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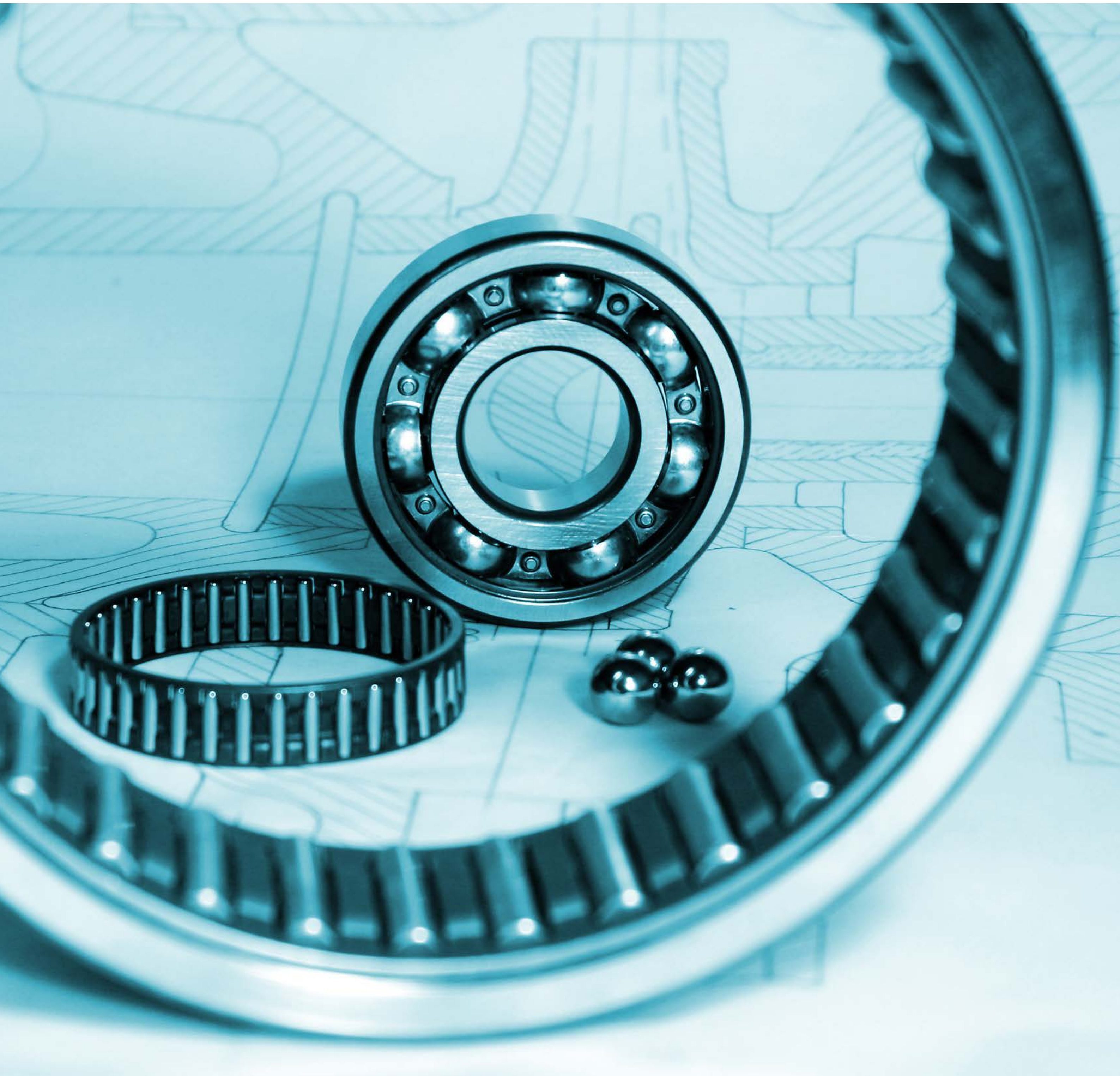
EVERYTHING ABOUT ROLLING BEARINGS



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Basics and areas of application

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Summary

- Rolling bearings are machine components that are used in many applications
- Rolling bearings enable load transfer with minimal friction
- In rolling bearings, the rolling elements perform the rolling motion
- Rolling bearings are installed in almost all areas where something rotates
- Rolling bearings can basically be divided into two types: ball bearings and roller bearings

What is a rolling bearing?

Would you like to learn more about rolling bearings? Then you’ve come to the right place. But let’s start with a short explanation: A rolling bearing is a machine component that is used in various applications. Through the rolling bearing, a movable connection of two components (shaft and housing) can be created, whereby load transmission is made possible with minimal friction. The term “rolling bearing” is the umbrella term for bearings in which rolling elements perform rolling motion and transmit a load between two opposing surfaces. The main components of a rolling bearing are the inner ring, outer ring, cage and rolling elements. Rolling elements can come in different shapes.

Basics and areas of application

Rolling bearings come in a wide variety of sizes.

The rolling bearing types: Ball bearings and roller bearings

Rolling bearings can be divided into two types. In addition to ball bearings, which are probably the better-known rolling bearings, roller bearings are another type. Today, it is possible to manufacture rolling bearings in various sizes and with a wide variety of materials. As a general rule, the dimensions are standardised, but there are also special bearings tailored to specific applications.

Ball and roller bearings can be further subdivided into different types of rolling bearings. Here at wälzlagerwissen.de you will find relevant information not only on these numerous types, but also on everything else worth knowing about rolling bearings!

Application areas of rolling bearings

The functions of the rolling bearing are very important, as they are installed in all areas where something rotates. The wide range of uses extends from large wind turbines to small electric toothbrushes – rolling bearings are needed in a wide variety of applications.

Basics and areas of application

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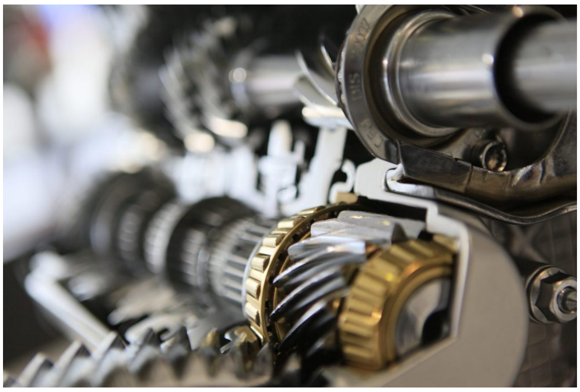
Mobility represents a diverse field of application: Rolling bearings are required in aerospace technology and the automotive market, among others. For example, they are used in aircraft engines of Airbus and Boeing planes; and in the turbines and rotors of helicopters. In addition, rolling bearings are installed in turbine pumps and satellites. In the aviation and automotive sectors, they can also be found in the chassis as wheel bearings or in gearboxes. Last but not least, rolling bearings are suitable for use in (hybrid and electric) car engines or as clutch bearings. Other areas of application are the bicycle industry and railway technology as well as agricultural and construction machinery.

Roller bearings are hidden in engines as well as in the landing gear and flaps.



Whether engine, gearbox, wheel or clutch: few of us probably think about it, but rolling bearings are also abundant in cars.

As previously mentioned, rolling bearings are also indispensable in the wind energy sector. In this innovative sector, they are used, among other things, as rotor, gearbox and generator bearings. The bearings used here are primarily roller bearings such as spherical or cylindrical roller bearings.

The wind energy industry is a multi-faceted field of application for rolling bearings. Bearing locations include main rotor bearings, bearings for variable speed gearboxes, blade bearings, gearbox bearings and tower bearings.

Other industrial sectors in which rolling bearings are used are, for example, robotics and the food industry. In the former, they are in demand in the form of crossed roller bearings for precision or reduction gears for robots and in absolute sensor systems. Bearings in the food industry, on the other hand, are subject to stringent demands. Above all, they must meet the relevant health requirements so that food quality can be maintained. For this reason, a solid lubricant – and not grease or oil as is usually the case – is used here. Rolling bearings are also indispensable in industrial solutions, machine tools, textile machines, material handling, cement production and the steel industry.


Rolling bearings also play an important role in cutting-edge robotics.


Among other things, housed bearings and deep groove ball bearings are used in the food industry and conveyor technology.

As you can see, rolling bearings fulfil a central function in numerous industries and without rolling bearings many things could not be driven or moved efficiently. Rolling bearings often accompany us in everyday life without us noticing, so it's likely that you will also have to deal with rolling bearings in your professional life.

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Summary

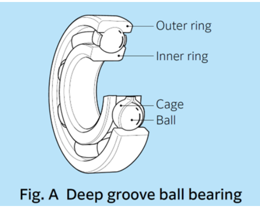
- Main components of rolling bearings: Inner ring, outer ring, rolling elements, cage
- Optionally, a seal can be installed in a groove on the inner and outer ring
- Lubrication of rolling bearings with grease or oil reduces friction and wear
- Axial vs radial bearings

Components of rolling bearings

The basics of rolling bearing technology include the structure and function of rolling bearings. To get you started slowly, you will learn everything about the essential components before we explain how they are arranged and function within the rolling bearing. Let’s go!

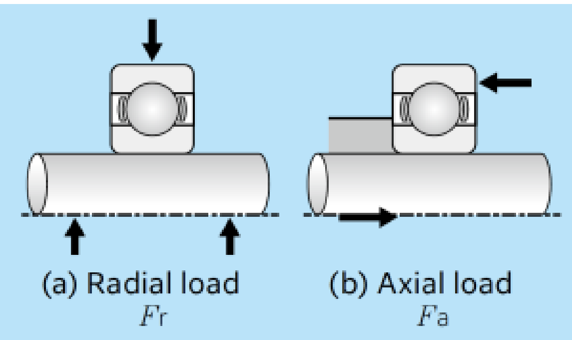
In total, there are four main components: Rolling bearings consist of an inner ring, outer ring, rolling elements and a cage. The inner ring is usually mounted on an axle or shaft and the outer ring in a housing. Optionally, a seal can be installed in a groove on the inner and outer ring. On the outside of the inner ring as well as on the inside of the outer ring lies the bearing raceway. The rolling elements move along the raceway surface, and are manufactured in ball or roller form, depending on the bearing type. The rolling elements serve to ensure that the inner and outer rings can move with minimum friction. To minimise friction and protect against wear, the bearing raceways must be sufficiently lubricated with grease or oil. Between the inner and outer ring there is also a cage, whose function is to separate the rolling elements. It should also position the rolling elements around the circumference of the rings and guide them. Cages can be made of different materials, so a distinction is made between sheet metal, solid metal or plastic cages.

