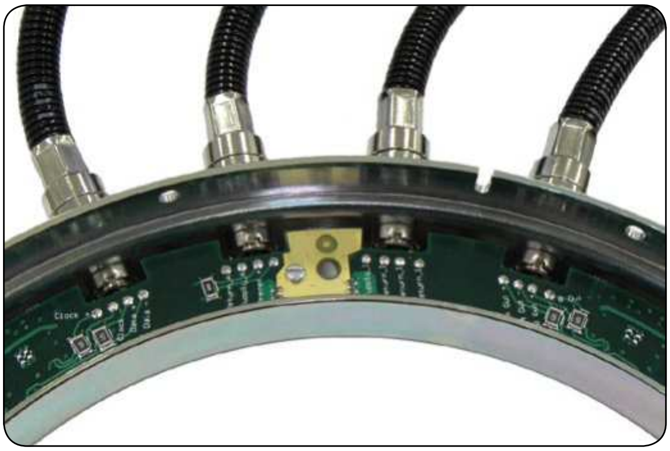
	Min.	Typical	Max.	Unit
Supply voltage (HAPS, IIS)[1]	10	12	30	V
Supply current (HAPS)	40	140	200	mA
Supply current (IIS)	15	50	100	mA
Output[2]	RS485 compatible output			
Sensor accuracy (HAPS)	–0,075		+0,075	%
Sensor accuracy (IIS)	–1		+1	%
Sensor resolution (HAPS)		5632[3]		ppr
Sensor resolution (IIS)		440[3]		ppr
Permissible rotational speed	0		750[4]	r/min
Measuring range	0		360	°

1) HAPS = High resolution absolute position sensor, IIS = Integrated incremental sensor
2) HAPS angle is provided by a data frame, other outputs on request.
3) Full rotation sensor resolution optimized for application.
4) Higher speeds not tested yet.

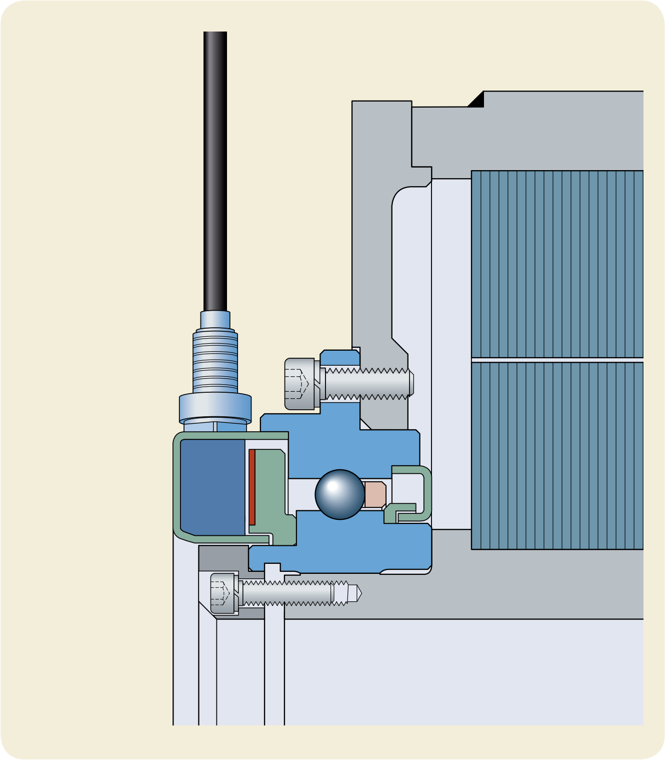
Environmental data

	Min.	Typical	Max.	Unit
Operating temperature	–30[1]	20	+105	°C
CE/EMC	According to EMC directive 2004/108/EC, the sensor meets the harmonized standard EN 50121-3-2 (2006) Railway			
Protection class		IP 67		
Shock and vibration	According to EN 61373 class 2			

1) Lower minimum temperature design can be offered on request



Sensor equipment for absolute position detection



Traction motor equipped with TMBU and absolute position detection sensor

8

9 Condition monitoring

Condition monitoring

Condition monitoring is a mature technology, offering new capabilities to increase safety and reliability as well as to extend maintenance intervals. Using condition detection systems and applying sophisticated algorithms for data processing, can detect incipient damage. This provides sufficient time for repairs, before significant mechanical damage or failures occur.

Capabilities

Condition monitoring is the process of monitoring parameters of condition in machinery. The interpretation of the data is based on a significant change that could indicate damage that is developing into failure. This process forms the basis for a predictive maintenance routine. It enables maintenance staff working with a condition based maintenance routine to take actions that minimizes the possible consequences of failure, before these failures occur.

Instead of traditional mileage and time based maintenance, the condition based maintenance can be applied to utilise the maximum performance of the components. The maintenance intervals for drive systems can be based on the real wheel life when a complete bogie overhaul could be planned so as to optimize maintenance costs. The SKF Multilog online system IMx-R for railway condition monitoring can be used as a tool to provide reliability and safety when extending maintenance intervals.

Condition monitoring is an available technology offering new capabilities for drive systems. The railway industry is very much interested in taking a proactive approach with a goal of reaching economical and safety targets.

Developed exclusively for railway applications, the SKF Multilog online systems such as the IMx-R offer a functional and cost-effective alternative. Using several modular sensors which monitor and transmit a range of bogie operating condition data simultaneously, the SKF Multilog IMx-R works with SKF @ptitude Observer software as a complete mechanical condition monitoring and protection system.

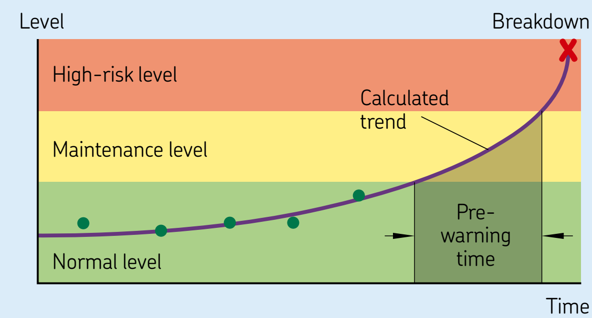
Along with enabling incipient damage detection, the SKF Multilog IMx-R generates automatic advice for corrective actions to be taken for the existing or impending conditions. The system also provides automatic load- and speed-dependent warnings and alarms. This initiates on-board and external communications, data processing for automatic diagnosis and root cause analysis. In addition, the date can be used as links to maintenance management systems for scheduling, spare parts and work order management and end-user, system and web-based data access.

Traction motor and gearbox components such as bearings, toothed wheels and rotor bars, may also be monitored, as well as shafts and couplings, using vibration sensors as part of the bogie condition monitoring system. Gearbox oil temperature and level can be included in the bogie condition monitoring system. Vibration signatures from propulsion components vary, depending on the actual traction effort applied. This means that information about train speed and load needs to be considered in the data processing, together with certain geometric parameters and gearbox ratio.

Drive systems condition monitoring may be part of a complete bogie monitoring system that detects further parameters such as bogie hunting, wheel condition and axlebox bearing(s) condition.

Bogie condition monitoring includes sensors for the detection of running instability, in accordance with the requirements of the European Technical Specification for Interoperability (TSI) Directive 96/48 EC. The TSI stipulates that the monitoring of the running stability must be continuous or at a frequency to provide reliable and early detection of damage. For Class 1 trains, the system must also be linked to the onboard juridical recorder unit (JRU) in order to enable traceability request. Further information can be found in the SKF *Railway technical handbook, Volume 1*, **chapter 8** [34, 35, 36].

All rotating components of a bogie produce typical vibration spectra. This makes it possible to identify each component via the frequency separation analysis.

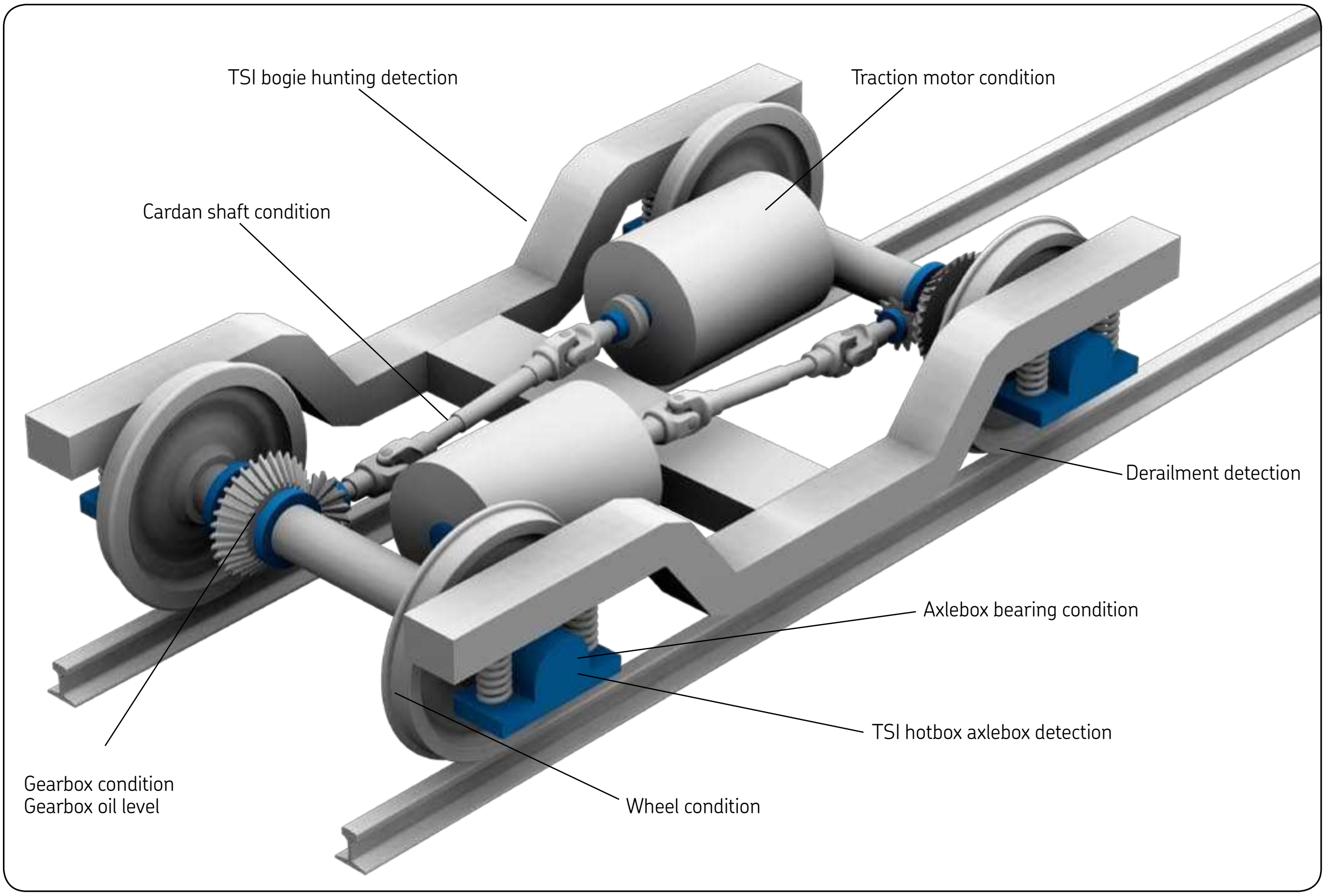


Failure protection via trend observation

Bogie condition monitoring capabilities

Capabilities and functions related to drive systems

Subsystem	Detection parameters
Wheel	Wheel profile/out of roundness
Axlebox bearing(s)	Temperature Relative temperature in comparison to other axlebox bearings Early bearing damage Vibration levels
Gearbox (transmission)	Bearing temperature Early bearing damage Unbalance Misalignment Shaft deflection Loose parts Vibration levels Damaged gear wheel Resonances
Gearbox oil	Oil temperature Oil level
Traction motor	Bearing temperature Early bearing damage Vibration levels
Cardan shaft	Unbalance Damaged coupling



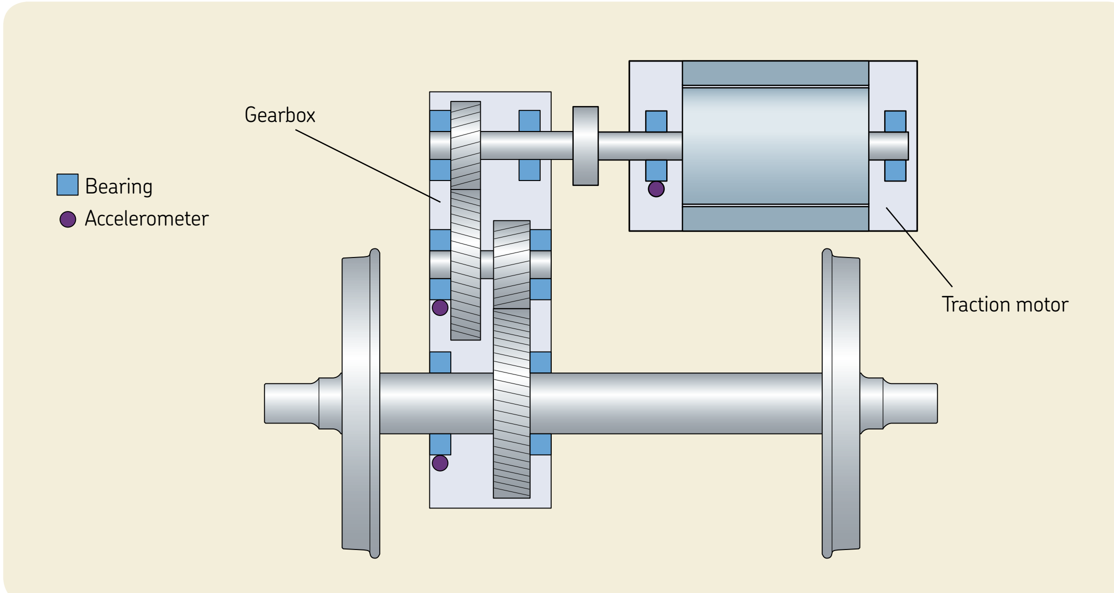
Drive systems condition monitoring may be part of a complete bogie monitoring system, which detects further parameters like bogie hunting, wheel condition and axlebox bearing condition [1]