Axial- and radial bearing

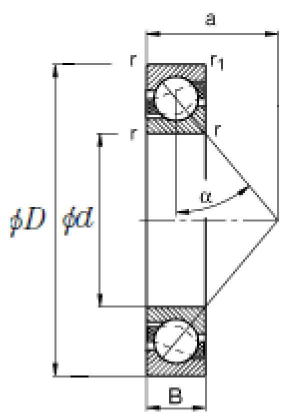


The arrangement of the essential components in a deep groove ball bearing.

Depending on the direction of the load to be transmitted (the contact angle), a distinction is made between axial and radial bearings. With axial load, the force acting on the rolling bearing (axial bearing) runs parallel to the axis. However with a radial load, the force acts perpendicular to the axis of the rolling bearing (radial bearing). Fortunately, this is relatively easy to remember because the word “axial” comes from “axis”, whereas “radial” comes from “radius”. The contact angle α for axial bearings is between 45° and 90° whereas for radial bearings, it is between 0° and 45°. Thus, the contact angle is higher for axial bearings relative to radial bearings.



Graphical representation of radial and axial load.



The contact angle α as seen on an angular contact ball bearing, which is a radial bearing.

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Characteristics of spherical roller bearings Spherical roller bearings are real all-rounders. They are able to support heavy loads in both axial and radial directions. Spherical

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History of rolling bearings

Summary

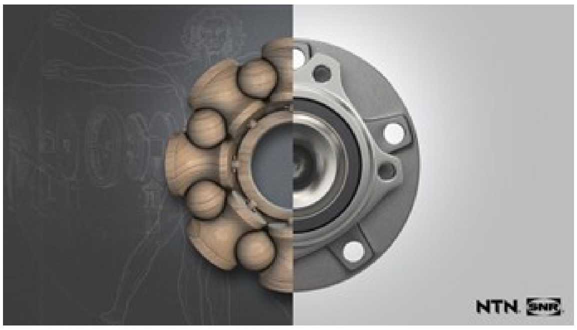
- The history of rolling bearings goes back to 2500BC
- Da Vinci was already sketching bearing concepts at the end of the 15th century
- Invention of the Pedal Cycle (now known as the Bicycle) led to increased demand for industrially manufactured ball bearings in the 19th century
- The first fully automatic ball milling machine appeared in the second half of the 19th century

The origins of rolling bearings

Did you know that the precursors of rolling bearings already played an important role very early on? For example, at around 2500BC, heavy loads were already transported from A to B on skids in ancient Egypt. Later, rollers were placed between the transport surface and the skids. With this strategy, the gliding motion was thus replaced by a rolling motion, which is still used today. A pivotal event in history was the invention of the Wheel. First made of stone, then later of wood. A challenge, however, was the friction within the wheel hub, which led to severe wear and tear. Even Leonardo da Vinci (1452-1519) was already thinking about how bearings could function with minimal friction. Powerful, isn't it?

Da Vinci and the rolling bearing

Da Vinci's ideas were generally very progressive. As early as 1500, he made some sketches, drawings and designs on the

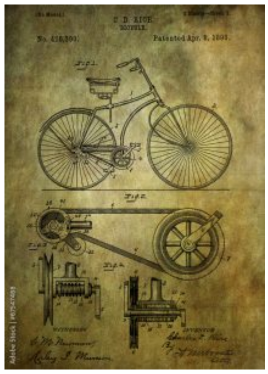


Old but gold: The idea da Vinci had of a ball bearing definitely bears similarities to rolling bearings in use today.

subject of ball bearings, which interested him in the context of his development of the Helical Air Screw (a kind of helicopter). In this way, da Vinci was able to gain his first insights into a low-friction bearing.

The importance of rolling bearings during industrialisation

The bicycle had a decisive impact on the development of the rolling bearing. After the invention of the Draisine in 1817, which already vaguely resembled a bicycle, both the treadwheel and the rear-wheel chain drive were developed in the second half of 19th century. Since people had to propel the bicycle themselves, the desire for low-friction movement finally increased. This created a high demand for industrially manufactured ball bearings. Finally, Friedrich Fischer designed the first fully automatic ball milling machine with which steel balls could be produced instead of stone balls. From 1886, Fischer even manufactured entire ball bearings. A short time later, NTN began producing ball bearings in 1918 and has since become one of the largest manufacturers worldwide.



The first Treadwheel Pedal Cycle was built in 1853 by Philipp Moritz Fischer, the father of Friedrich Fischer.

Enough history lessons: Since Fischer's invention in the 19th century, ball bearings are probably the best-known rolling bearing type, but not the *only* one. You can find out more in our article on rolling bearing types.

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Point and line contact

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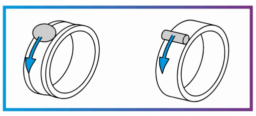
Summary

- Point and line contact describes the type of contact between rolling elements and a raceway surface
- Point contact in ball bearings: Contact of the rolling elements with the raceway at one point
- Line contact in roller bearings: Contact of therolling elements with the raceway in a line

What is meant by "point and line contact"?

You may have already heard that rolling bearings can be split into two types. The classification depends on the shape of the rolling elements (balls or rollers/needles), so that a basic distinction is made between ball and roller bearings.

The main difference between the two designs lies in the contact between the rolling elements and the raceway surface. Imagine a deep groove ball bearing and a cylindrical roller bearing: In a the deep groove ball bearing, the contact between the balls and the raceway is point-shaped from a geometrical point of view. Whereas in the rolling elements of a cylindrical roller bearing contact the raceway in a linear manner.



Graphic representation of point and line contact.

The advantages and disadvantages of point and line contact

Both types of contact have advantages and disadvantages. Point contact offers the advantage that ball bearings can be operated at a high speed. They are sometimes used in machine tools or electric motors. However, ball bearings cannot support as much load as roller bearings. The rolling elements of roller bearings offer a larger contact area to the raceways than balls. As a result, bearings with line contact can generally support higher loads than ball bearings and have greater stiffness. On the other hand, the frictional torque is higher than with ball bearings. Due to the linear contact, roller bearings are therefore used in applications with comparatively low speeds – for example in gearboxes.

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Characteristics of tapered roller bearings Here you see an NTN tapered roller bearing. As the name suggests, tapered roller bearings are roller bearings, whereby the

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Summary

- Bearing rings and rolling elements are made of rolling bearing steel or ceramic
- Cages are made of sheet steel, brass or plastic
- Manufacturing of bearing rings: Steel is heated, quenched and tempered
- Manufacturing of rolling elements: Steel is pressed, stamped and deep-drawn. Later, it takes on a round shape and is heat-treated
- Manufacturing of cages: Cage material is stamped or moulded, rolling elements are inserted and the cage is fitted between the bearing rings

Materials and manufacturing

Have you already had a look at our chapter on structure and function? Maybe you asked yourself what rolling bearings are actually made of. You can find some answers to these questions and further background information on rolling bearing production here.

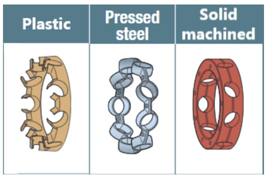
Materials: Rolling elements and bearing rings

In most cases, both the rolling elements and the bearing rings are made of rolling bearing steel, which is standardised according to designation 100Cr6. The steel used must be of high purity and should contain only the smallest metallic inclusions. Another important requirement is that the material must be able to withstand high loads. This is the only way to guarantee that the rolling bearings will maintain high precision and rotational accuracy. The materials from which the rings and rolling elements are made should also have a high hardness after machining. They must alsohave good resistance to rolling fatigue and wear, and have sufficient dimensional accuracy. At NTN, the Japanese rolling bearing steel designated “SUJ2“, (equivalent to 100Cr6), is used.

The spherical roller bearing is a prime example: Here you can clearly see that the rolling elements are made of rolling bearing steel.

Nowadays, rolling elements can also be made of ceramic. This offers various advantages. For example, ceramic rolling elements are lighter than steel rolling elements, which leads to lower centrifugal forces and thus better energy efficiency. Ceramic rolling elements are therefore used at very high speeds and are also suitable for cold and extremely high operating temperatures. Another advantage of ceramic rolling elements is that they prevent the passage of current through the bearing, as they are not electrically conductive. The bearing rings can also be made of ceramic, but this is very rare and only necessary for special applications with extreme temperatures.

Materials: Cage



The three central cage types. In this case, the designs are tailored to ball bearings.

With regard to the cages, it should be noted that they must have sufficient strength in order to be able to absorb vibration and impact loads. In addition, the cage materials should have a low coefficient of friction, low weight and be able to withstand the temperatures generated by the bearing. Small and medium-sized rolling bearings are generally fitted with sheet steel cages, while large bearings tend to be fitted with solid cages, which are mostly made of brass. Brass cages are suitable for strong vibrations and can withstand greater loads during acceleration and deceleration of the rolling elements compared to sheet steel cages. Additionally, cages made of plastic are also used. These cages are well suited to strong vibrations and are characterised by the fact that their friction, temperature and noise generation are low overall.

Cage material	Advantages and disadvantages
Sheet steel	Advantages: Does not restrict the operating temperature of the bearing, cost-effective Disadvantages: Only limited suitability for vibratory applications
Brass	Advantages: No temperature restriction, suitable for vibratory applications, good resistance to extreme accelerations Disadvantages: Expensive
Plastic	Advantages: Elastic and suitable for strong vibrations, low temperature and noise generation, low friction Disadvantages: Limited operating temperature

Here you will find an overview of the advantages and disadvantages of the three cage materials

Manufacturing of bearing rings

It isn't just the materials used in the production of rolling bearings, but also how they are manufactured which is interesting. Raw material in the form of tubes or rods are used for bearing rings. These are initially either machined or formed. In machining, the rings, which are in a cold state, are coarsely and finely turned with a cutting tool. Forming is divided into forging and rolling. In forging, a previously heated blank is re-shaped. The material, which remains warm, is then further shaped in the process of rolling by turning it with the help of a shaping tool. After the steel has been processed into a ring shape using one of the two methods, the rings are first heated to their phase transformation temperature in the process of austenitisation. Then, the bearing rings are quenched. The aim here is for the rings to achieve the desired hardness. In the third step, during tempering, the steel is heated again to reduce the residual stresses that have developed in the material. To produce the final shape, the bearing rings are now ground further so that the diameters of the rings are brought to the desired size and the bearing raceways are completely machined.