Condition monitoring benefits

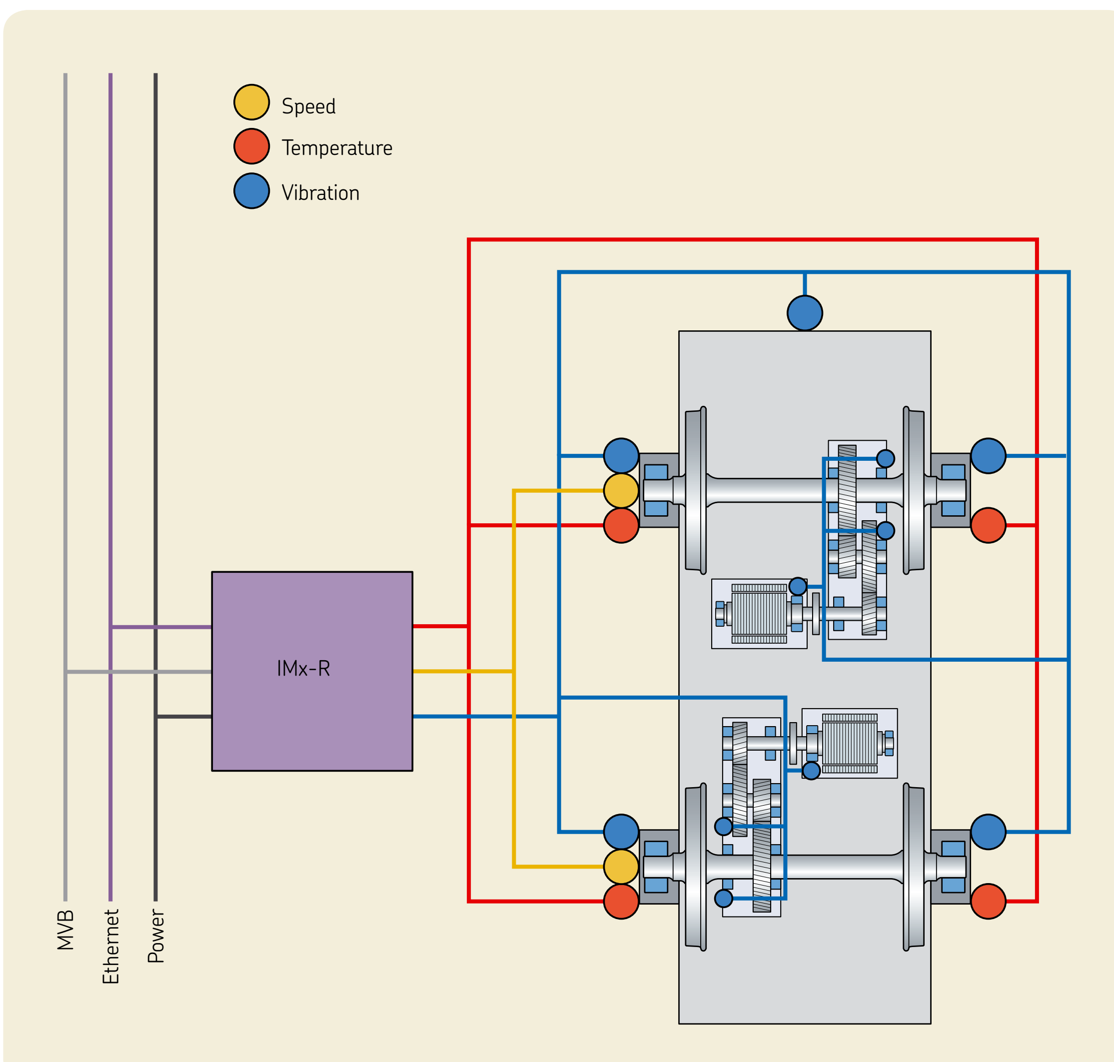
- increased vehicle service reliability
- reduced maintenance costs for the operator:
  - reduction of operational costs, because of damage detection in a very early stage, enabling an optimized maintenance schedule
  - reduction of vehicle standstills
  - reduced need for maintenance
  - reduction of maintenance overtime work
- optimization of spare part logistics

9

Schematic illustration of a gearbox and traction motor with a reduced number of vibration measurement points, meaning only one sensor per gearbox and per traction motor. This arrangement is more cost-effective, but potential failures are only detected in a more progressed stage.



IMx-R system design of vibration monitoring and diagnostic of bogie hunting and axleboxes and, additionally, axlebox hotbox detection



IMx-R online system

The SKF Multilog IMx-R online system is the latest generation of powerful, cost-effective solutions for railway vehicles. Together with SKF @ptitude Observer software, the IMx-R provides a complete system to improve machine reliability, availability and performance. This is done by providing early damage detection and automatic advice for correcting existing or impending conditions and advanced condition-based maintenance.

In addition to the analogue channels, four digital channels are used for measuring speed, trigger or digital status, such as indicating when a measurement can take place. Several measurement points may be attached to one channel. Both AC and DC measurements can be measured on the same channel. Individual conditions for warning and alarm may be set for each point. Warning and alarm levels may be controlled by machine speed or load.

The IMx-R works as a mechanical condition monitoring and protection system with several other units in a network with the SKF @ptitude Observer monitor. The system can even run in an existing LAN, together with other computers, printers, servers, etc. or over the Internet.

The unit's unique built-in hardware auto diagnosis system continuously checks all sensors, cabling and electronics for any damage, signal interruption, shortcuts or power failure. Any malfunction triggers an alarm. In the case of system power failure, the system will automatically restart when the power returns.

SKF Multilog IMx-R online system

Monitoring principles

Bearing damage frequencies are generated by the impact of the rolling elements on a spall (very small piece of material removed) on the outer or inner ring; a spall on a rolling element can also generate a specific frequency. The cage frequency is based on the angular rotational speed of the cage that optimally coincides with the rotational speed of the centre of the rolling elements. The amplitude of the cage frequency is normally very low on the vibration spectra, but it is more evident if one considers high rotational speed machines operating at 6 000 r/min. In this case, the amplitude is strongly related to the clearance in the bearing and to the circularity of the housing.

The following explanation is based on an application with a rotating inner ring and a stationary outer ring, which is the most common case.

Because all the four frequencies are proportional to the inner ring speed, they are normalized, considering a fixed inner ring speed of one hertz. To obtain the actual defect frequencies, the rotational frequency of the shaft should be multiplied by the values resulting from the formulae mentioned in the table.

SKF enveloping technique

The SKF enveloping technique is basically a demodulation process that filters out the exponentially damped part of the signal that is produced during the impact of the rolling elements on a spall on the inner or outer ring of the bearing. The SKF enveloping principle is based on the Hilbert Transform[1].

In principle, the envelope is the module of the analytical signal associated with the real signal.

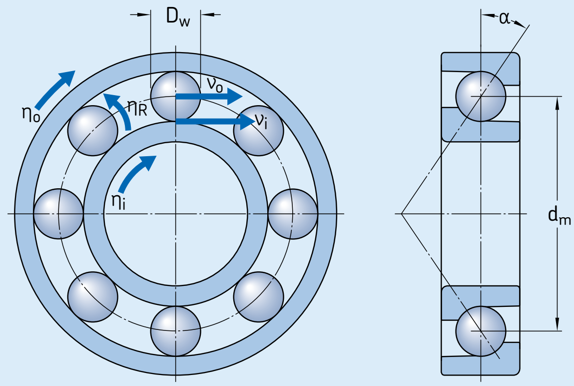
This method enables to display a sequence of pulses equally spaced of the frequency of interest.

The bearing signal is normally hidden in the structure of the vibration signal because of the high amplitude of the vibration due to unbalance, misalignment etc. To make the SKF enveloping effective, a band pass filter is applied to cancel the part of the signal due to this type of structural vibration.

The acceleration SKF enveloping process groups energy related to the bearing damage harmonics and excludes all others. The practical result is to enhance a signal formed by a sequence of periodic pulses.

1) named after David Hilbert (1862–1943)

Ball pass inner/outer ring raceway and ball spin frequencies



Ball pass frequency of the inner ring (BPFI)

$$BPFI = \frac{z}{2}\left(1 + \frac{D_w}{d_m}\cos\alpha\right)$$

where
BPFI = ball pass frequency of the inner ring, the frequency at which the rolling elements pass the inner ring raceway. Indicative of inner ring raceway damage (crack or spall)
z = number of rolling elements in each row of rolling elements
D_w = rolling element diameter
d_m = rolling element pitch diameter
α = contact angle

Ball pass frequency of the outer ring (BPFO)

$$BPFO = \frac{z}{2}\left(1 - \frac{D_w}{d_m}\cos\alpha\right)$$

where
BPFO = ball pass frequency of the outer ring, the frequency at which the rolling elements pass the outer ring raceway. Indicative of outer ring raceway damage (crack or spall).

Ball spin frequency (BSF)

$$BSF = \frac{d_m}{2D_w}\left[1 - \left(\frac{D_w}{d_m}\cos\alpha\right)^2\right]$$

where
BSF = ball spin frequency, the frequency at which a rolling element rotates in the bearing. Indicative of individual rolling element damage

Fundamental train frequency (FTF)

$$FTF = \frac{1}{2}\left(1 - \frac{D_w}{d_m}\cos\alpha\right)$$

where
FTF = fundamental train frequency, the frequency at which the cage that contains the rolling elements rotates. Indicative of cage damage

9

Technical description

The IMx-R is designed to operate worldwide in typical railway environments, as defined in customer specifications, railway operator standards and international standards. The IMx-R complies with EN 50155 regarding electromagnetic compatibility (EMC), shock and vibration levels as well as ambient temperatures.

Parameter	Condition
Ambient temperature	EN 50155, class TX
Humidity	Max 95% condensed
EMC	In accordance with EN 50121-3-2. Maximum noise level during test: sensor sensitivity 100 mV/g and hot axlebox bearing detection HABD = 2 °C
Altitude	In accordance with EN 50155, usage up to 1 200 m altitude
Vibration and shock	In accordance with EN 61373, category 1B
Encapsulation	IP20 (EN 60529)
Power supply	Power supply interruptions in accordance with EN 50155, chapter 3.1.1.2, class S2

IMx-R design details

- in accordance with TSI regulations UIC 515-1
- SIL Safety Integrity Level 2 on request (measurement of performance required for a safety instrumented function)
- mounted in a 19" rack
- true simultaneous measurement of all channels
- multi-parameter gating
- SKF acceleration enveloping
- adaptive alarm levels
- data buffering in non-volatile memory when communication is down
- output relay drivers
- fully supported by SKF @ptitude Observer

IMx-R reference standards

Document number	Document title
EN 50155	Railway applications – Electronic equipment used on rolling stock
EN 50126	Railway applications – The specification and demonstration of reliability, availability, maintainability and safety (RAMS)
EN 50128	Railway applications – Communication, signalling and processing systems - Software for railway control and protection systems
EN 50129	Railway applications – Communication, signalling and processing systems – Safety related electronic systems for signalling
EN 61373	Railway applications – Rolling stock equipment – Shock and vibration tests

Sensors for condition monitoring

In addition to the SKF Multilog IMx-R condition monitoring system and the SKF @ptitude Observer software, SKF offers several solutions to detect operational parameters like speed, temperature and vibration.

Sensorized traction motor bearing units are already mentioned in **chapter 8**.

The speed signal can also be monitored on the wheelset by using SKF Axletronic solutions [37, 38], for additional information refer to the SKF *Railway technical handbook*, *Volume 1*.

Hybrid traction motor bearing units
Left: equipped with a speed sensor (→ ***page 184***)
Right: equipped with a speed and an absolute position sensor (→ ***page 187***)

SKF Axletronic sensorized axlebox bearing unit

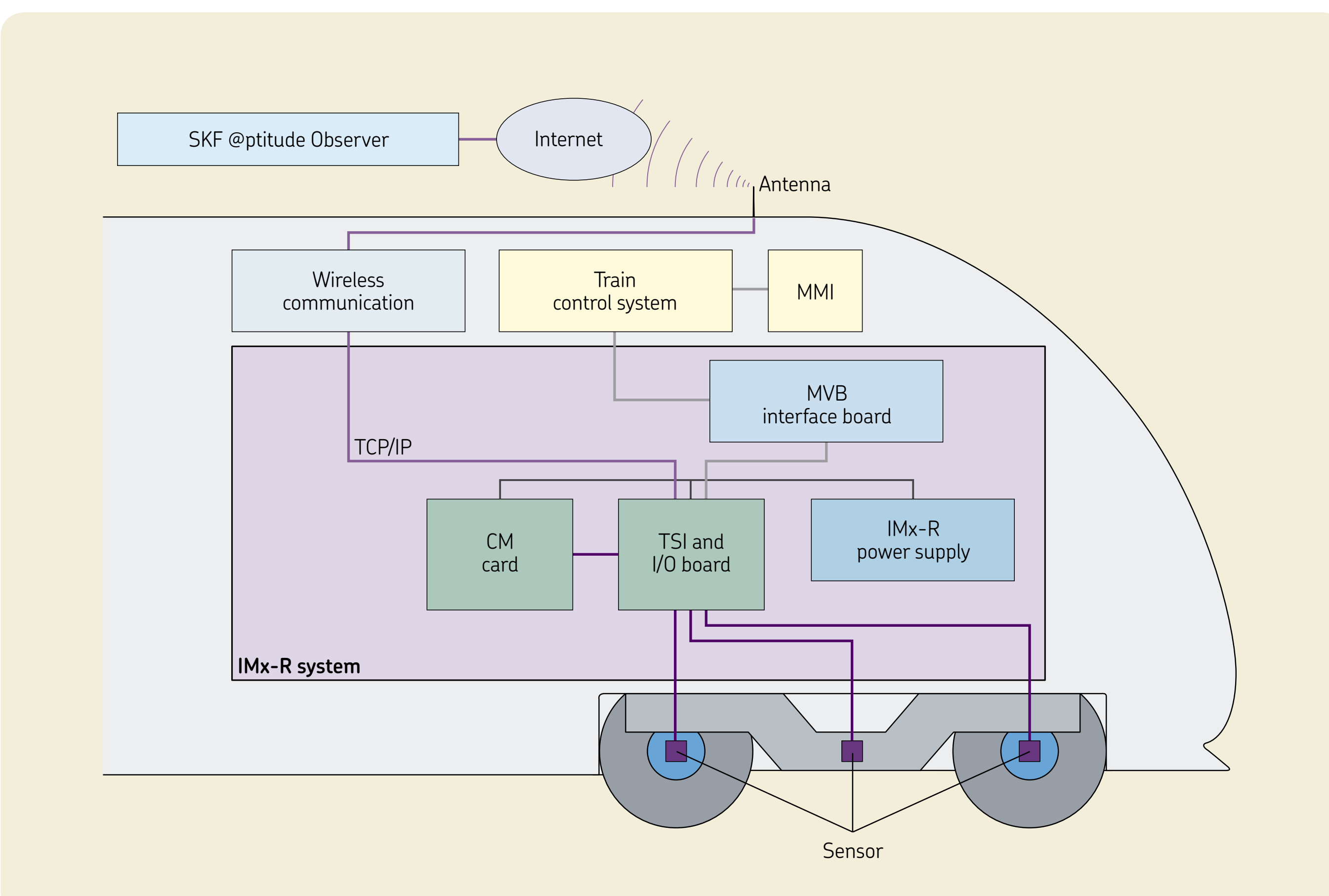
Axlebox equipped with a front cover and AXLETRONIC sensors

SKF @ptitude Observer analyse software

One task for the IMx-R is to monitor and timely report bearing temperatures when observed in accordance with TSI. In addition, the IMx-R is able to monitor the condition of wheelsets, axleboxes, traction motors, gearboxes and cardan shafts.

The hot box axlebox detection and bogie hunting detection and condition monitoring results are stored in the SKF @ptitude Observer database. Results from the IMx-R units are further processed by the SKF @ptitude Observer machine diagnostics into machine condition results such as trends and clear text messages showing detected machine damage. These results can be easily accessed using the SKF @ptitude Observer software.

IMx-R monitoring system and its boundaries



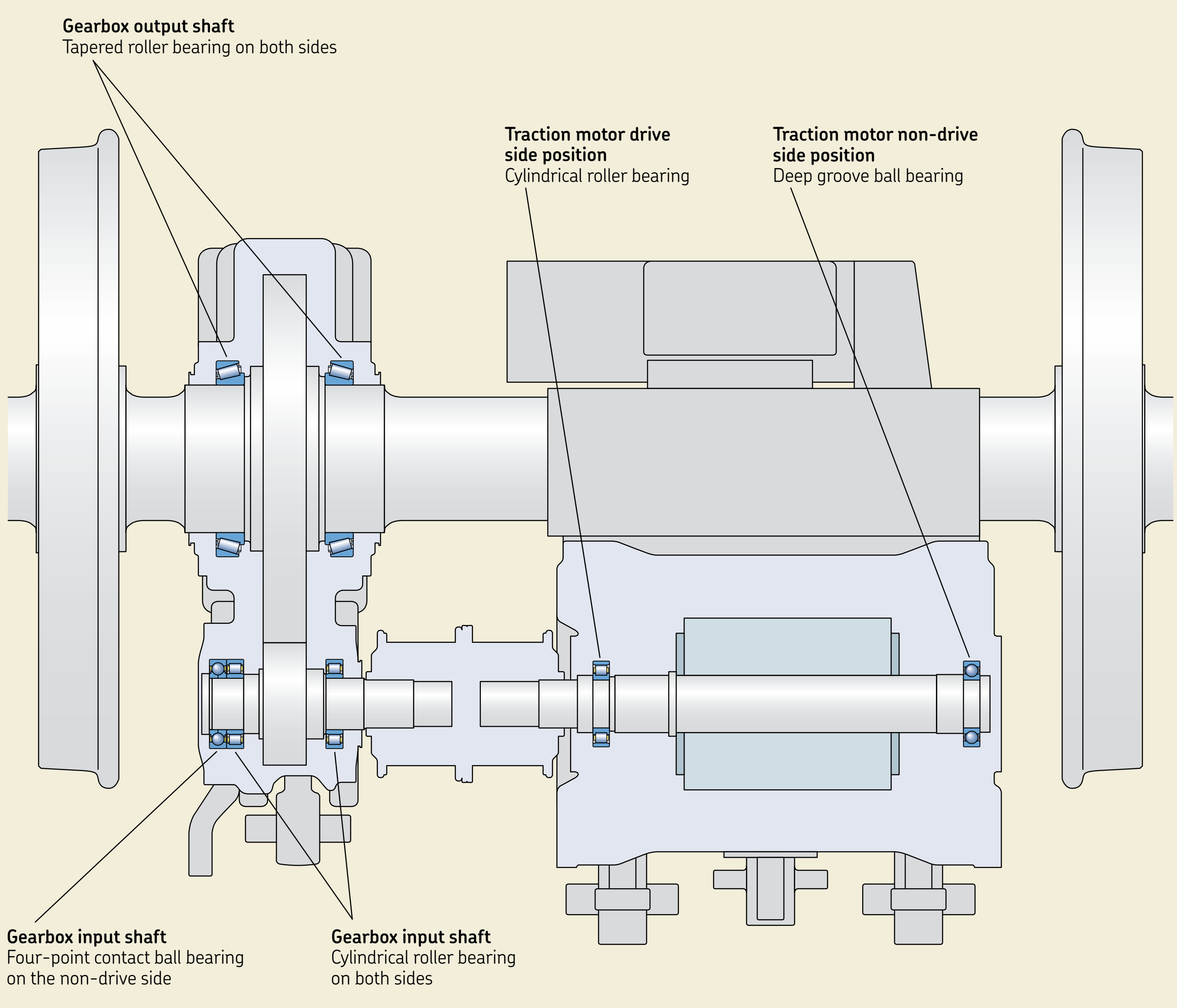
Validation testing

To validate the condition monitoring data provided by the IMx-R system, extensive research [39] has been conducted with real drive systems. Main efforts were put into reproducing the very heavy noisy and dynamic behaviour conditions of the operation of the traction system measured in train service. The test-rig was developed to reproduce the kinematics of the suspension and the vibration caused by vehicle and track condition interaction. The long term test was based on different operating conditions, such as motor torque and speed. The relative movements between the traction motor and the axle mounted gear in vertical, lateral and longitudinal direction were simulated.

Acknowledgements

The authors would like to thank Bombardier Transportation for granting permission to publish details from the report as mentioned in the references under [38].

Drive system validation testing arrangement



9

Typical bearings that had been operating in the field, as well as several intentionally and artificially damaged bearings, were tested in the laboratory. As very typical for these applications, the gearbox bearings were lubricated with oil and the traction motor bearings with grease.

These examples of traction motor and gearbox validation testing confirmed the capability to identify the condition of bearings installed. In total, 43 different cases of damaged and non-damaged bearings were tested under very different operating conditions such as speeds, direction of movement and loads. All bearing damage was detected with the IMx-R system. These tests were done by Fondazione Politecnico di Milano, Italy, Joint Research Centre for Transportation at the Milano University, which is an authorized independent research institute [39].

Validation testing key findings in brief

- The SKF Multilog IMx-R system is capable of detecting bearing damage under many different operating conditions.
- Heavier bearing loads increase both the visibility and the stability of the damage indicators.
- Temperature affects the ability to detect the damage, depending on the type of lubricants such as oil and grease. For instance, grease could hide small damage at low bearing temperature, i.e. at the beginning of the test.
- The research also made clear that general indexes such as local temperature are insufficient to detect a failure at an early stage, making the installation of accelerometers necessary.

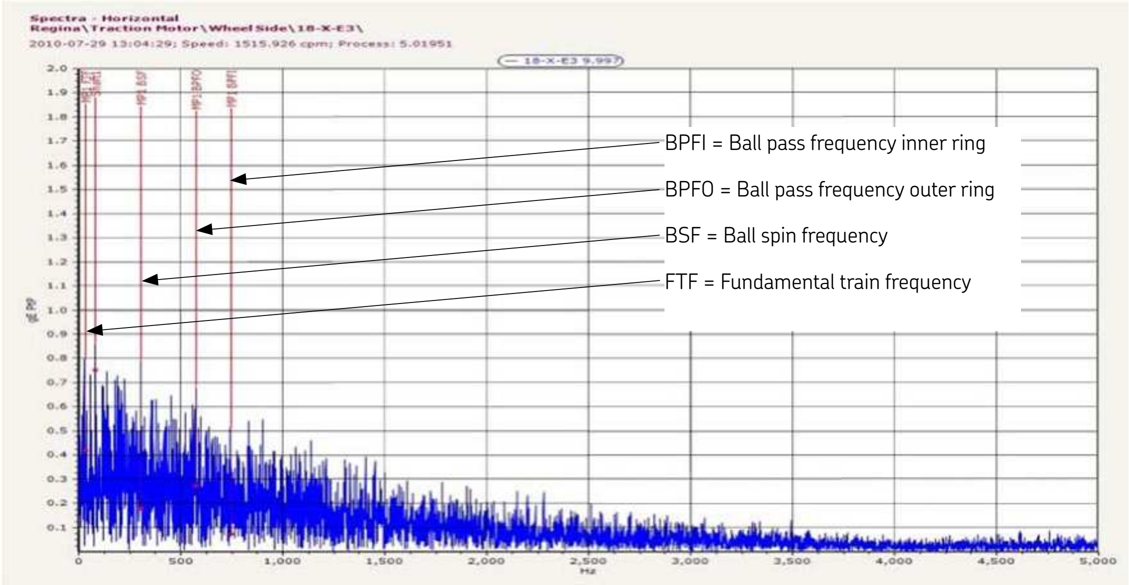
Traction motor bearing validation testing

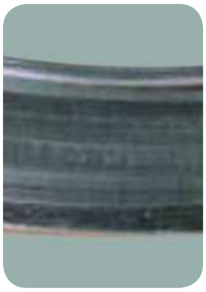
Drive side position cylindrical roller bearing

The traction motor bearing at the drive position was taken from the field, cleaned, relubricated and reused for the validation testing.

The frequency diagrams below show no relevant peaks which confirms the good bearing condition.