Manufacturing of rolling elements

Steel in the form of round bars is used as the raw material for the rolling elements. The blank, as it is known, is cut to length, pressed, punched and deep-drawn before being shaped into a round form with the help of a ball mill. Rolling elements are also subjected to the same heat treatment as the inner ring and outer ring. The geometry of the balls is then improved by grinding them in several machining stages. In the final machining stage, the rolling elements are inspected, sorted and preserved.

Manufacturing of cages

The process of cage production using a sheet steel cage as an example, can be described as follows: First, a sheet steel strip is punched out and shaped so that that pockets are created for the rolling elements. The cage consists of two halves, which are later joined either by spot welding or riveting. After the balls have been inserted and positioned between the bearing rings, the cage can be inserted and both halves joined.

Material	Components	Advantages and disadvantages

Steel	Bearing rings, rolling elements	Advantages: Withstands high loads and impact forces, not susceptible to breakage, quieter than ceramics Disadvantages: High weight and quite low limiting speeds, not suitable for temperatures above 120°C as standard without special heat treatment
Ceramics	Bearing rings, rolling elements	Advantages: Lighter than steel and higher limiting speeds, suitable for use at cold and hot temperatures Disadvantages: Less tolerant of high loads and impacts, higher noise generation than steel, comparatively expensive

The types of application as well as advantages and disadvantages of steel and ceramics can be found here.

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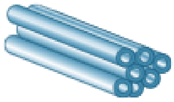
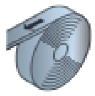
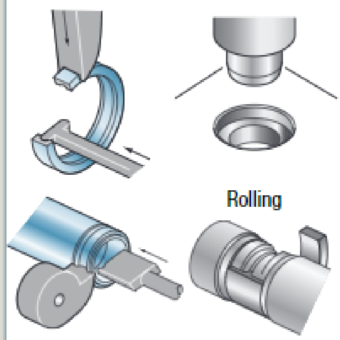
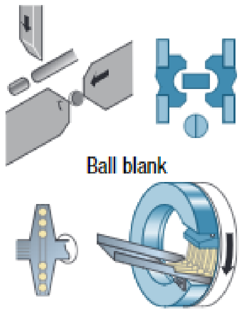
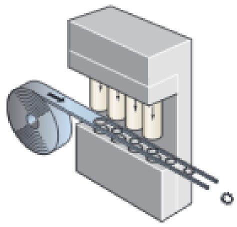
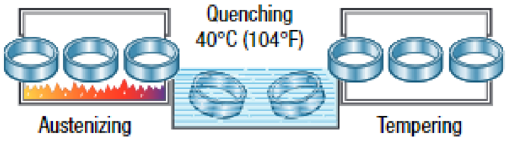
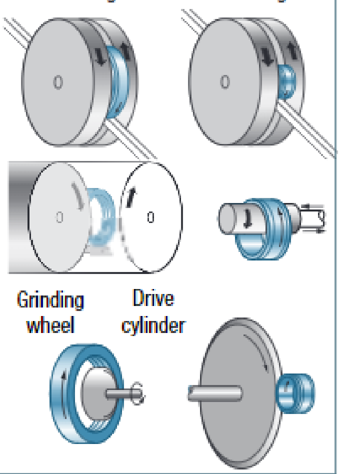
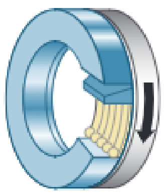
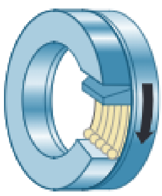
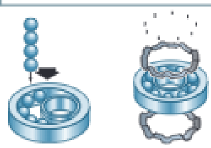
Operation	Rings	Rolling elements	Cage
Material	Tubes, bars 	Wire	Coil strips 
Shaping	Turning / Forging / Rolling 	Cutting and cold heading / Ball blank 	Drawing steel cages  Molding of plastic cages / Turning of solid metal cages
Heat treatment	 Austenizing 830° (1,526°F) / Quenching 40°C (104°F) / Tempering 170° (338°F)		
Finition	**Finishing**  **Honing**	Grinding on grinding wheel  Lapping with abrasive paste between 2 plates 	
Assembly of the bearing	Washing, Marking, Final inspection, Packing		

Here you can see an overview of the individual steps in the production process of standard rolling bearings.

Further information

Now it has become clear what rolling bearings are made of and how they are made. If you want to learn more, you can also find out about the different types of rolling bearings, selecting the correct bearing or the design of bearing arrangements on this platform.

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Summary

- There are basically two types of rolling bearings: Ball bearings and roller bearingsger
- Ball bearing: Spherical rolling elements, point contact between rolling elements and bearing raceway, suitable for high speeds (e.g. deep groove ball bearing)
- Roller bearings: Roller-shaped rolling elements, line contact between rolling elements and bearing raceway, suitable for high loads (e.g. cylindrical roller bearings

If you have read our article on rolling bearing basics, you probably already know that rolling bearings can basically be divided into two types – ball bearings and roller bearings.

Ball bearing

Ball bearings are generally characterised by the fact that their rolling elements have the shape of a ball and contact the bearing raceway at one point. When they are loaded, the contact area forms a circle due to elastic deformation. Due to the point contact, the rolling resistance of this type of bearing is low, so the bearings are primarily used in applications with higher speed and lower loads. Normally, their load capacity is not as high as that of roller bearings, however radial ball bearings can support loads in both axial and radial directions.

Rolling bearing types overview

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Ball bearings are circular and have round rolling elements.

The elongated rolling elements of the roller bearings, here using cylindrical roller bearings as an example, have linear contact with the raceway.

Roller bearing

Roller bearings generally have the opposite characteristics of ball bearings: The contact surface of the loaded rolling elements with the raceway has the shape of a rectangle due to elastic deformation. Line contact leads to a comparatively high frictional torque and higher rigidity. For this reason, roller bearings are more suitable for applications with lower speeds compared to ball bearings. Roller bearings have a high load carrying capacity. With a few exceptions, they mainly support radial loads only.

Ball bearing	Roller bearing
Point contact	Line contact
Low rolling resistance	High frictional torque
Suitable for high speed applications	Applications must have lower speed than ball bearings
Lower load capacity	Higher load capacity, high stiffness
Load capacity typically possible in radial as well as axial direction	Load capacity in most cases only possible in radial direction

Where there is light, there is also shadow: Speed and load carrying capacity are important factors in the context of rolling bearings, but they can never be high at the same time.

Rolling bearing types overview

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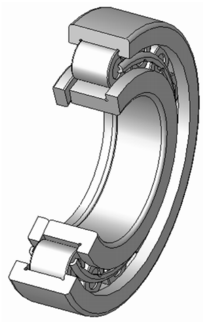
Ball bearing and roller bearing types

Well-known ball bearing types are deep groove ball bearings, angular contact ball bearings and four-point contact bearings. Among the roller bearings, cylindrical roller bearings are particularly noteworthy. Other roller bearing types in which the rolling elements have a slightly modified form of a cylindrical roller are, for example, needle roller bearings and tapered roller bearings. In the subchapters of the rolling bearing types section, in-depth information on the individual ball bearing and roller bearing types as well as housing bearings can be found. The main properties of individual bearing types can be viewed in the table as an overview.

Type	Image	Advantages	Disadvantages
Ball bearing			
Deep groove ball bearing		• Many lubrication options • Available in many sizes	• Sensitive to shock loads • Relatively low service life
Angular contact ball bearing		• Can be mounted in pairs. Higher load capacity than deep groove ball bearings • Preload possible	• Comparatively complex assembly and higher costs

Thrust (axial) deep groove ball bearing		• Separate installation of individual components possible • Can only compensate for misalignments to a limited extent • Must be radially clear by design	• Lower speeds
Roller bearing			
Cylindrical roller bearing		• High load rating with the same installation space as other bearings • Highest speeds of all roller bearings	• Misalignment should be avoided • High friction with full complement types
Tapered roller bearing		• Supports combined radial and axial loads • For use in pairs. Bearing clearance and preload can be adjusted as required	• Lower limiting speeds than other roller bearings • Oil lubrication often necessary

Rolling bearing types overview

Spherical roller bearing		• Support combined radial and axial loads • Highest load capacity of all rolling bearings • Accommodates misalignment	• None other than typical roller bearing disavantages in general
Needle bearing		• Compact • Suitable for oscillating loads • Low cost • Highest load ratings with minimum space requirement compared to other rolling bearing types	• Increased noise • Misalignment should be avoided

In addition to the general advantages and disadvantages of ball bearings or roller bearings, the individual bearing types have specific properties.