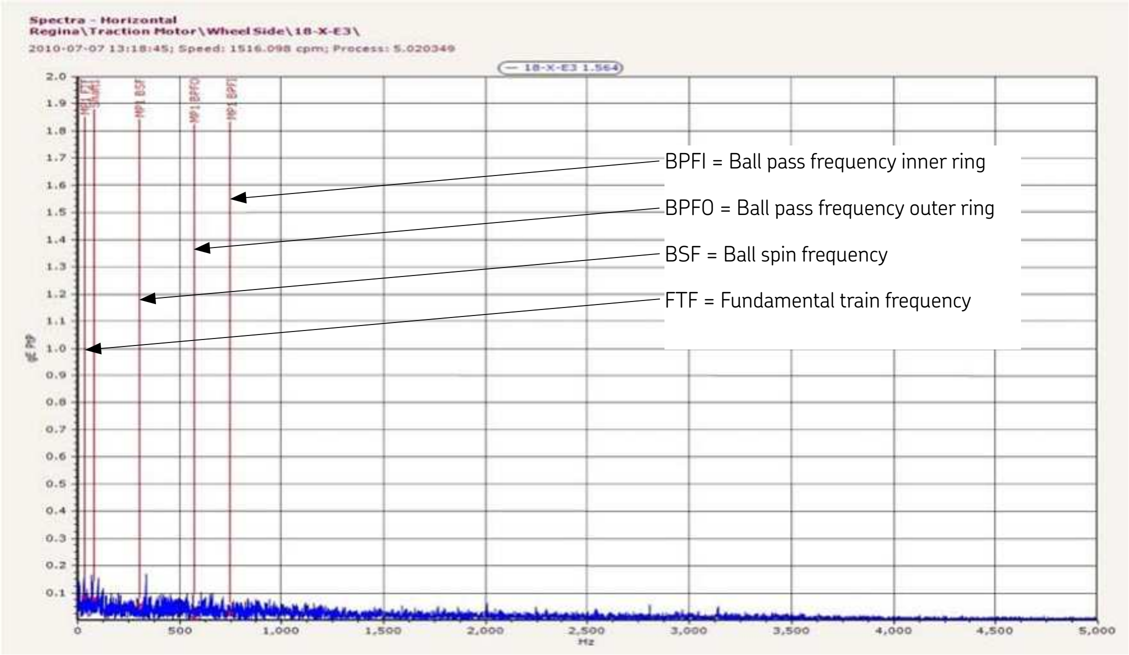
Inner ring





Outer ring

Cage and roller assembly

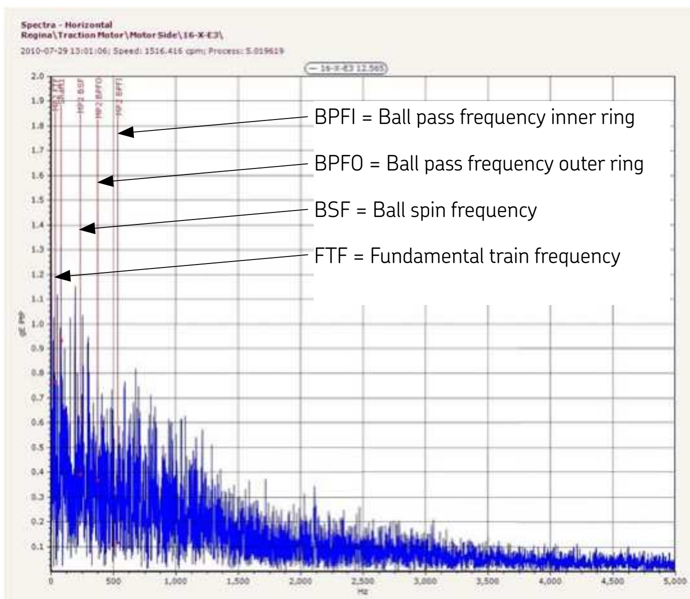


Non-drive side position deep groove ball bearing

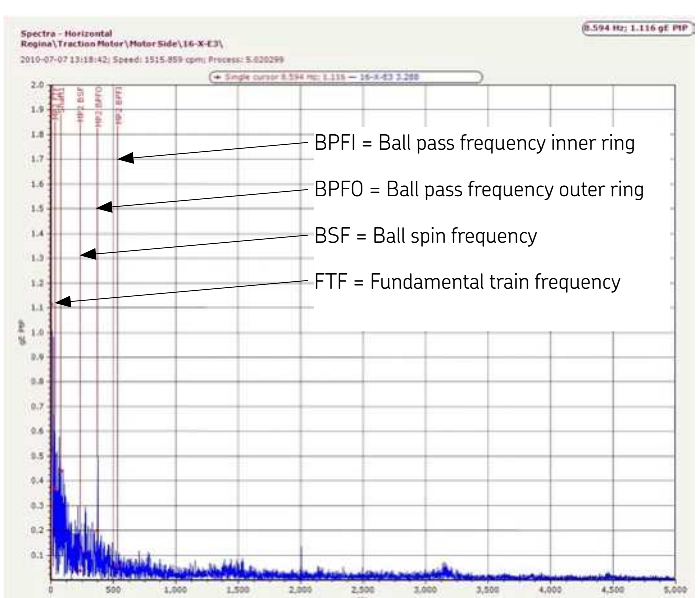
The traction motor bearing at the non-drive position was taken from the field, cleaned, relubricated and reused for the validation testing.

The frequency diagrams below show no relevant peaks which confirms the good bearing condition.

Inner ring



Outer ring



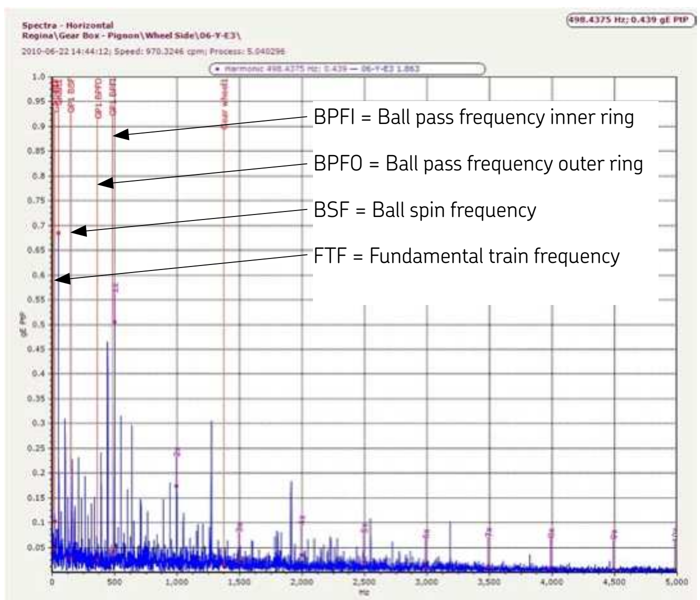
Balls

Gearbox bearing validation testing

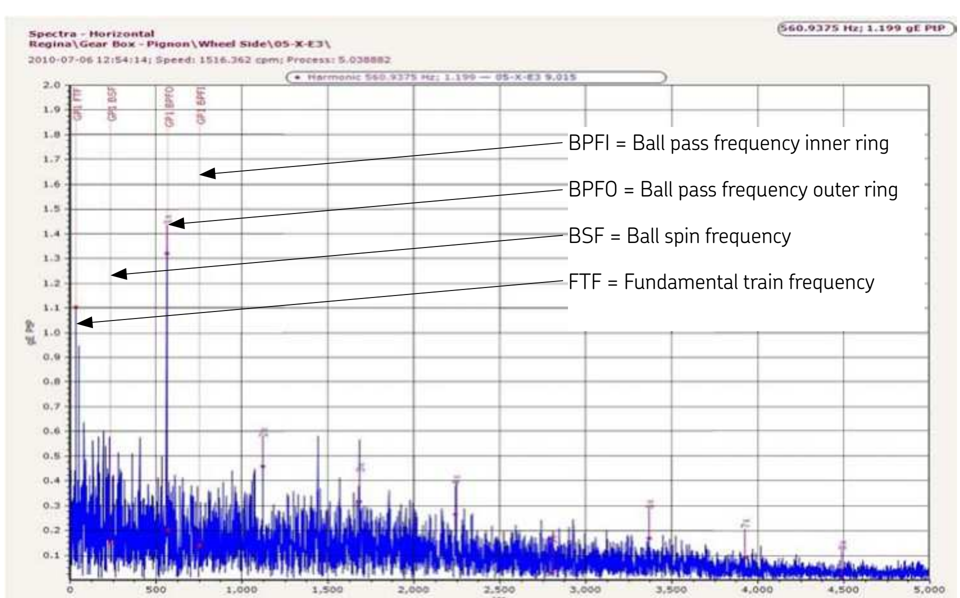
Input shaft position four-point contact ball bearing with damage

This bearing with damaged inner ring and balls was used to verify the result of the condition monitoring equipment. Both graphs show a relevant ball and inner ring related frequency in peaks.

Four-point contact ball bearing inner ring with damage



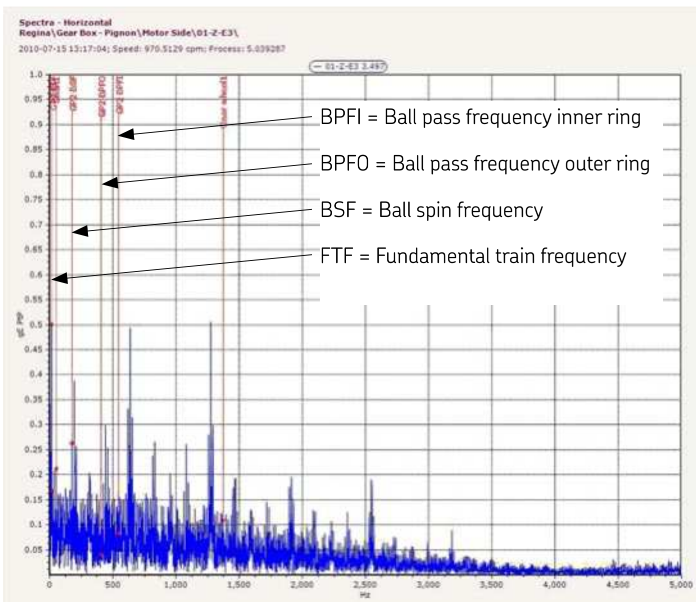
Four-point contact ball bearing components

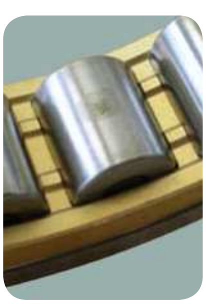


Input shaft position, cylindrical roller bearing with damage

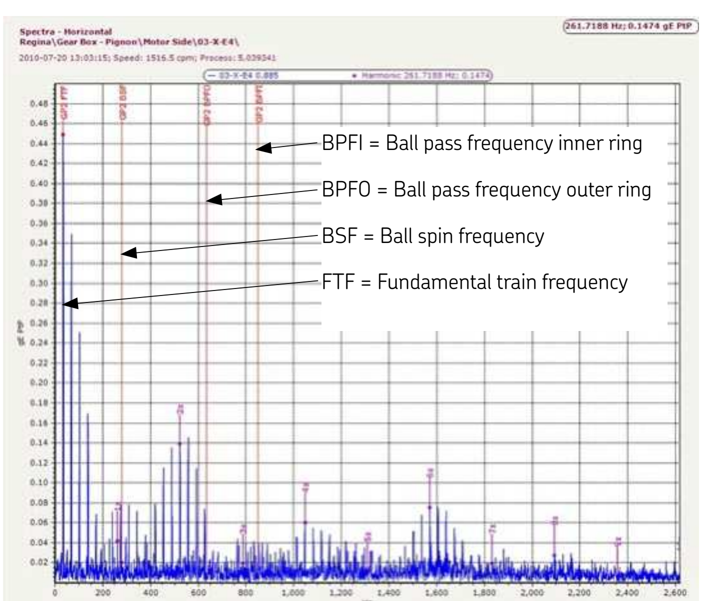
This bearing with artificial damaged roller and cage was used to verify the result of the condition monitoring equipment. Both graphs show a relevant roller and cage related frequency in peaks.

Cage damage





Roller damage



MICROLOG analyser

The SKF Microlog analyser range takes the difficulty out of performing condition monitoring by analysing vibration signal and process variables using up to four channels (model dependent). Add to this the option to carry out one or two plane static or dynamic couple balancing, transient analysis (bode, nyquist, waterfall and spectrogram), modal and operational deflection shape analysis and to record raw signals for further post processing, all as optional upgrade application means that the SKF Microlog analyser is an essential tool to assist the user in keeping assets running. Bearing assessments are carried out using the industry proven SKF Acceleration Enveloping (gE) technology. The SKF Microlog range utilizes the latest advances in analog and digital electronics, including digital signal processing (DSP) and high resolution sigmadelta A/D converters, to provide both speed and accuracy in the data collection process.

MICROLOG CMXA series

The SKF Microlog CMXA series of instruments are the most advanced analysers offered by SKF today. From the range of application modules available, it is apparent that the equipment is suitable for both an advanced power user and a novice.

Two hardware options are available, a larger screened 4 channel instrument or a smaller screened 3 channel instrument that can be configured to individual requirements. The analysers are supplied fully featured but to be cost-effective, and to make sure one pays only for what is needed, applications are activated by licence keys. This enables the user to complete the equipment in accordance with their needs and make sure upgrades are effected while the equipment is with the user.

SKF's Microlog range connects seamlessly with SKF @ptitude Analyst software for route based data analysis or to SKF Analysis and Reporting Module software for stand alone analysis.

Technical description

- simultaneous three or four channel measurements for fast data collection
- 806 MHz XScale Intel processor means faster real time rate and display updates
- rugged, dust/waterproof IP 65 design for reliability in industrial environments
- rechargeable lithium battery supports eight hours of continuous data collection
- 0,16 Hz to 40 kHz (smaller screen) 80 kHz (large screen) frequency range with up to 25 600 lines of resolution

SKF Microlog CMXA
Large screen
0,16 Hz to 80 kHz frequency range with up to 25 600 lines of resolution

SKF Microlog CMXA
Small screen
0,16 Hz to 40 kHz frequency range with up to 25 600 lines of resolution

Applications

Locomotives

The first bogie online condition monitoring application was introduced in 2001 with the installation of the earlier SKF MasCon16R railway system. SKF signed a long term contract with the Swedish MTAB iron ore railway operator to increase the reliability of 14 triple locomotives Dm3 type. They operate at the Swedish – Norwegian line Kiruna – Narvik. The aim was to increase reliability and to avoid unplanned stops caused by problems with equipment like axleboxes, traction motors and gearboxes. Before that, many mechanical breakdowns caused lost time and high costs to haul the trains with the defective locomotive on the single track line. During the SKF monitoring and scheduled maintenance, not one unplanned stop was registered. The locomotives were taken out of service in 2005 when a new locomotive generation started operation. With the SKF contract, MTAB drastically saved costs and increased vehicle reliability.

Vibration sensor arrangement in a Swedish MTAB Dm3 locomotive axlebox

Vibration sensor installation in a Swedish MTAB Dm3 locomotive traction motor/gearbox

Multiple units and mass transit vehicles

A wide range of applications are electrical and diesel multiple units as well as mass transit vehicles. These trains are typically equipped with a larger number of driven wheelsets and drive systems which all together have to be part of a reliable and safe system.

The extensive network of Barcelona Metro consists of several lines that run underground in central areas and above ground into the city's suburbs. Since December 31 2010, Barcelona Metro system has consisted of 8 lines and a funicular with 140 stations and 103 km track length in total.

Transportes Metropolitanos de Barcelona (TMB) has equipped some bogies (in different trains) of the series 5000 metro cars with a condition monitoring system. These very modern trains have a max. speed of 80 km and a total installed power of 2 000 kW. SKF contributed with bogie condition monitoring system engineering capabilities and supplied all equipment including all needed hardware, software and sensors. Mounting of the system was supervised and afterwards, system start up was also performed. The service package includes follow-up of alarms with remote data communication done by a UMTS system, as well as periodic report of the bogie status [40].

The installation performed in the bogies enables full bogie subsystem monitoring like gearbox, traction motor, coupling, axleboxes as well as wheel and rail condition interaction recording for bogie health recognition algorithm development.

In this case, special focus has been put on the traction motor and gearbox monitoring capabilities, to be able to detect:

- unbalance
- misalignment
- shaft deflection
- loose parts
- bearing damage
- gear wheel damage
- resonance

The signals from all bogie sensors installed are sent to the on-board monitoring unit, which has continuous reading and data processing. In case of alarm detection, the system sends an alarm immediately, otherwise the data are sent once per day to a remote server where data are stored for SKF condition monitoring services experts to analyse with SKF @ptitude Observer software. Transportes Metropolitanos de Barcelona has continuous access to bogie signals through the Internet, using a dedicated SKF application.

This system enables Transportes Metropolitanos de Barcelona to extend maintenance intervals and better plan the operations according to the condition of the bogie equipment. For those bogies equipped with the online monitoring system, it will have a positive effect in the following areas identified as drivers for this innovative and challenging customer project.

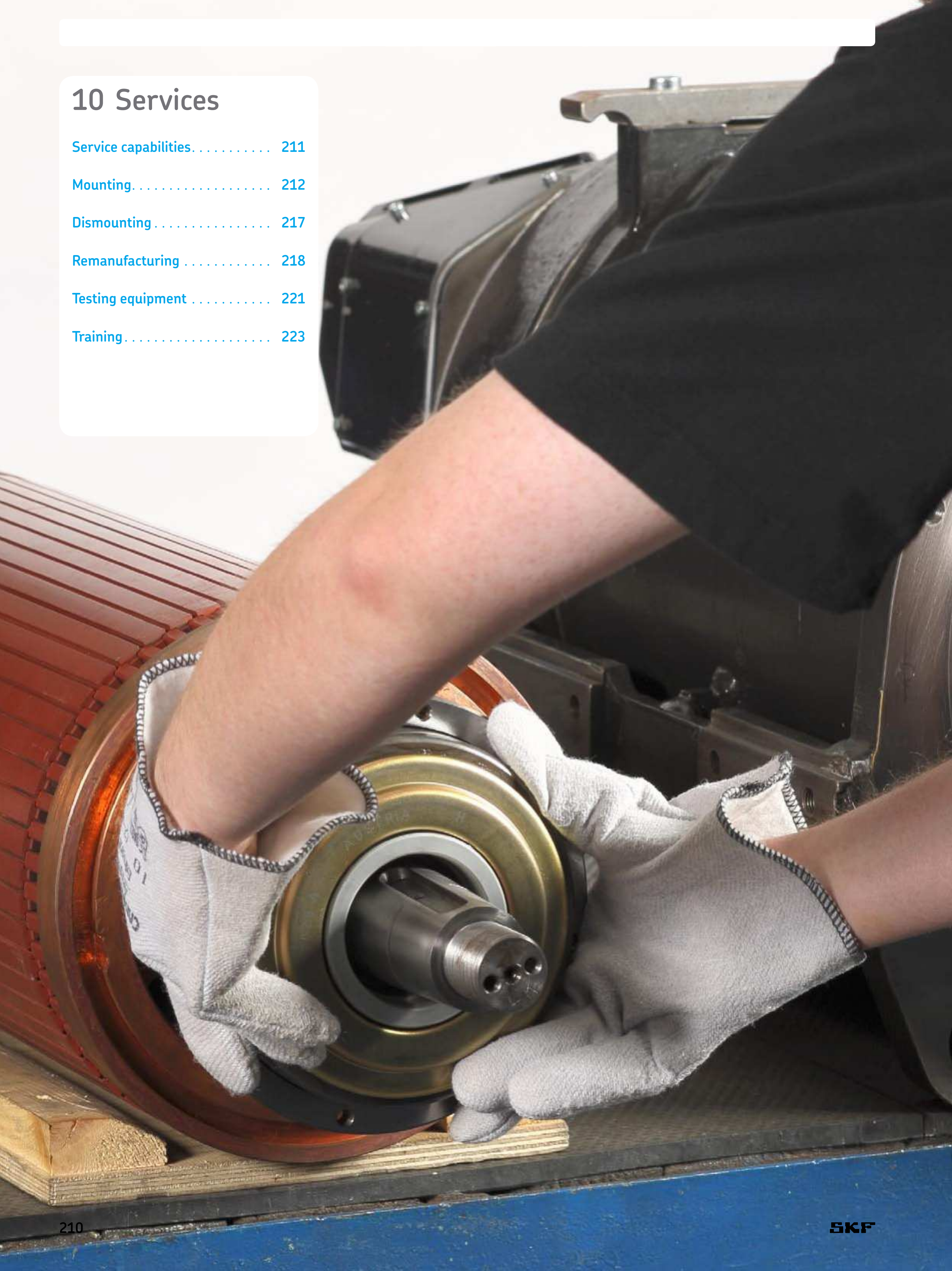
- increase vehicle reliability
- reduce the total costs of maintenance
- reduce operational costs because of problem detection in a very early stage, which enables optimization and scheduling of maintenance at a convenient time
- reduce vehicle standstills
- reduce the number of stops for train maintenance
- reduce maintenance overtime work
- optimize spare parts logistics

Monitoring packages

- Data submission:
  - Condition monitoring data based on IMx-R output
  - Data hosted by customer side server
  - Data analysed by the customer
- Data evaluation:
  - Condition monitoring data based on IMx-R output
  - Data hosted by SKF server
  - Data analysed by SKF condition monitoring centres
  - SKF provides constant status reports, either everything is OK or an error report

Metro Barcelona coaches in different trains are equipped with condition monitoring units

10 Services



Services

The unique global SKF railway network offers a range of services to the manufacturers of drive systems and train operators. Sales, service and application engineers provide technical assistance and organize service opportunities for SKFs customers. In addition, SKF remanufacturing units offer cost-effective and environmentally friendly solutions to railway customers.

Service capabilities

SKF services help manufacturers and operators to achieve safety, excellent performance and life cycle cost expectations.

Some selected service capabilities are:

- unique testing resources to validate reliability and safety requirements (→ **pages 97**, **125**, **221** and **222**)
- application engineering focused on specific customer specifications to achieve optimized solutions, providing maximum customer value
- on-site service engineering, which includes mounting and a bearing or bearing unit replacement service.
- remanufacturing options
- maintenance products such as mounting, dismounting and lubrication tools
- special training courses for customer's senior technical or project management staff as well as for shop floor staff to gain a deeper understanding about railway solutions which can help realize longer service life and utilization of bearings

Mounting

To achieve proper bearing performance and prevent premature failure, skill and cleanliness are necessary when storing and mounting bearings and bearing units. As precision components, rolling bearings should be handled carefully during mounting. It is also important to choose the appropriate method of mounting and to use the correct tools for the job.

Note

Always read complete instructions before mounting; general mounting instructions can be found in SKF catalogues or online at skf.com/bearings.

SKF provides several on-site service engineering options, training courses for shop floor staff and detailed mounting instructions for specific applications (→ page 223).

Mounting example

To give a brief overview, the example described and shown below illustrates the main mounting procedures.

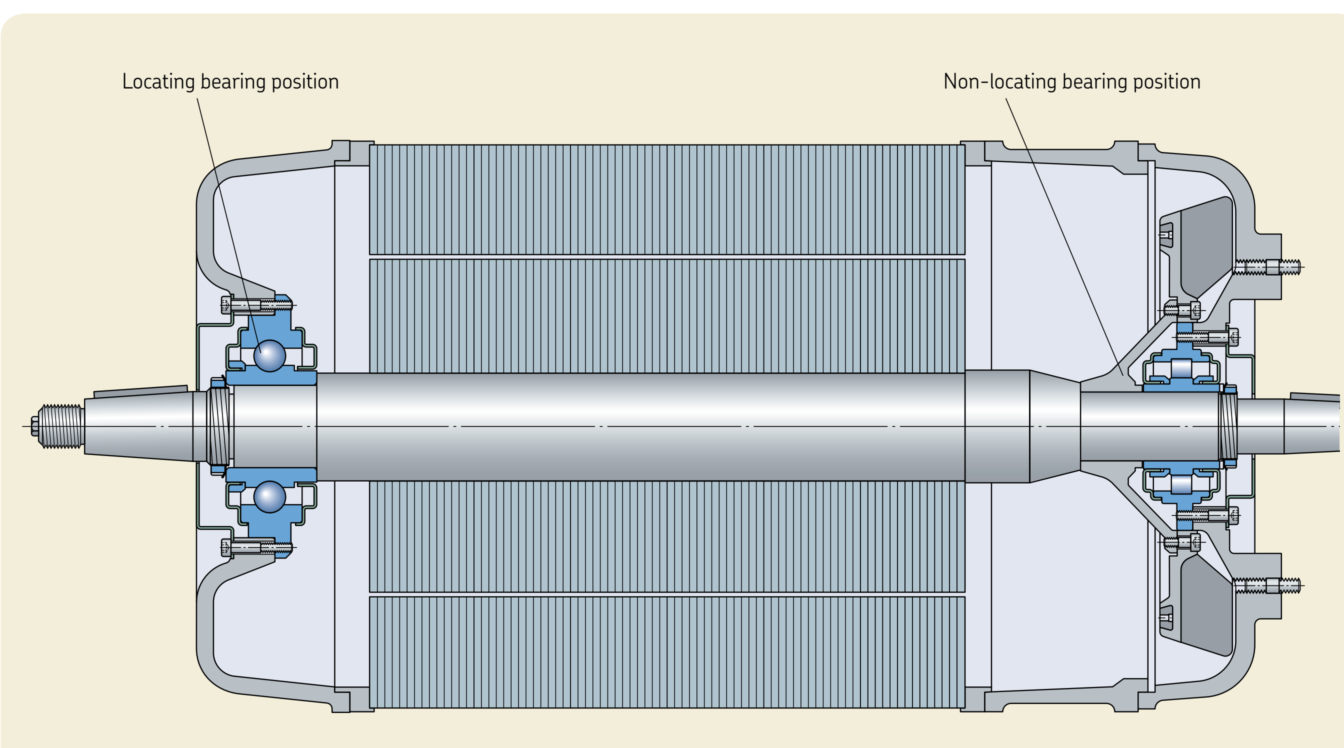
Locating bearing position

The traction motor bearing unit (TMBU) is flanged and fitted to the traction motor shield. This bearing unit is based on a ball set.

Non-locating bearing position

The traction motor bearing unit (TMBU) is flanged and fitted to the traction motor shield. This bearing unit is based on a cylindrical roller set.

Traction motor bearing arrangement equipped with a traction motor bearing unit (TMBU) on both sides [41]



Preparation

Step 1: Unpack the TMBU only immediately before mounting

Step 2: Heating with an SKF portable induction heater TIH 030m, max. temperature for pre-lubricated TMBU with labyrinth seals is 90 °C. This process is for locating and non-locating TMBU bearing units. NOTE: induction heating is not allowed for units equipped with a sensor!

Portable induction heater TIH 030m

The SKF small induction heater TIH 030m combines high heating capacity with portability. The compact lightweight design makes the TIH 030m portable. Placing the induction coil outside the heater's housing enables heating bearings weighing up to 40 kg. The induction heater is equipped with thermal overheating protection to reduce the risk of damage to the induction coil and the electronics. In addition to temperature mode, the TIH 030m is equipped with a time mode for heating components other than bearings. The induction heating system is supplied standard with three yokes and is available in two versions:

- 230V/50 – 60Hz
- 100 – 110V/50 – 60Hz

Technical features:

- compact lightweight design
- 2-step power setting and smaller yokes enable heating smaller bearings safely and at lower power consumption
- capable of heating a 28 kg bearing in just 20 minutes
- temperature mode pre-set at 110 °C to help prevent overheating when mounting open bearings
- automatic demagnetization

10

The SKF working glove TMBA G11W is specially designed for general purpose industrial maintenance work. The inside palm of the glove is coated with non flammable dots providing an excellent grip

Locating bearing unit

Step 3: Installing the locating TMBU

Step 5: Securing the locknut by bending one of the locking washer tabs

Step 4: Securing the TMBU in the axial direction with a lock nut

The SKF hook spanner set
contains 9 spanners based on the DIN 1810 standard suitable for tightening and loosening lock nut sizes 4 up to 16. The hook spanners are designed for use with SKF KM nuts as well as any other KM nuts conforming to the DIN 981 standard.

Non-locating bearing unit

Step 6: Installing the non-locating bearing unit

Step 8: Securing the locknut by bending one of the locking washer tabs

Step 7: Securing the TMBU in the axial direction with a lock nut

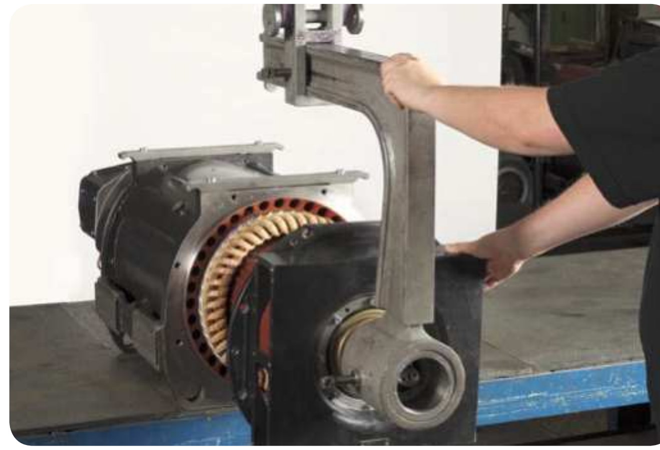
10

Traction motor shield (locating side)

Step 9: To fit the motor shield on the locating bearing side, it is possible to heat the motor shield up to 100 °C. Carefully mount (slide) the motor shield onto the seat of the TMBU flange. Be sure not to apply any excessive axial force. The TMBU bearing unit is very sensitive for axial (shock) loads. A too heavy axial load can press the very hard ceramic balls into the raceways, resulting in dents.