Rolling bearing types overview

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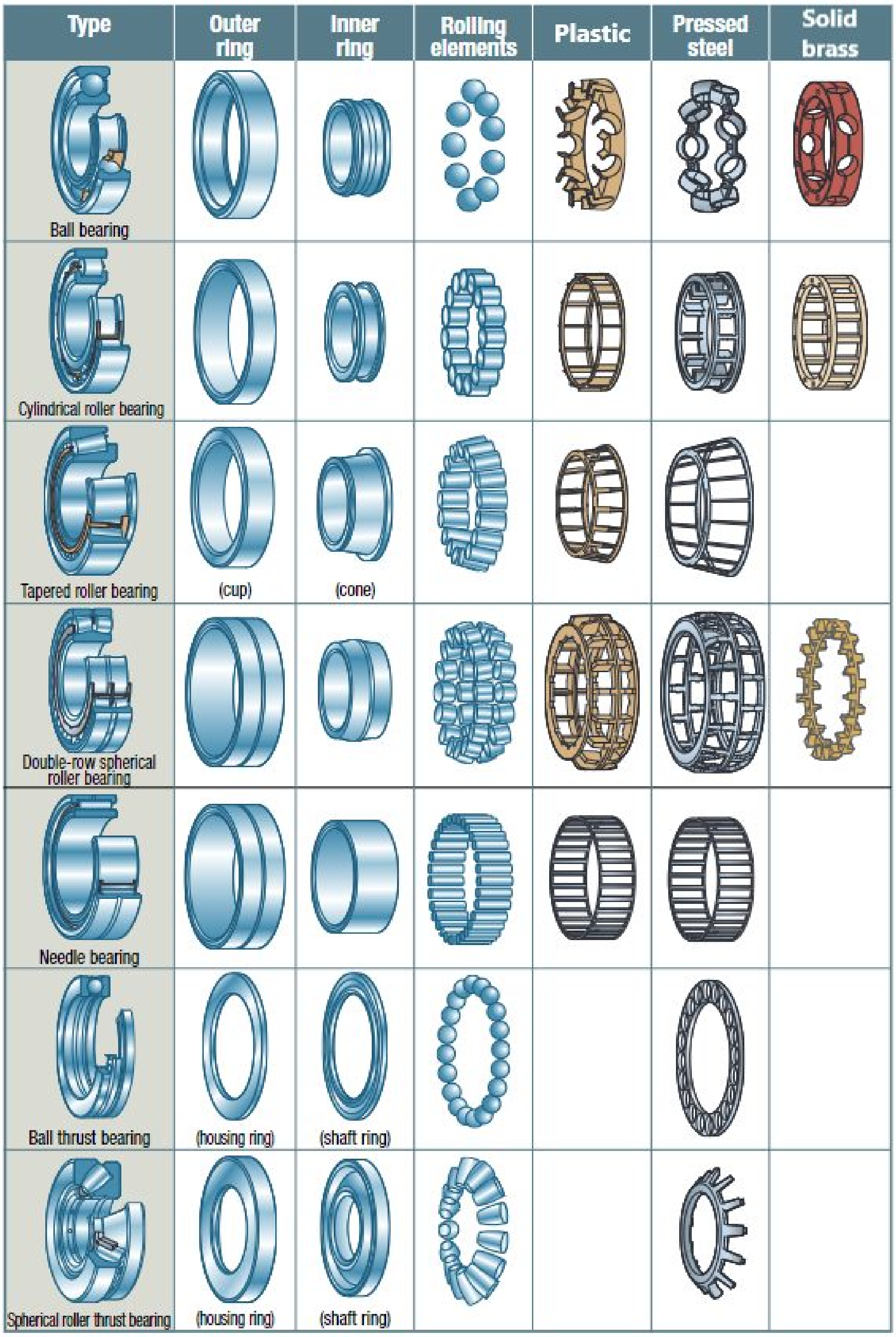

Rolling bearing types overview

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This table gives you an overview of the most important types of rolling bearings, including their rolling elements and cage designs.

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The deep groove ball bearing

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Summary

- Deep groove ball bearings are the most widely used bearing type
- They are used in many different ways in a wide variety of applications
- Suitable for high speed applications
- Bearing code: 6
- Axial (thrust) deep groove ball bearings can only support axial loads and are not suitable for high speeds
- Sealed deep groove ball bearings have grooves in the bearing rings that allow seals to be fitted

Characteristics of deep groove ball bearings

In its current form, the deep groove ball bearing has existed – subject to some optimisation – for about 150 years. However, deep groove ball bearings are not only one of the oldest rolling bearing designs, but also the most common bearing type and are therefore, so to speak, the classic among rolling bearings. They can be used in a wide variety of applications. Among other things, deep groove ball bearings are installed in electric motors, small gearboxes and PC drives. It is therefore very likely that you have already come into contact with deep groove ball bearings during your studies, training or career.

Deep groove ball bearings are non-separable bearings with deep raceways that are suitable for supporting both radial and axial loads from both directions. Accordingly, they can also

Like all rolling bearings, the deep groove ball bearing is composed of an inner ring, outer ring, rolling elements (balls) and a cage.

support complex loads. These are loads resulting from the combination of radial and axial forces. When balls are used as rolling elements, they are in point contact with the raceway surfaces. In rolling contact, only a small area is stressed with each overrolling, which means that only a small amount of heat is generated. Deep groove ball bearings are therefore particularly suitable for applications with high speeds. In addition, these bearings can be lubricated with grease or oil. Last but not least, deep groove ball bearings are available in many sizes and designs. A characteristic disadvantage of ball bearings, on the other hand, is that the load capacity is limited due to the point contact of the rolling elements. Furthermore, deep groove ball bearings are sensitive to impact loads and they may have a relatively low life expectancy.

A deep groove ball bearing can always be recognised by the code number 6. It can be divided into eight different dimensional series. The dimensional series is identified by the second (or third for 160) digit of the bearing designation and indicates the width and diameter series of the deep groove ball bearing in each case. Regardless of the dimensional series, it is usual that the cages for smaller sizes are made of sheet steel unless otherwise stated. For some deep groove ball bearing series (especially for large bearings and bearings for high speeds), solid cages are mainly used. Incidentally, there are fixed rules for the pronunciation of bearing designations: For example, a deep groove ball bearing with the code number 6307 is verbally referred to as “sixty three oh seven”.

Bearing series	Sheet steel cage	Solid brass cage
67	6700-6706	—-
68	6800-6834	6836-68/600
69	6900-6934	6936-69/500
160	16001-16052	16056-16072
60	6000-6052	6056-6084
62	6200-6244	—-
63	6300-6344	—-
64	6403-6416	—-

Deep groove ball bearings of series 68, 69, 160 and 60 are equipped with a solid brass cage as standard at NTN for larger sizes.

Axial deep groove ball bearings are defined with the code number 5 and a five-digit

Axial (thrust) deep groove ball bearing

A subgroup of deep groove ball bearings are thrust deep groove ball bearings. With regard to their design, the advantage is that these bearings are self-contained and consist of several parts (a shaft locating washer, housing locating washer, a ball and cage assembly).

bearing designation.

This makes it possible to install the parts separately. The shaft washer of the bearings has a ground bore; in contrast, the bore of the housing washer is larger and turned. Both washers also have formed rolling bearing raceways, also called running grooves. As with conventional deep groove ball bearings, sheet steel cages are often installed in axial deep groove ball bearings. However, the use of other cage materials is also possible here. Axial deep groove ball bearings must be radially floating.

As can be assumed from the name, these bearings can only support axial loads. Depending on the design, these axial forces may act on one or both sides, but the bearings are not capable of supporting radial forces. In terms of their design, double direction axial deep groove ball bearings have one or two differences compared to single direction bearings. Although there is a shaft locating washer, there are two housing locating washers and ball and cage assemblies. Last but not least, they can guide the shaft to both sides.

Axial deep groove ball bearings usually have a contact angle of 90° and differ from standard deep groove ball bearings in that axial preload is necessary to prevent slippage between the rolling elements and the races. Bearings with a housing washer with a spherical outer diameter are basically able to compensate for misalignments that occur between the shaft and housing. Unlike radial ball bearings, axial deep groove ball bearings are not suitable for applications with high speeds.

The deep groove ball bearing

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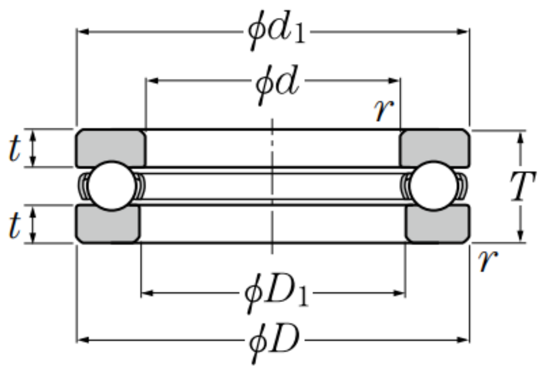
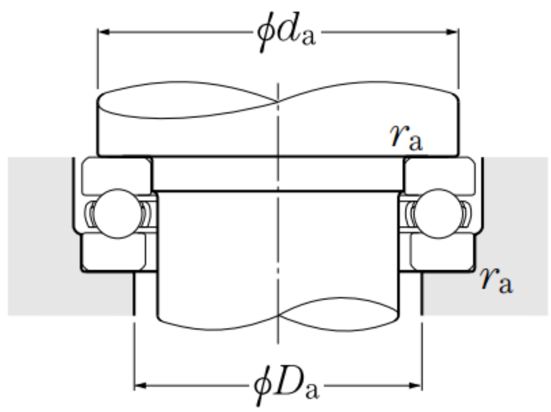
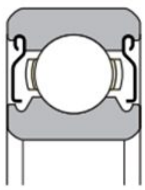
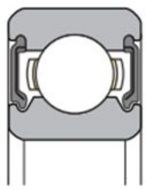
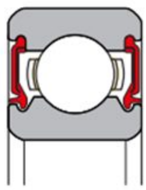
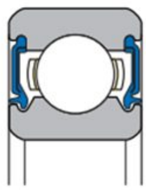




This is what the technical drawing of a single direction axial deep groove ball bearing looks like.

Types and codes		Shielded type	Sealed type		
		Non-contact type ZZ	Non-contact type LLB	Contact type LLU	Low torque type LLH
Construction					
		Metal shield plate is fixed to the outside ring; the inner ring incorporates a V-groove and labyrinth clearance.	The outer ring incorporates synthetic rubber molded to a steel plate; seal edge is aligned with V-groove along inner ring surface with labyrinth clearance.	The outer ring incorporates synthetic rubber molded to a steel plate; seal edge contacts V-groove along inner ring surface.	Basic construction is the same as LLU type, but a specially designed lip on the edge of the seal prevents foreign matter penetration; low torque construction.
Performance comparison	Torque	Small	Small	Higher	Medium
	Dust proofing	Good	Better than ZZ-type	Excellent	Much better than LLB-type
	Water proofing	Poor	Poor	Very good	Good
	High speed capacity	Same as open type	Same as open type	Limited by contact seals	Much better than LLU-type
	Allowable temp. range [(1)]	Depends on lubricant	-25 to 120°C	-25 to 110°C	-25 to 120°C

Common seal types for deep groove ball bearings at a glance. In the lower part of the *pictures you can see the V-shaped groove on the inner ring.*

Sealing **of deep groove ball bearings**

In this context, some basics on the subject of seals are also important. It is helpful to know that for attaching a seal, the inner ring has a V-shaped groove. The seal is attached on the opposite side, i.e. on the outer ring, and extends to the groove. It depends on the design of the seal whether and to what extent it touches the inner ring at the groove. During the rotation of the bearing and the associated effect of the centrifugal force, the groove also serves to keep dirt on the outside. The grease in the bearing, on the other hand, is conveyed further inwards.

If you want to know more about this, you can find more detailed information in our chapter on seals.

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The angular contact ball bearing

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Summary

- Angular contact ball bearings can be used universally and are more robust than deep groove ball bearings
- Use of a seal is optional
- Code number: 7 (single row), 3 or 5 (double row)
- Pairing of two angular contact ball bearings (in O, X or tandem arrangement) possible, but this leads to relatively complex mounting
- Other angular contact ball bearing types are spindle bearings and four-point contact bearings

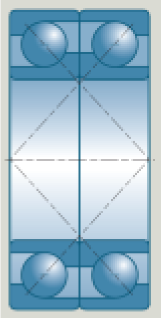
The angular contact ball bearing is virtually the brother of the deep groove ball bearing.

Characteristics of angular contact ball bearings

Perhaps you already know some characteristics of the deep groove ball bearing. This will be helpful in this text, because the angular contact ball bearing is very similar to the deep groove ball bearing in terms of its structure. Nevertheless, there are a few crucial differences. Angular contact ball bearings can also be used universally in many applications and are sometimes installed specifically in machine tools.

Just like deep groove ball bearings,

angular contact ball bearings cannot usually be dismantled. They have a defined contact angle α, which is relative to the radial plane and represents a connecting line between the contact points on the inner ring, on the ball and on the outer ring.



With paired angular contact ball bearings in an X arrangement, axial forces can be absorbed in two different directions.

A double-row angular contact ball bearing cross-section. The rolling elements have a common inner and outer ring.

Angular contact ball bearings can support radial loads as well as axial loads from one direction. Depending on the ratio of axial and radial loads, angular contact ball bearings with different contact angles are used. With regard to axial forces, angular contact ball bearings are therefore also more robust than, for example, a deep groove ball bearing. Two angular contact ball bearings are often paired with each other, which results in two rows of rolling elements next to each other. As a result, axial forces acting on the bearings can run in two different directions (O or X arrangement) or a greater load can be supported in one axial direction (tandem arrangement). In addition, angular contact ball bearings may be preloaded so that there is little or no bearing play . The advantage of preloading is that angular contact ball bearings can thus be adapted to the application in terms of bearing rigidity, shaft guidance and concentricity.

The angular contact ball bearing

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The fact that axial loads can only be absorbed in one direction, can be more of a curse than a blessing, as it is imperative to pay attention to the mounting direction when mounting individual angular contact ball bearings. However, if it is clear that axial forces can occur in both directions, the use of paired angular contact ball bearings is indispensable. Similar to deep groove ball bearings, angular contact ball bearings can also have a seal. Due to the paired installation, the mounting of angular contact ball bearings is more complicated than with deep groove ball bearings. In addition, the costs are higher if two bearings have to be installed.

According to the standard, single-row angular contact ball bearings are marked with the code number 7 and double-row angular contact ball bearings with 3 or 5. Cages for angular contact ball bearings are basically available in the three common materials: plastic, sheet steel and brass. The cage material used can be adapted according to the application. For smaller sizes, a plastic or sheet steel cage is often used for cost reasons.

Type	Bearing series	Plastic cage	Sheet steel cage	Solid brass cage
Standard	79 70 72 73 72B 73B	7904-7913 7000-7222 —- —- —- —-	—- —- 7200-7222 7300-7322 7200B-7222B 7300B-7322B	7914-7960 7026-7040 7224-7240 7324-7340 7224B-7224B 7324B-7340B
Double row	52 53	—- —-	5200S-5317S 5300S-5314S	—- —-
4-point contact	QJ2 QJ3	—- —-	—- —-	QJ208-QJ224 QJ306-QJ324

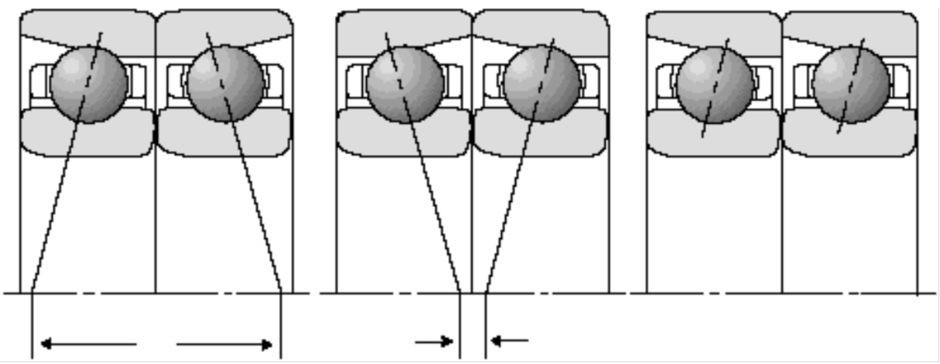
Merrily mixed: some NTN bearing series come as standard with plastic cages, some with *sheet steel cages and others with solid brass cages.*

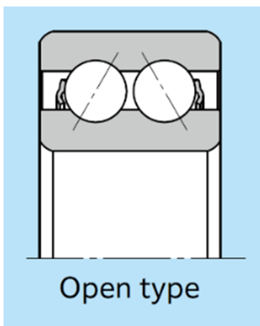
Angular contact ball bearing pairing

As mentioned before, angular contact ball bearings can be paired. It is possible to install the rolling elements into different arrangements. The most common arrangements of the bearings are the O, X and tandem arrangement. Especially in machine tools, bearings can also be arranged in multiple combinations of more than two.

Other angular contact ball bearing types: Spindle bearings and four point contact bearings

In addition to single and double row angular contact ball bearings, there are other types. These include, for example, spindle bearings or four-point contact bearings. Spindle bearings are manufactured in better tolerance classes than standard angular contact ball bearings and have smaller rolling elements. These are useful for achieving very high speeds. What is special about four-point contact bearings is that they can be loaded axially from any direction.





The O, X and tandem arrangement of rolling elements in paired angular contact ball bearings.

O arrangement of rolling elements in a double row angular contact ball bearing.

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The spherical roller bearing

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Summary

- Spherical roller bearings are universally applicable rolling bearings
- They are mainly used in heavy industrial machinery
- They are self-aligning and have two rows of rolling elements
- Spherical roller bearings have a high load carrying capacity and can compensate for relatively large misalignments
- Bearing code: 2
- Two spherical roller bearing designs at NTN: B-type and E-type
- When mounting bearings with a tapered bore, an adapter sleeve may be used

Characteristics of spherical roller bearings

Spherical roller bearings are real all-rounders. They are able to support heavy loads in both axial and radial directions. Spherical roller bearings are mainly used in heavy industrial machinery – for example in ship propellers, stone crushers or as main rotor bearings in wind turbines.

The raceways of spherical roller bearings are spherically ground, allowing the rows of rolling elements to oscillate about the axis of rotation. The rolling elements are barrel-shaped and, due to their axes being inclined relative to the axis of rotation of the bearing, can swing out and counteract a misalignment. Spherical roller bearings are completely self-aligning.

The spherical roller bearing

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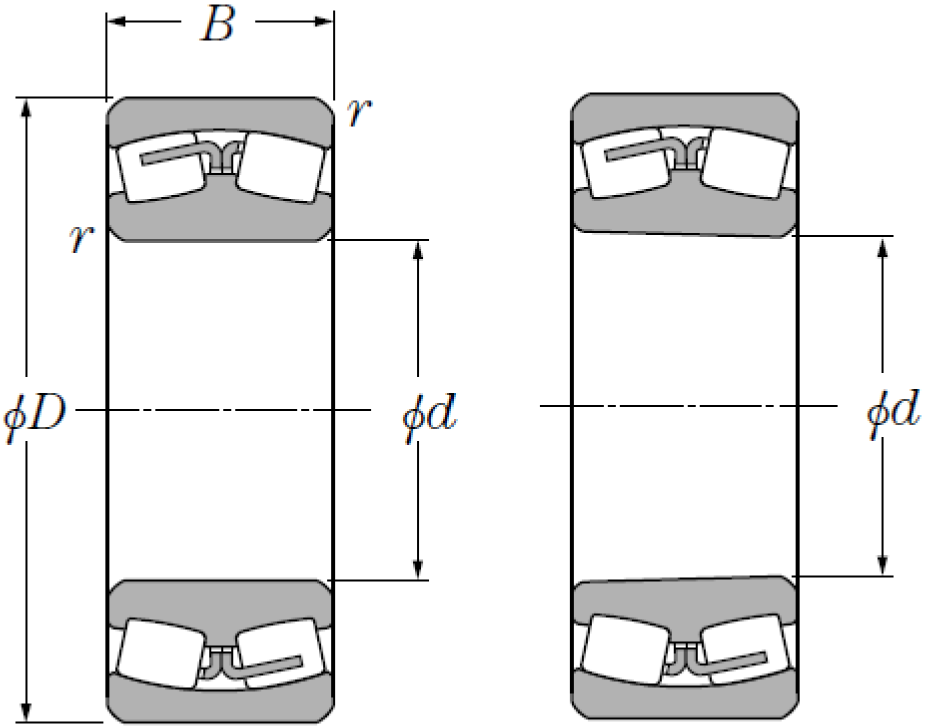


In this technical drawing of a spherical roller bearing, the inner ring, outer ring, both rows of rolling elements and cage are clearly visible.

The striking thing about the rolling elements of spherical roller bearings is their barrel shape.