Step 10: Tighten the flange screws to secure the motor shield to the TMBU

Traction motor assembly



Step 11: Insert the rotor with assembled TMBUs and motor shield into the stator.

Step 12: Fit the motor shield on the non-locating bearing side (opposite side) on the stator and onto the seat of the TMBU flange. Keep the rotor and stator aligned to avoid the denting or scoring of the raceways. Tighten the flange screws to secure the motor shield to the TMBU.

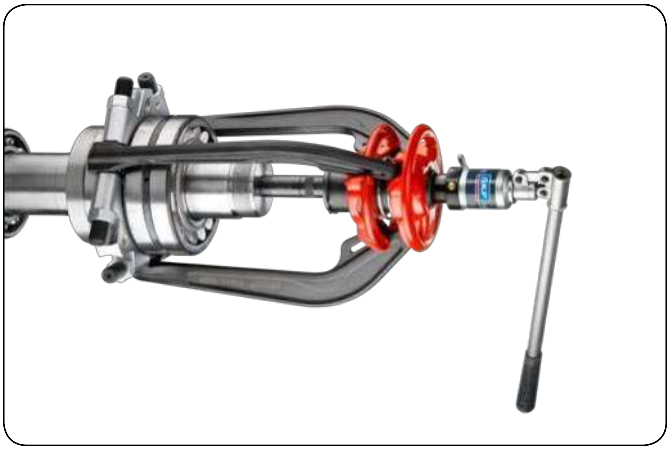
Dismounting

When dismounting bearings, care must be taken not to damage other machine components, such as the shaft or housing, as damage can result in compromising the machine's efficiency and lifetime. Bearings are sometimes dismounted to maintain or replace other components of the machine. These bearings are often re-used. Selecting the appropriate dismounting methods and tools is essential to reduce the risk of damaging the bearing, allowing it to be used again.

Dismounting bearings can be a hazardous and demanding task. Selecting the correct dismounting methods and tools is, therefore, of utmost importance for reducing the risk of personal injuries.

SKF TMMA pullers series: hydraulic EasyPull set
A complete bearing dismounting solution

Strong SKF back pullers TMBS E series
Easy bearing dismounting even in the tightest spaces



Appropriate tools for mechanical bearing dismounting
Reduce the risk of damaging components and personal injury

10

Remanufacturing of traction motor bearing units
Discarding the transportation protection

Remanufacturing of traction motor bearing units
Disassembled bearings, outer rings with cage and roller assembly, ready for inspection of the condition of the grease prior to cleaning

Remanufacturing of traction motor bearing units
Disassembled bearings, inner ring assemblies ready for inspection of the condition of the grease prior to cleaning

Remanufacturing

Bearing remanufacturing[1] can result in a significant reduction of CO_2 emissions compared to the production of a new bearing. Remanufacturing requires up to 97% less energy than producing a new bearing. By extending the service life of bearings, the process avoids the scrapping of components and the unnecessary use of natural resources.

SKF specialists can judge whether a bearing can be remanufactured or not [42].

To do this, send the case data including:

- detailed, close-up pictures of component damage
- general pictures of the bearing arrangement
- technical input such as:
  - application description
  - lubricant characteristics (oil/grease)
  - lubrication method
  - bearing service time, loads and speed

More information can be found in the SKF *Railway technical handbook, Volume 1*, **page 192**.

[1] In addition to the overall term "remanufacturing", some railway operators and manufacturers are using the terms "reconditioning" and "refurbishment" as well to differentiate specific requests. The term "remachining" includes usually polishing and grinding operations. However, it seems that there is no global definition for these terms and they overlap and can be contradictory.

SKF remanufacturing benefits

Bearing remanufacturing is a major contributor in optimizing the life cycle cost:

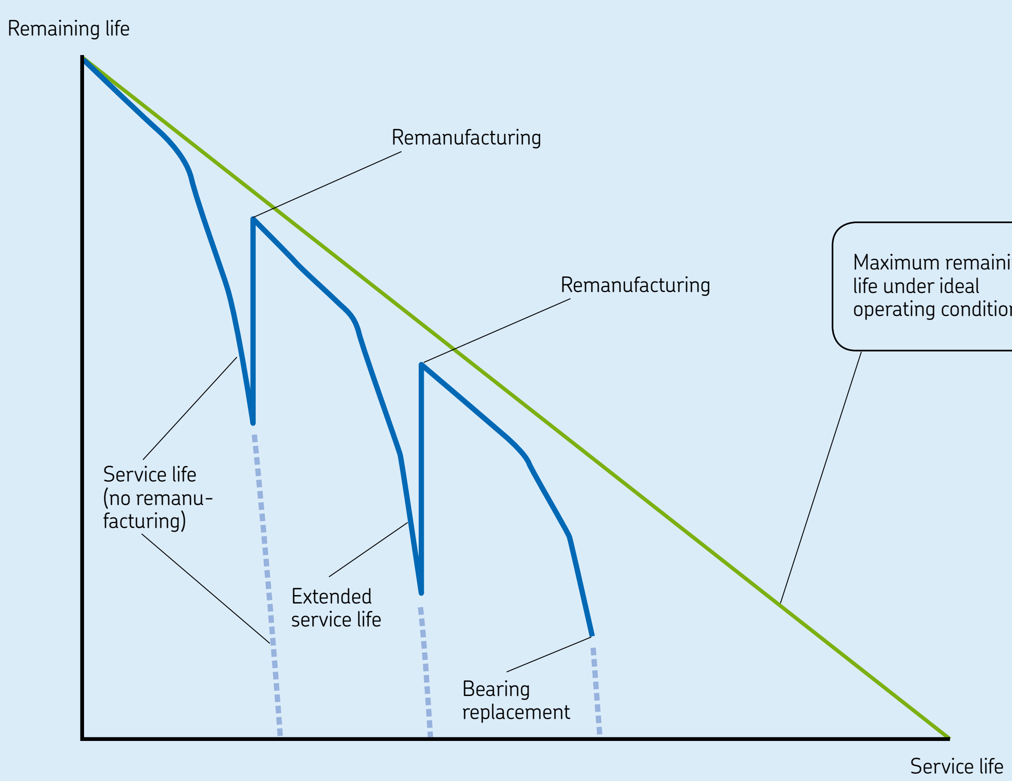
- significant cost reduction compared to new bearings
- extended service life
- better availability, leading to stock reduction
- damage analysis and investigation of corrective actions
- increased performance capability by upgrading during the remanufacturing process
- application feedback for improved operational and maintenance customer technology
- reduced environmental impact due to reduced waste, use of raw material and energy consumption

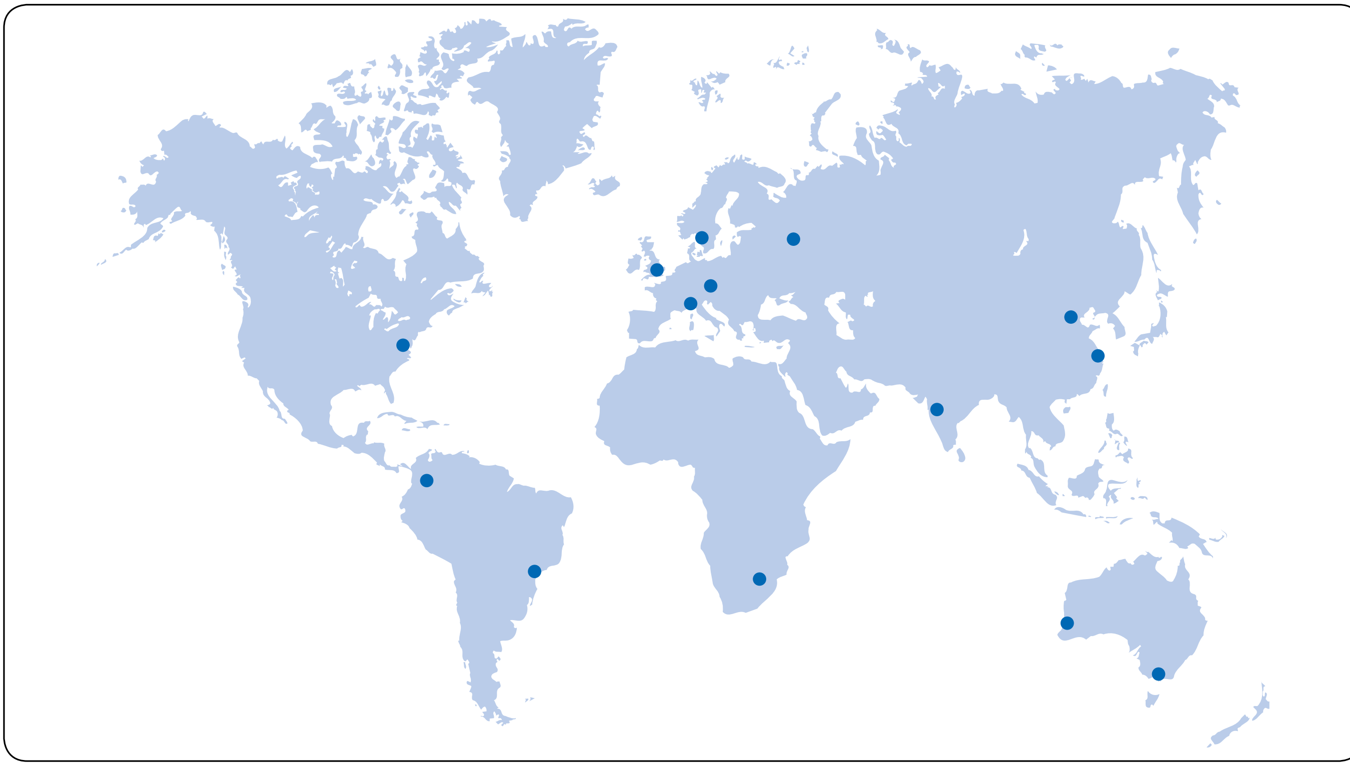
Remanufacturing of suspension tubes

In addition to the bearing and traction motor bearing unit (TMBU) remanufacturing programme, SKF offers remanufacturing of suspension tubes (→ **pages 60** to **61**). This includes quality inspection and remanufacturing like turning, spiral welding and re-machining the bearing fits.

Remanufacturing of tapered roller bearings for suspension tubes
Inspection of the condition of the cage and roller assembly after cleaning

Extending service life through remanufacturing example





SKF's locations of dedicated state-of-the-art remanufacturing service centres

Global network of remanufacturing service centres

SKF has developed a range of core capabilities, resources, and infrastructure that makes sure that SKFs bearing remanufacturing services are truly world-class:

- quality resulting from consistent processes
- global database for knowledge sharing
- reconditioning adapted processes
- computerized case handling
- bearing analysis reports
- measuring protocols
- traceability

These service centres handle a large volume of bearings and related equipment annually. All service centres are well organized and operate with highly trained teams that have special competencies. Operating as a global network, they regularly share knowledge, spare part procurement and capability development.

Testing equipment

Static motor testing equipment

There is an important need of instrumentation that fits the needs of professionals to perform predictive maintenance and condition monitoring of electric motors and rotating machinery.

Since acquiring Baker Instrument Company in 2007, SKF has become the industry leader in motor circuit analysis solutions for electric motor maintenance professionals.

Static equipment tests the insulation system within AC and DC motors and is used as a quality test during the production or rewinding process. Bad connections, misconnections and unbalanced windings can also be detected. Static testing is also used to test for weakening insulation during the motor's life, and thus prevent sudden insulation failure. Static equipment provides a series of tests including winding resistance, megohm, polarisation index (PI), DC step voltage and surge tests.

The megohm test is used worldwide, but has limited capability when testing motor insulation. Based on the law of physics, a potential difference between turns of at least 325 V is required in order to detect weak insulation. The DC megohm test raises all turns to the same potential, thus explaining why weak turn insulation cannot be detected. Since 80% of electrical failures in AC motors begin as a turn to turn insulation weakness, it is important to have a test that is able to detect this problem at an early stage.

The surge test injects high voltage pulses into the winding, creating the required voltage potential difference between turns, and is therefore able to detect weak turn insulation. A motor with weak turn insulation will worsen over time though heat, contamination such as oil and chemicals, mechanical movement of the coils during motor starting, and overvoltage spikes during starting and during motor operation. As the turn insulation weakens further, arcing between turns takes place during motor starting, leading to more rapid insulation weakening.

Eventually, the arcing turns weld together, and very high circulating currents are generated in that localized area, due to the auto transformer effect. The additional heat created by these currents burns away the remaining insulation on the wire, and starts to degrade the slot liner which is the main insulation barrier to ground. Studies have shown that a welded short in an AC motor will cause the motor to fail to ground within 15 minutes of the welded short occurring.

The surge test can detect weak turn to turn, coil to coil and phase to phase insulation in advance of the welded short occurring; hence giving advanced notice of the developing problem, and aiding prevention of sudden motor failure.

In addition to the static motor equipment testing, dynamic and portfolio of online testing equipment can be offered as well.

Static testing of an AC stator

Static testing of a DC rotor

10

Lubrication investigation

SKF Grease Test Kit TKGT 1

The Grease Analysis Kit TKGT 1 has been designed to properly apply this methodology. The content of the kit makes it possible to perform three different tests:

- consistency
- oil bleeding properties
- contamination

This enables the user to have a good understanding of the grease condition and make immediate decisions on-site. The kit includes guidelines for properly interpreting the results of the tests.

For stored greases, the kit can help to establish the remaining shelf life of the grease, as well as assessing the consistency of the quality level among different production batches. When testing used greases, the results will help the user to evaluate such things as: the suitability of the tested grease for the application, the accuracy of relubrication intervals, and the possible sources when contamination occurs.

Customer benefits of the Grease Test Kit

- grease relubrication intervals can be adjusted according to real conditions
- grease quality can be evaluated to detect possible unacceptable deviations from batch to batch
- grease performance can be assessed, allowing verification of the suitability of a certain grease for a specific application

SKF portable grease analysis kit for field use

Training

Today, manufacturers are under tremendous pressure to provide the highest equipment productivity and quality at the lowest possible cost, whilst attaining ever more stringent safety and environmental legislative requirements. To meet these business-critical demands, maintenance professionals need to maximize equipment reliability whilst minimizing maintenance costs – a very difficult balancing act indeed.

Like any difficult skill, training is key to provide effective performance. Many companies offer training in one or more of these areas, but only SKF offers a comprehensive programme that covers every aspect of equipment reliability – from the shop floor to the executive office.

SKF training courses

SKF training courses are typically composed of theoretical and practical features.

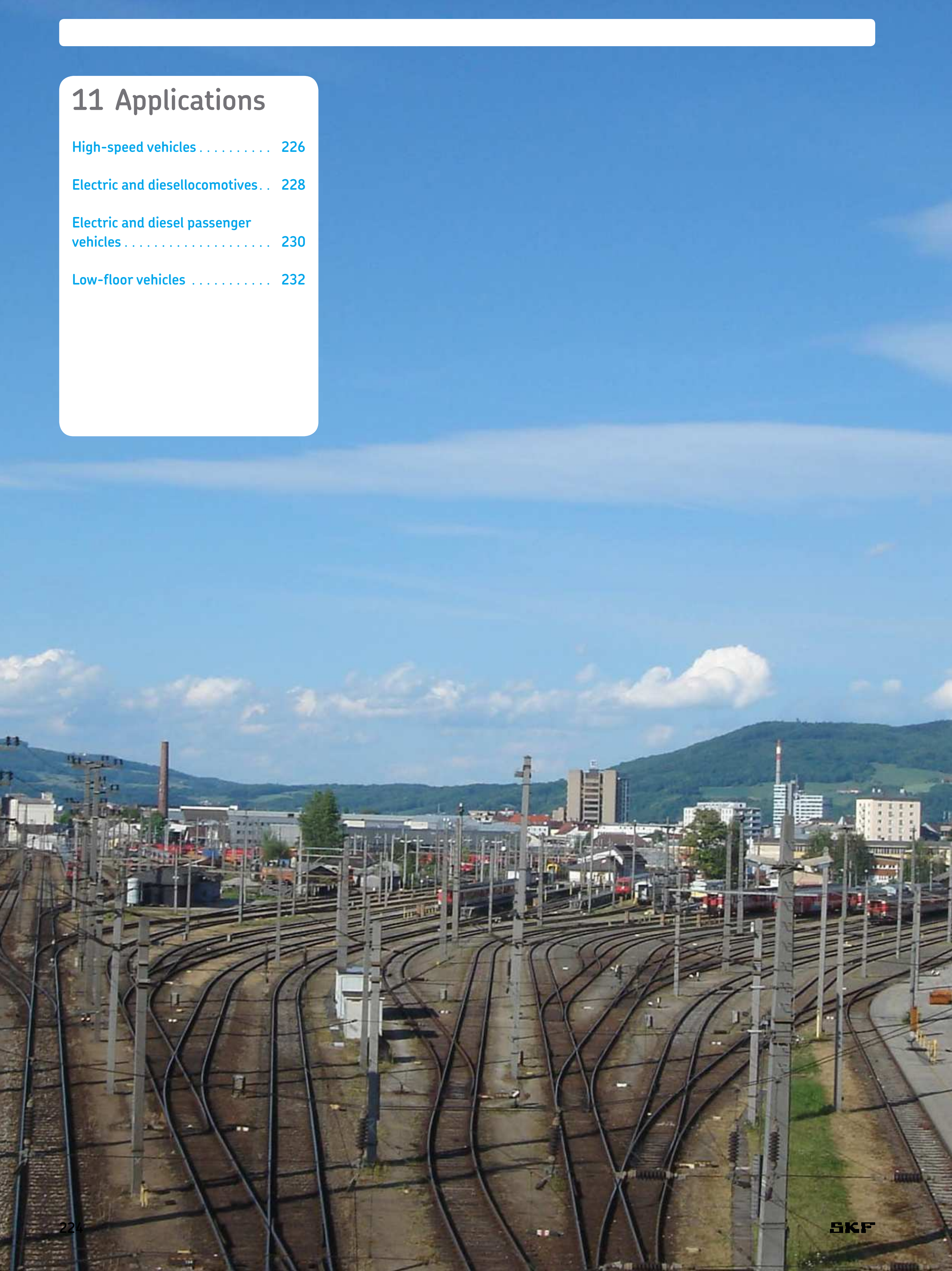
More information can be found at skf.com, by going to local SKF websites where actual training programmes are listed.

In addition to the actual local training programmes, SKF offers customer training programmes that are tailored to the specific customer needs. These courses can be held at customer facilities or in SKF training centres.

Customer benefits

- gaining deeper understanding of bearings and related problems
- awareness of appropriate handling techniques to ensure quality and reliability
- customized training specific to customer's needs
- increase knowledge and retain high competence levels

11 Applications



Applications

Improvements to traction motors and gearboxes has been made continuously for a very long time. SKF has contributed with many innovations, as mentioned in previous chapters. These innovations are based on SKF's unique experience in developing, designing, application engineering and manufacturing of bearings and bearing units as well as mechatronics, seals and services. The following pages include an overview of designs currently in use and some of the major applications in which SKF's wide range of solutions are incorporated.

In most cases, drive systems are tailored to the specifications of the manufacturers and the requirements of the railway operators. In several cases, drive systems are used for the same or similar applications of bogie supplier platforms which are deployed for very different vehicles and operators.

Some brief comments about the applications listed on the following pages:

- SKF solutions for drive systems are used worldwide in all types of railway rolling stock. Like in axlebox applications, there is an ongoing global trend to use ready-to-mount bearing units that are lubricated at the factory and have an integrated sealing system on both sides.
- To protect bearings from damaging electrical current, SKF offers electrically insulating solutions like INSOCOAT and hybrid bearings and traction motor bearing units. These are currently widely used, especially for frequency converter controlled propulsion systems.
- An increasing number of traction motors are equipped with mechatronic systems to measure operational parameters, to detect rotor positioning for propulsion control systems and to monitor drive system conditions.
- Service packages are tailored to the manufacturer's and operator's needs, including application and service engineering, mounting, global aftermarket service, remanufacturing options and logistic services.
- SKF offers a unique global network of sales, application and service engineers, who work on domestic and international projects and are in close contact with manufacturers and operators.
- SKF offers tailor-made solution packages that are based on individual customer's requirements.

High-speed vehicles

For medium distances of several hundred kilometres or more, high-speed railways offer an attractive, environmentally friendly alternative to aircraft and cars. In most cases, trains directly serve city centres without time consuming shuttle transfers or driving on crowded motorways and encountering any parking problems.

There are various definitions of high-speed trains. Usually, these trains have a maximum speed of at least 200 km/h, but there are other categories that define travel at more than 250 km/h. Usually, very high speed trains operate at 300 km/h and even faster. Achieving very high speeds and long-distance maintenance intervals are typical requirements for high-speed trains.

Some time ago, high-speed trains were hauled by power units, similarly designed as locomotives with one driver's cab in front. Because of the larger installed power, this locomotive design requires a much higher axle load than a multiple unit design. Modern high speed trains are mostly composed of several coaches. Around half or one third of these bogies are usually motorized. Very high total power ratings per train can be achieved. These drive systems are relatively small compared with locomotives, because of the advantage of lower axle load and unsprung mass and a better dynamic performance.

SKF offers unique package solutions comprising bearings and tailor-made bearing units, condition monitoring systems, plus application and service engineering support.

Photo: Bvehk

Chinese CRH1A and CRH1B, high speed trains,
max. speed 200 and 250 km/h, power 5 300 and 11 000 kW, in operation since 2004.

SKF INSOCOAT traction motor bearings

Photo: Bombardier

Chinese CRH 1 E, Zefiro 380 high speed trains,
max. speed 380 km/h, power 16 x 500 kW, in operation starting 2012.

SKF INSOCOAT traction motor bearings

SKF gearbox bearings

Photo: Siemens press picture

Chinese CRH3, Velaro CN high speed trains,
max. speed 350 km/h, power 8 800 kW, in operation since 2007.

SKF INSOCOAT traction motor bearings

Photo: Poeloq

Chinese CRH5, Pendolino high speed trains,
operational speed 250 km/h, power 10 x 550 kW, in operation since 2007.

SKF traction motor bearings

Photo: KTX

Korean KTX high speed trains,
operational speed 300 km/h, power 12 x 1 130 kW, in operation since 2004.

SKF traction motor bearings

Photo: DB AG/Wolfgang Klee

German DB ICE 3 high speed trains,
max. speed 330 km/h, power 16 x 500 kW, in operation since 1999.

SKF INSOCOAT traction motor bearings

SKF gearbox bearings


Photo: Bonaventura Leris

Spanish AVE S 103, Velaro E high speed trains,
max. speed 350 km/h, power 16 x 550 kW, in operation since 2007.

SKF INSOCOAT traction motor bearings

SKF gearbox bearings


Photo: SBB

Italian ETR 460, ETR470 (photo above) and ETR 480 Pendolino tilting trains,
max. speed 250 km/h, total power 6 000 kW, in operation since 1992.

SKF INSOCOAT traction motor bearings

SKF gearbox bearings


Photo: Talgo

Spanish AVE S 102, high speed trains,
max. speed 330 km/h, traction motors made by Siemens, power 8 x 1 000 kW, in operation since 2005.

SKF INSOCOAT traction motor bearings

Electric and diesel locomotives

Electric and diesel locomotives haul freight and passenger cars, and are the work horses of all railway operators. They are even used by some operators for high-speed operation. A locomotive is a railway vehicle that hauls the train without carrying any passengers or freight.

Diesel locomotives can be powered by electric or hydraulic propulsion. In addition, these diesel electric locomotives have a generator that is equipped with bearings (→ page 39). Because of the incorporated diesel motor, the total power is limited. In some cases, two diesel motors per locomotive are used.

Electric locomotives can be designed for higher power rating than diesel locomotives that have to accommodate a heavy diesel motor. For higher speeds, an increasing number of complex gearbox designs are used to reduce the unsprung weight and to achieve a better dynamic performance.

High traction motor power requests relatively large drive end side traction motor bearings with high dynamic and static load ratings. Some designs are based on gearbox oil lubricated drive side traction motor bearings, where this bearing is becoming an integral part of the gearbox. SKF offers special cage designs for these applications (→ chapter 3).

Nose suspended traction motor designs are used for lower speeds for things such as freight operation. The max. speed is in the range of 120 to 140 km/h depending on the operator specification. The speed has a direct influence on the wear of rails, wheels and related components.

SKF offers unique package solutions comprising bearings and tailor-made bearing units, condition monitoring systems plus application and service engineering support.

American diesel-electric locomotives
are typically hauling very long freight trains, total power rating 2 200 kW (3 000 HP) up to 4 500 kW (6 000 HP).

SKF INSOCOAT traction motor bearings

SKF generator bearings

Photo: ÖBB

Austrian ÖBB 1016/1116, Taurus electric locomotives,
max. speed 230 km/h, power 4 x 1 600 kW, in operation since 2000.

SKF INSOCOAT traction motor bearings

SKF gearbox bearings

Photo: Siemens press picture

Chinese Railways DJ4 electric locomotives,
max. speed 120 km/h, power 8 x 1 200 kW, in operation since 2006.

SKF INSOCOAT traction motor bearings

Photo: Alancrh

Chinese Railways HXD1B (6F) electric locomotives,
max. speed 120 km/h, power 9 600 kW, in operation since 2006.

SKF INSOCOAT traction motor bearings

Indian WDG-2A diesel locomotives,
max. speed 100 km/h, total power 2 300 kW (3 100 HP), in operation since 1995.

SKF traction motor bearings

Photo: www.zacliu.com

Chinese Railways HXN5 diesel locomotives,
Co'-Co' bogie max. speed 120 km/h, power 4 660 kW, in operation since 2008.

SKF INSOCOAT traction motor bearings

SKF gearbox bearings

Photo: Orlovic

Italian Trenitalia E464 electric locomotives,
max. speed 160 km/h, power rating 3 000 kW, in operation since 2000 [43].

SKF traction motor bearings

SKF gearbox bearings

Photo: Photo: DB AG/Wolfgang Klee

German DB-Railion 189 electric locomotives,
suitable for different European electric systems, max. speed 140 km/h, power 4 x 1 600 kW, in operation since 2003.

SKF INSOCOAT traction motor bearings

SKF gearbox bearings

Photo: SBB

Swiss SBB Re 460 electric locomotives,
max. speed 230 km/h, power 4 x 1 525 kW, in operation since 1992.

SKF INSOCOAT traction motor bearings

SKF gearbox bearings

Electric and diesel passenger vehicles

In passenger transportation, an increasing number of electric and diesel multiple units are used for long and short distance service, especially where shorter trains operating with shorter intervals are needed. In addition, there are trains composed of one or two locomotives and passenger coaches.

Like locomotives, diesel units can be powered by electric or hydraulic propulsion. In addition, these diesel electric multiple units have generators that are equipped with bearings (→ chapter 2). Because of the diesel motor and the limited space, the total power is limited. In some cases, two diesel motors per unit are used.