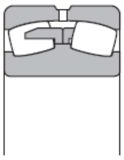
Spherical roller bearings have various advantages. On the one hand,

Easy to swing the 'cassette': Spherical roller bearings inner ring can swing out very far without causing increased Hertzian pressures in the edge area of the rolling elements.

thanks to their design, they can support a combination of radial and axial loads on both sides (combined loads). On the other hand, spherical roller bearings generally have a high load carrying capacity and are capable of withstanding shock loads. The main advantage over other rolling bearing designs is that spherical roller bearings can compensate for static and dynamic misalignments up to a maximum of 2°. Spherical roller bearings are universally applicable rolling bearings and when cost is measured against their high performance, have an optimal price-performance ratio.

After the whole series of advantages that spherical roller bearings bring with them, the question arises as to whether they also have disadvantages. Strictly speaking, there is only one aspect worth mentioning here: Spherical roller bearings capability to support purely axial loads is limited.

B type



The centre ribs in direct contact with the asymmetrical rolling elements are clearly visible.

The bearing type code number for spherical roller bearings is 2. There are also various spherical roller bearing designs, the first of which is the B design.

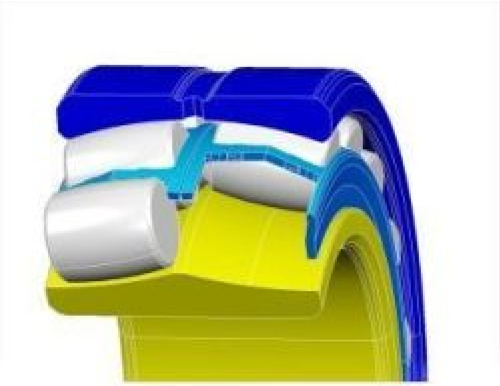
This is the original standard type at rolling bearing manufacturer NTN. It is characterised by asymmetrically ground rollers. Due to their geometry, the rollers are pressed against the integral centre rib, resulting in excellent kinematic rolling behaviour with low friction. The disadvantage of the B-type is a relatively lower load rating in relation to the symmetrical roller type (E-design). The B-type can be equipped with a plastic, sheet steel or solid cage and is useful for various types of applications.

E type

In addition to the B-type, E-type spherical roller bearings are also of importance and are generally characterised by a particularly high load carrying capacity. They can be subdivided again; the EA, EM, EMA and EG15 designs are worth mentioning in this context. All four have in common that they are part of the NTN Ultage series (Ultage is the premium design of various rolling bearing types at NTN). They are thus optimised E-type bearings. Furthermore, the rolling elements of all E-Type bearings have symmetrical rollers. They also have a circumferential groove and lubrication holes, so the bearing can be relubricated easily. All open spherical roller bearing designs from NTN can be used at operating temperatures of up to 200°C.

EA type

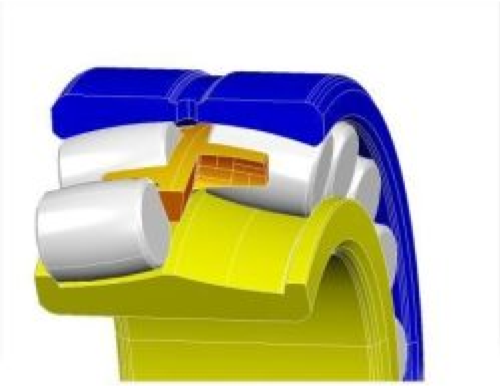
There are some differences between the various E types, which is why the individual designs are presented in more detail below, starting with the EA type. This type has a sheet steel cage with inner ring guide, which consists of two halves. The cage has special pockets that precisely guide and hold the rolling elements. The EA design is used in general applications.



EA-type bearings are sometimes characterised by improved speed properties, and all Ultage designs also feature a longer service life.

EM type

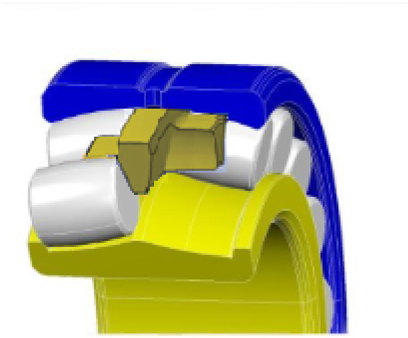
The EM type differs from the EA type in that it is equipped with a one-piece solid brass cage. This is indicated by the suffix M in the type designation. In this case, the cage is roller-guided and there are side ribs on the inner ring which serve as roller guides. The use of bearings of EM design makes sense in difficult application conditions such as high levels of shocks and vibrations.



The solid brass cage of the EM design has - compared to other types of cages - very good impact and vibration resistance.

EMA type

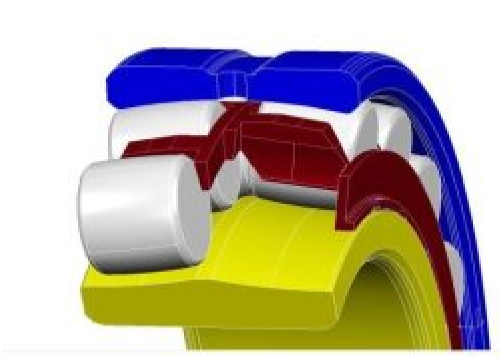
The EMA types have a one-piece reinforced solid brass cage. Similar to the EM type, the EMA design also has side ribs for roller guidance on the inner ring, but the cage is outer ring guided. The EMA type is used in applications where the demands on the cage are even higher than with the EM design. Designs such as the EMA design may be more expensive than EM designs due to the more complex production technology.



Optimised raceway curvature, which all four E-types presented have, also leads to high load-bearing capacity in the EMA design.

EG15 type

In a bearing of the EG15 design, a two-piece polyamide cage, which is rolling element guided, is installed as standard. The EG15 type has no conventional side ribs; instead an optimised contour is built into the cage, which serves an efficient roller guide as well as distributing lubricant more efficiently. Due to the use of plastic (polyamide) as cage material, it has a maximum operating temperature of 150°C. EG15 bearings are therefore only suitable for applications with moderate operating temperatures and are often used in applications where low noise is required.



Attention! You must not forget that EG15 designs cannot be used at temperatures higher than 150°C.

Sealed spherical roller bearings

In E-Design there are also other spherical roller bearing types, for example sealed bearings. These are used in environments where there is a risk of foreign particles entering the bearing. In addition to bearings with a contact seal, NTN also offers types with metal shields, referred to as the 'Kizei' ® series. These are located between the inner and outer ring and are intended for use in applications with particularly coarse contamination, as there is still a small gap between the outer ring and the shield (suffix Z). The advantage of this bearing type is that they still have the standard width of an open spherical roller bearing and do not require additional installation space, unlike types with a contact seal.

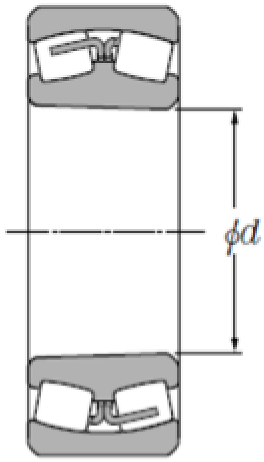
A version of the E-design with contact seals (left) as well as the E-design with shields (right) are also part of the Ultage series from NTN.

Spherical roller bearings with tapered and cylindrical bore

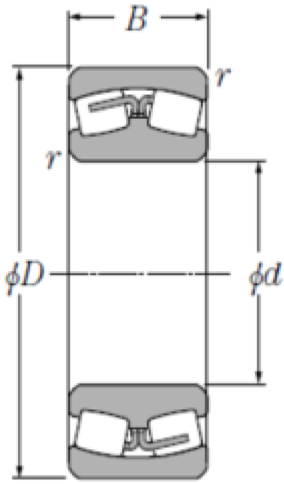
For spherical roller bearings, types exist with either a conical or tapered bore (suffix K) and with a cylindrical bore.

Adapter sleeves play a central role in installing spherical roller bearings with a tapered bore. An adapter sleeve is used between the shaft and the inner ring in these bearings and facilitates fitting. In this case, the bearing and the adapter sleeve can be freely positioned on the shaft before the bearing is fastened. In addition, the adapter sleeve offers the advantage that the bearing clearance can be adjusted a little with its help. Lock nuts and locking plates are also required for mounting. In addition to adapter sleeves, there are also withdrawal sleeves that are used not only for mounting but also for easier dismounting of the bearings.

The installation of a bearing with a cylindrical bore on the other hand, makes sense in applications that do not offer much space. In such cases, the bearing is heated and mounted using a suitable heating source.



The bearing clearance of spherical roller bearings with a tapered bore can be adjusted more precisely via the displacement path compared to other spherical roller bearings.



For bearings with a cylindrical bore, a suitable heating source is often used.

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The tapered roller bearing

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Characteristics of tapered roller bearings Here you see an NTN tapered roller bearing. As the name suggests, tapered roller bearings are roller bearings, whereby the

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The cylindrical roller bearing

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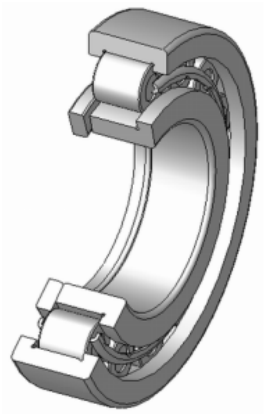
Summary

- Cylindrical roller bearings have a high load rating but relatively low limiting speeds
- Use in gearboxes, as wheelset bearings or in electric motors
- They may have lips on the bearing rings
- Bearing code: N (N, NU, NJ, NF, NUP and NH)
- Ultage cylindrical roller bearings have an optimised roller profile and profiled raceway surfaces. They can have a longer service life than conventional bearings
- They are also available in 2 and 4 row designs

Characteristics of cylindrical roller bearings

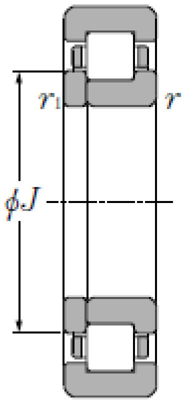
Do you remember the characteristic that all roller bearings have in common? We are talking about line contact, which can also be seen in cylindrical roller bearings. These bearing types are therefore suitable for supporting very high loads, especially radial loads. For this reason, cylindrical roller bearings are typically used in gearboxes of, for example, wind turbines; as wheelset bearings of rail vehicles or as non-locating bearings in electric motors.