In many cases, the propulsion design for electric multiple units and metro cars has a lot of similarities with high speed applications. On the other hand, some of these electric multiple unit designs can be used for mass transit applications as well, like suburban and metro cars. These drive systems are relatively small with the advantage of a low axle load and unsprung mass and a better dynamic performance.

As with locomotives, nose suspended traction motor designs are used for lower speeds only. The speed has a direct influence on the wear of rails, wheels and other related components.

SKF offers unique package solutions comprising bearings and tailor-made bearing units, condition monitoring systems plus application and service engineering support.

Photo: Bombardier

Chinese Shanghai Metro,
speed 120 km/h, power 7200 kW, in operation since 2006.

SKF INSOCOAT traction motor bearings

Photo: Petr Štefek

Czech electric multiple units 471
max. speed 160 km/h, power 4 x 500 kW, in operation since 2001.

SKF traction motor bearing units

Photo: Rolf Hafke

German Cologne light rail vehicles, K 5000,
max speed 80 km/h, power 4 x 120 kW, in operation since 2002 [41].

SKF hybrid traction motor bearing units

Photo: Platte C

German Hamburg DT4 metro vehicles,
max. speed 80 km/h, power 8 x 125 kW, in operation since 1988 [4].

SKF traction motor bearings

SKF gearbox bearings

Photo: Oxyman

UK electric multiple units class 350, Desiro UK operated by several companies
max. speed 160 km/h, total power 1500 kW, in operation since 2005.

SKF INSOCOAT traction motor bearings

Photo: Siemens press picture

Slovenian EMR 312, Desiro electric multiple units,
max. speed 140 km/h, power 4 x 412 kW, in operation since 2000.

SKF INSOCOAT traction motor bearings

Photo: CAF

Turkish Istanbul metro vehicles,
max. speed 80 km/h, power 8 x 200 kW, in operation since 2012.

SKF hybrid traction motor bearings

Photo: SBB

Swiss SBB RABe 521/523, FLIRT electric multiple units,
max. speed 160 km/h, power 4 x 500 kW, in operation since 2004.

SKF INSOCOAT traction motor bearings

Photo: Leif Åbjörnsson

Venezuelan Caracas metro vehicles,
max. speed 80 km/h, power 24 x 200 kW, in operation since 2010.

SKF hybrid traction motor bearings

Low-floor vehicles

Mass transit railways are becoming an important alternative to cars in the crowded streets of cities and suburban areas. Vehicles like suburban trains, metros or underground, light rail vehicles and tramways operate worldwide.

In many cases, the differences between suburban, metro, underground, light rail and tramways are based on different legal definitions. These vehicles can meet railway vehicle standards and are operated by railway companies. Vehicles for non-railway companies like local mass transit operators are designed in accordance with special standards (like country specific tramway standards) requested by the operator.

In comparison to other application fields, light rail and tramway vehicles can be designed based on very different technical concepts, like low-floor, medium high floor and standard floor designs. Some vehicles are articulated by use of very different body section lengths. As a consequence, different drive designs or single wheel arrangements are used. These can be designed as hub traction motors (→ chapter 2).

Trolleybuses are used in several cities to reduce pollution in crowded areas when compared with traditional bus services. The traction motors of these trolleybuses have a lot of similarities with tramway applications and are included in this chapter. The gearbox design is typically based on current bus differential and axle gearbox components.

SKF offers unique package solutions comprising bearings and tailor-made bearing units, condition monitoring systems plus application and service engineering support.

Photo: Grazer Verkehrsbetriebe

Austrian Graz, Cityrunner light rail vehicles,
max. speed 70 km/h, power 8 x 50 kW, in operation since 2001.

SKF hybrid and INSOCOAT traction motor bearings

Photo: Gunter Mackinger

Austrian Salzburg, trolleybuses
max. speed 65 km/h, power 1 x 172 kW, in operation since 1996 [44].

SKF INSOCOAT traction motor bearing units

Photo: Honza Groh

Czech Prague, 15T light rail vehicles
max. speed 60 km/h, power 16 x 60 kW, in operation since 2010 [33].

SKF hybrid traction motor bearing units with absolute positioning sensors

1) Similar traction motors are used in Austria: Linz and Salzburg; Belarus: Minsk; Czech Republic: Hradec Králové; France: Lyon; Germany: Esslingen and Solingen, Greece: Athens; Hungary: Budapest; Italy: Bologna, Milan, Modena and Parma; Netherlands: Arnhem; Romania: Bucarest; Switzerland: Bern and Biel; USA: Boston.

Photo: ŠKODA ELECTRIC a.s.

Czech Plzen 21 Tr trolleybuses
max speed 65 km/h, power 140 – 175 kW[1)], in operation since 2001 [41].

SKF hybrid traction motor bearing units

Photo: Liesel

German Nuremberg light rail vehicles
max. speed 80 km/h, power 3 x 120 kW[4)], in operation since 1995.

SKF INSOCOAT traction motor bearings

SKF gearbox bearings

4) Similar traction motors and gearboxes are used in Germany: Augsburg, Berlin, Braunschweig, Bremen, Frankfurt (Oder), Jena, München and Japan: Kumamoto

2) Similar traction motors and gearboxes are used in Australia: Melbourne: France: Bordeaux, Lyon, Montpelier, Orléans and Paris; Ireland: Dublin; Netherlands: Rotterdam; Spain: Barcelona

Photo: Schachi

France Paris line 2 Citadis light rail vehicles
max. speed 70 (80) km/h, power 4 x 120 kW[2)], in operation since 2003.

SKF traction motor bearings

SKF gearbox bearings

Photo: Darkone

German Rostock 6NGTWDE light rail vehicles
max. speed 70 km/h, power 4 x 95 kW[5)], in operation since 1994 [4].

SKF traction motor bearings

5) Similar traction motors are used in Germany, including Bielefeld, Darmstadt, Erfurt, Essen, Freiburg, Heidelberg, Karlsruhe, Leipzig, Ludwigshafen, Magdeburg, Mannheim and Rostock, as well as in Belgium: Antwerpen

3) Similar traction motors are used in Germany: Bochum, Duisburg, Heidelberg, Ludwigshafen, Mainz, Mannheim, München, Nürnberg, Potsdam; Australia: Sydney; Austria: Graz; Finland: Helsinki and Norway: Bergen.

Photo: Olaf Just

German Chemnitz Variobahn light rail vehicles
max. speed 70 km/h, hub traction motor drive system (→ chapter 2), power 8 x 45 kW[3)], in operation since 1998, prototype since 1993 [4].

SKF traction motor bearings

Photo: Siemens press picture

USA - Houston TX, MetroRail, Avanto light rail vehicles
max. speed 105 (120) km/h, power 4 x 130 kW, in operation since 2001.

SKF INSOCOAT traction motor bearings

11

Index

Keywords

SKF

References

[1] Kuře, G.: *Railway technical handbook.* Axleboxes, wheelset bearings, sensors, condition monitoring, subsystems and services. Volume 1, SKF (2011). ISBN 978-91-978966-3-4.

[2] Reimann, R.: *Von der UEG zur AEG. Elektrische Bahnen 1897–1898.* Stuttgart: Motorbuch Verlag, reprint 1997, p. 12. ISBN 3-87943-555-3.

[3] Bendel, H.: *Elektrische Triebfahrzeuge.* Berlin: Transpress 1981.

[4] Neudorfer, H., Kuře, G.: *New drive systems for mass transit.* SKF Evolution magazine (2001) 2, pp. 26–29.

[5] Köhler, O.: *Mechanische Antriebskonzepte für Hochleistungs-Drehstrom-Lokomotiven.* Aachen: Shaker Verlag 2004. ISBN 3-8322-3513-2.

[6] Seefehlner, E., Peter, H.: *Elektrische Zugförderung.* Berlin: Verlag von Julius Springer 1924.

[7] Grünholz, H.: *Elektrische Vollbahnlokomotiven.* Berlin: Druckerei und Verlagsanstalt Norden 1930.

[8] Müller, P.: *Elektrische Fahrzeugantriebe.* Beiheft zur Zeitschrift Elektrische Bahnen (1960).

[9] Baur, K. G.: *Drehgestelle – Bogies.* Freiburg: EK-Verlag 2009, p. 109. ISBN 978-3-88255-147-1.

[10] Haigermoser, A.: *Schienenfahrzeuge.* Vorlesungsskriptum (2002) Technical University Graz.

[11] Bertorelli, D.: *Italian high speed train.* SKF Kugellager Zeitschrift 241 (1993), pp. 11–14.

[12] Jürgensmeyer, W.: *Die Wälzlager.* Berlin: Verlag von Julius Springer 1937.

[13] Weidinger, A.: *100 Jahre Zylinder-rollenlager.* SKF (2009), pp. 58–59.

[14] Albert, M., Kuře, G.: *Wälzlager in Schienenfahrzeugen.* ZEV-Glasers Annalen 107 (1983) 8/9, pp. 326–336.

[15] Kuře, G.: *Wälzlager in elektrischen Fahrmotoren.* Veröffentlichung 3.4D. STEYR (1990).

[16] Kuře, G., Palmetshofer, W.: *Electrically insulated bearings.* SKF Evolution magazine (1996) 3, pp. 22–24.

[17] Kohaut, A.: *Riffelbildung in Wälzlagern infolge elektrischer Korrosion.* Zeitschrift für angewandte Physik. 1 (1948) 5, pp. 197–211.

[18] Wallin, E., Andéason, S., Botö, P. A.: *Stromdurchgang durch Wälzlager.* SKF (1967) WTS 67 06 01.

[19] Pittroff, H.: *Wälzlager im elektrischen Stromkreis.* Elektrische Bahnen (1968) 3, pp. 54–61.

[20] Schenk, O.: *Stromdurchgang durch Wälzlager.* Der Maschinenschaden 26 (1953) 11/12, pp. 135-135.

[21] Kuře, G.: *Electric insulated rolling bearings in railway vehicles.* English translation by STEYR. Neue Bahn (1989) 4, pp. 26–34.

[22] Kahlman, L., Nilsson, K. A., Preisinger, G.: *Hybrid bearings for electrical machinery.* SKF Evolution magazine (2001) 3, pp. 28–31.

[23] Preisinger, G., Gröschl, M., Köttritsch, H.: *Industrial Prevention of electric erosion in bearings.* SKF Evolution magazine (2001) 2, pp. 21–25.

[24] Zika, T., Gebeshuber, I. C., Buschbeck, F., Preisinger, G., Gröschl, M.: *Surface analysis on rolling bearings after exposure to defined electric stress.* Proc. IMechE Vol. 223 Part J: J. Engineering Tribology (2009), pp. 787–797.

[25] Madzia, N.: *Electrically insulated rolling bearings.* English translation by STEYR. M + F (1986) 10, pp. 222–226 and 11/12, pp. 252–254.

[26] Schöppl, O.: *Developments in ceramic bearing balls.* SKF Evolution magazine (2012) 1, pp. 25–29.

[27] Kuře, G.: *Development of traction motor bearings.* SKF Evolution magazine (1996) 2, pp. 19–22.

[28] Lulek, A.: *Grease life calculation guidelines for traction motors.* SKF report XT10U003. SKF (2011), (not published).

[29] Göbel, S., Lawrenz, D., Weigert, E. A.: *1000 Schienenfahrzeuge.* Köln: Naumann & Göbel Verlagsgesellschaft. ISBN 978-3-625-12225-8.

[30] Kuře, G.: *Tests, test runs and applications of rolling bearings in railway vehicles.* ZEV Glasers Annalen 113 (1989) 6–7, pp. 313–322.

[31] Kerry, M., Peterson, L., Cagnasso, R.: *An Atlas of railway axle bearing defects including guidelines on how to examine bearings and overhaul practice.* SKF (2008).

[32] Verhaert, W.: *Golden opportunities.* SKF Evolution magazine (2011) 3, pp. 28–32.

[33] Kuře, G., Sobotka, L.: *Sensorized traction motor bearing units.* SKF Evolution magazine (2009) 3, pp. 28–31.

[34] Kuře, G., Skiller, J.: *Added safety for today's railway industry.* SKF Evolution magazine (2001) 1, pp. 21–24.

[35] Kuře, G.: *Condition monitoring: the apotheosis of maintenance.* International Railway Journal 49 (2009) 5, pp. 42–43.

[36] Kuře, G., Schmiechen, R.: *Solutions for railway bogie condition monitoring.* SKF Evolution magazine (2010) 1, pp. 25–27.

[37] Kuře, G., Martinetti, M., Moretti, R.: *Sensors for railway bearing units.* SKF Evolution magazine (2002) 3, pp. 24–26.

[38] Kuře, G., Martinetti, M.: *New sensor solutions for railways.* SKF Evolution magazine (2005) 3, pp. 25–27.

[39] Pennacchi, P., Chatterton, S., Borghesani, P., Ricci, R., Unger-Weber, F., di Donato, A., De Ponte, A., Porzio, F.: *CBM on traction system.* Fondazione Politecnico di Milano. Joint Research Centre for Transportation (2011), (not published).

[40] Kuře, G., Martinez, V.: *Applied condition monitoring in railways.* SKF Evolution magazine (2011) 4, pp. 21–25.

[41] Kuře, G., Babka, J., Schuster, J,: *Hybrid traction motor bearing units for mass-transit vehicles.* SKF Evolution magazine (2003) 4, pp. 21–24.

[42] Kerry, M.: *Wheelset maintenance... on a roll.* International Railway Journal 50 (2010) 5, pp. 35–38.

[43] Gukenbiehl, K., Kuře, G.: *Optimised bearings for locomotive transmissions.* SKF Evolution magazine (1999) 2, pp. 26–29.

[44] Hudzikowski, J.: *Bearings for drive systems for railway vehicles – an outline.* SKF science report, Development Centre Steyr (2005–2006), pp. 79–84.