Several components of cylindrical roller bearings are profiled, including the end faces of the rolling elements, the guide ribs of the raceway and the raceway itself. The rolling elements are also logarithmically profiled. The profiling of the rolling elements ensures better lubricant distribution on the guide rib, and also optimises the surface contact pressure. A special feature is that in addition to the mandatory components, e.g. inner ring, outer ring, rolling elements and cage, which are characteristic of every rolling bearing, cylindrical roller bearings can have additional lips. The fixed lips, which are directly integrated in the inner and/or outer ring, and the loose collar rings serve to guide the rollers on one or both rings. Depending on the design of the cylindrical roller bearing, which can be chosen based on application conditions, it is quite easy to remove one of the rings from the bearing. Furthermore, the lubrication of cylindrical roller bearings is even more important compared to other bearing types because their components are subjected to high friction.



In this cylindrical roller bearing example, you can find the removable collar ring on the left side of the inner ring.

So far, so good. But what other special features do cylindrical roller bearings have? On the one hand, it is worth mentioning that they have a higher load rating for the same installation space as ball bearings or tapered roller bearings and can support higher radial loads.. In addition, despite the line contact, cylindrical roller bearings achieve the highest limiting speeds compared to many other roller bearings. As already indicated, mounting and dismounting of these bearings is generally quite uncomplicated due to the separability of



Cylindrical roller bearings are primarily designed to support radial loads.

the inner and outer ring. In some designs, the rollers can also slide axially on the inner or outer ring, so that cylindrical roller bearings can be used as non-locating bearings. However, individual types (NUP, NH on both sides and NF, NJ on one side) are also suitable for supporting low axial loads. Full complement cylindrical roller bearings, (bearings without a cage), offer the advantage that more rolling elements are installed in the same space and the load rating is therefore increased.

A disadvantage in direct comparison with ball bearings is that cylindrical roller bearings have lower limiting speeds due to the line contact of the rolling elements. Furthermore, cylindrical roller bearings are significantly more sensitive to shaft deflection than ball bearings, so misalignment should be avoided with these bearing types. In full complement cylindrical roller bearings, higher friction occurs because the rolling elements are in direct contact with each other and therefore rub against each other at high speed. In order to keep the heat generation due to friction low, sufficient lubrication is necessary. With oil lubrication, heat can be further dissipated through the oil flow.

Basically, the designation of cylindrical roller bearings starts with the letter N. Types NU and N are typically used as non-locating bearings and are not suitable for axial loads, as they only have ribs on one bearing ring. Cylindrical roller bearings with the designations NJ and NF can support axial loads from one direction and types NUP and NH are even suitable for axial loads from both directions. However, the axial load should be kept low, otherwise the rollers will generate excessive contact pressure with the lips. These types can then be used as fixed bearings for the shaft.

The cylindrical roller bearing

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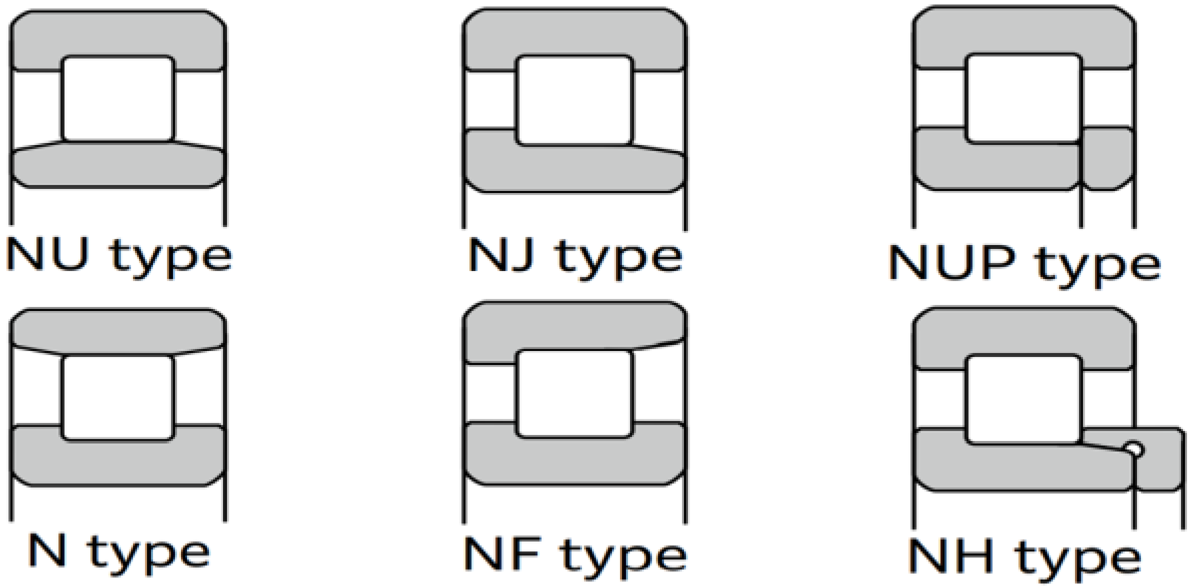

Type	Properties
NU	Two lips on the outer ring; outer ring, rollers and cage can be separated from the inner ring.
N	Two lips on the inner ring; inner ring, rollers and cage can be separated from the outer ring.
NJ	Two lips on the outer ring, one lip on the inner ring.
NF	One lip on the outer ring, two lips on the inner ring.
NUP	Two lips on the outer ring, one lip on the inner ring; a loose flanged ring on the rib-free side of the inner ring, which can be removed.

NH	Similar to the NJ version, but has an enclosed angle ring; the angle ring can be removed.

Here you can see cylindrical roller bearing types and their most important characteristics at a glance.

NTN cylindrical roller bearings can be combined with the three usual types of cage. Whether a plastic, sheet steel or solid cage is ultimately fitted in a bearing depends, as usual, on the bearing series and size as well as the application conditions.

Bearing series	Plastic cage	Pressed steel cage	Solid brass cage
NU10, NJ10, NUP10, N10	—-	—-	1005-10/500
NU2, NJ2, NUP2, N2, NF2, NU2E	204E-218E	208*-230	232-264
NU22, NJ22, NUP22, N22, NU22E	2204E-2218E	2208*-2230	2232-2264
NU3, NJ3, NUP3, N3, NF3, NU3E	304E-314E	308*-324	326-356
NU23, NJ23, NUP23, N23, NU23E	2304E-2311E	2308*-2320	2322-2356
NU4, NJ4, NUP4, N4, NF4	—-	405-416	417-430

Here it becomes clear that none of the bearing types at NTN can be assigned exclusively to one cage material.

The cylindrical roller bearing

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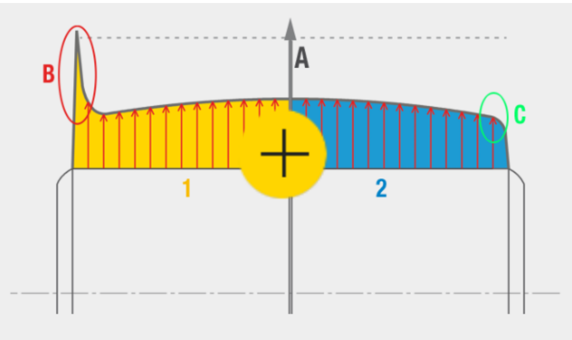

The illustration shows the difference between the load on a rolling element with a standard profile (1) and with an optimised profile (2).

Ultage cylindrical roller bearings

Have you ever heard of the Ultage series? Ultage bearings from NTN are a further development of standard bearings, for example cylindrical roller bearings. These not only have larger rolling elements and a generally optimised roller profile, but also profiled raceway surfaces. Due to this profiling, bearings of this series are characterised by larger permissible misalignments than the original cylindrical roller bearings. These features mean that the service life, dynamic load carrying capacity and also the limiting speeds are higher compared to the standard bearings.

Multi-row cylindrical roller bearings

As with various other types of rolling bearings, there are special types of cylindrical roller bearings. Just like angular contact ball bearings, cylindrical roller bearings can be used in double rows to increase the load capacity. It makes sense to

use them in applications where a reduced cross-sectional area is required. But that's not all: it is possible to directly line up four of these bearings. Four-row cylindrical roller bearings are predominantly used as roller journal bearings because of their maximum load carrying capacity.

Anyone who thinks double-row bearings are the limit is mistaken. It is actually possible to fit cylindrical roller bearings in *four rows.*

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Summary

- Tapered roller bearings are used, among other things, in wheel bearings
- They support a combination of radial and unilateral axial loads
- They absorb high loads, but at the same time are characterised by high friction
- The rolling elements can be subject to crowning (modification) to reduce contact stresses at the ends
- They can be paired and even used in four rows
- Bearing code: 3. Paired tapered roller bearings: 4

Characteristics of tapered roller bearings

Here you see an NTN tapered roller bearing.

As the name suggests, tapered roller bearings are roller bearings, whereby the term tapered is inspired by the shape of the rollers. Tapered roller bearings are used, among other things, in construction or agricultural machinery, in vehicle construction, for example in wheel bearings, but also in general mechanical engineering.

The tapered roller bearing

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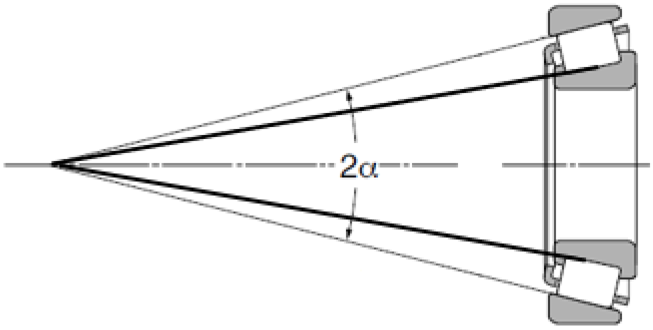
In tapered roller bearings, the inner ring and outer ring as well as the rolling elements are arranged in such a way that they form an angle that intersects the shaft axis at the same point. This inclined arrangement produces an axial force and the rolling elements theoretically roll without sliding friction components. Tapered roller bearings offer an advantage atypical of roller bearings in general. These bearings can support a combination of radial and unilateral axial loads, although care must be taken to ensure that no purely axial load is applied to the bearing.



The points of taper alignment of the inner and outer ring as well as the rolling elements (rollers) have a common point of intersection.

Because the contact angle of tapered roller bearings can be individually specified, the bearings can handle different radial-axial load combinations. Tapered roller bearings can support high loads and are usually used in pairs, in which case the bearing clearance or preload can be adjusted as required.

Compared to ball bearings, but also to cylindrical roller bearings, tapered roller bearings have lower limiting speeds, as additional friction occurs at the rib due to the design and use of a preload. In addition, tapered roller bearings require more lubrication than the other bearing types due to the high friction; therefore, elaborate oil lubrication is usually used. Furthermore, tapered roller bearings are characterised by complex and relatively expensive handling and mounting.

The tapered roller bearing

Without going into too much detail, it should be mentioned that for tapered roller bearings there are three different marking systems with different structures. In addition to the metric (Europe and Asia) and inch dimensions (USA), there is the J-series, which is a mix of the other two systems. In the metric system, tapered roller bearings can be identified by the bearing designation beginning with 3. In addition, as with other rolling bearing types, information follows on the width and diameter series as well as the bore diameter. The cages used in tapered roller bearings are mainly made of sheet steel, but plastic cages are also used, especially in small tapered roller bearings. These bearings are sometimes used in the automotive industry. Large tapered roller bearings, on the other hand, usually have brass cages.

Bearing series	Pressed steel cage, roller-guided	Solid steel cage, roller-guided
329...X	Up to 80	From 84
329...	Up to 80	From 84
320 X	Up to 64	—-
320...	Up to 68 (except 64)	64, from 72
330...	All	—-
331...	All	—-
302...	Up to 52	56-64
322...	Up to 52, 60	From 56 (except 60)

332...	All	—-
303...	02-38	From 40
303...D	Up to 24, 28	26, from 30
313...X	Up to 24, 28	26, from 30
323...	Up to 40	36, from 44

The cages used in tapered roller bearings are usually guided by the rolling elements.

Misalignment **of tapered roller bearings**

Another important question is to what extent tapered roller bearings can be subjected to misalignment, i.e. how much the angle between the bearing and the shaft or housing may deviate from a right angle. The allowable misalignment also depends on the bearing arrangement. Roller bearings are generally very sensitive to misalignment because the rolling elements are subjected to extreme loads at one point while the area at another point remains completely unloaded. In this context, the term “crowning” should be mentioned, which is understood to mean that the rolling element has a profiled surface in order to achieve a more balanced distribution of the force over its full length.

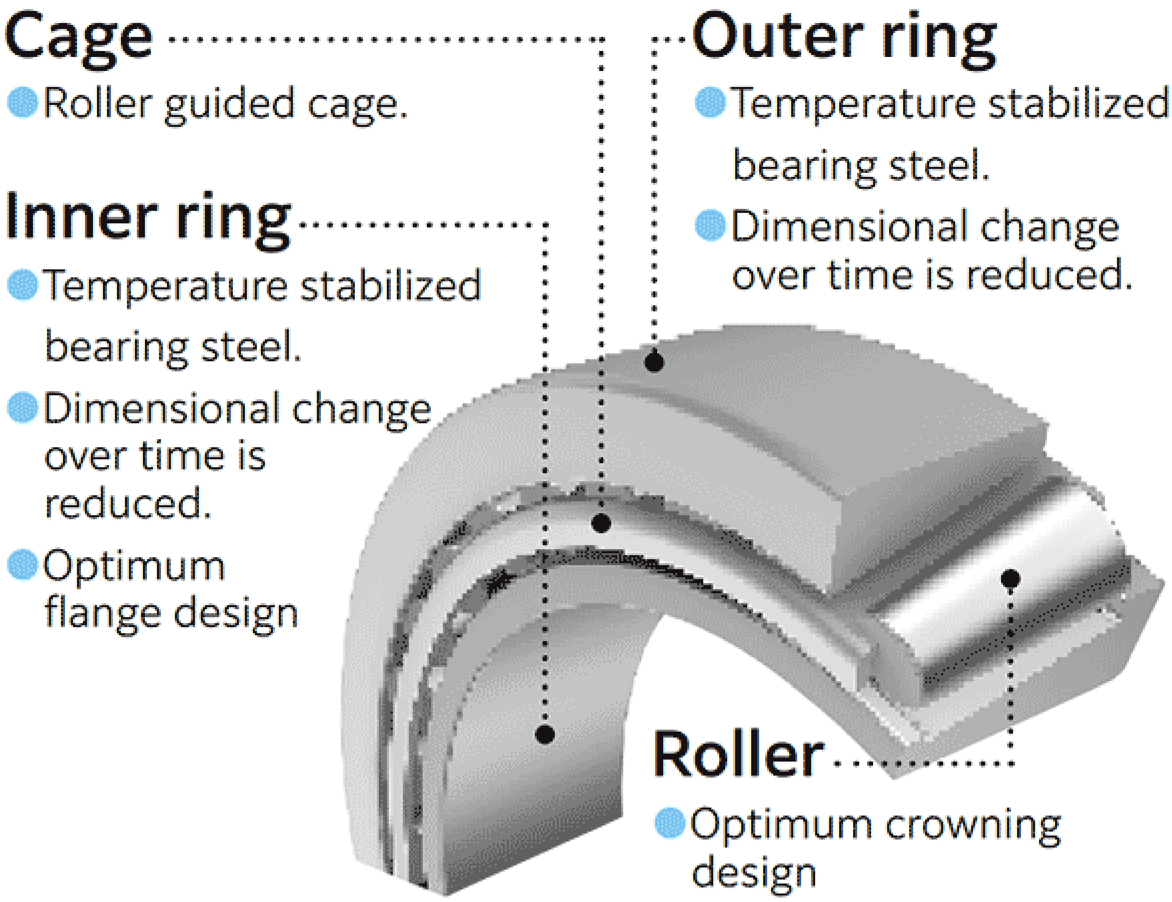
Bearing arrangement	Maximum permissible misalignment
Single	0.0005 rad (0°1’43”)
Back to back (X) arrangement	0.0005 rad (0°1’43”)

Face to face (O) arrangement	0.0010 rad (0°3’26”)

Not bad: Bearings in the X arrangement (Face to Face) are suitable for the highest misalignments.

Crowning

Crowning means a modification of the rolling elements with the aim of minimising stresses in the edge area. There are various approaches for profiling the rolling elements, working with logarithmic functions, but also with several radii along the profile. In addition to the rolling elements, the raceways of the tapered roller bearings can potentially also be profiled.



The profile of this rolling element was optimised by means of crowning.

Double row taper roller bearings

We will now take a look at two special types of tapered roller bearings. Just as with angular contact ball bearings, two tapered roller bearings can be paired with each other. In tapered roller bearings, double row bearings are not marked with a 3, but with a 4. The double-row bearings can support forces in both axial directions, with their rolling elements arranged in the O arrangement (back to back) or the X arrangement (face to face).

In this tapered roller bearing, the rolling elements are installed in the O arrangement.

Four row taper roller bearings

Comparable to cylindrical roller bearings, there are also four-row tapered roller bearings. These have the bearing designation E and consist of two double-row inner rings and two double-row outer rings. Four-row bearings are mainly used in applications with extremely high loads, where a single-row bearing would have been overloaded long ago.

This XXL version of tapered roller bearings is used, for example, in wheel bearings on trains.

So you can see that tapered roller bearings have a number of advantages and are available in a wide variety of designs. If you want to learn more about other types of rolling bearings, you can also find out about needle roller bearings, cylindrical roller bearings or spherical roller bearings on bearingwizard.co.uk.

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Summary

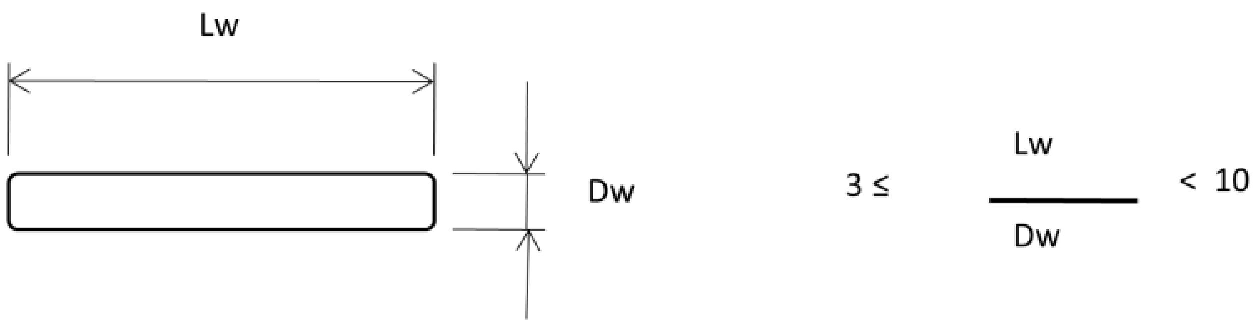
- Needle roller bearings are small and compact, their rolling elements are comparatively long
- Used in gearboxes, vehicle drives or packaging machines
- Ideal for swivel movements
- Bearing code number and designation scheme differs depending on the series
- Examples of needle roller bearing series: Needle roller and cage assemblies, drawn cup needle roller bearings, needle roller bearings with solid rings, stud type track rollers, yoke type track rollers
- Needle roller bearings usually do not have their own seal, but the use of an optional (contact) seal is still possible

Characteristics of needle bearings

Unusual, but not atypical: Needle bearings also do well without an inner and outer ring.

The needle roller bearing did not get its name by chance, because its rolling elements are – surprise – characterised by a needle shape! The rolling elements are also guided parallel to the axis, as needle roller bearings are a special type of cylindrical roller bearing. You are almost guaranteed to find needle roller bearings in gearboxes, vehicle drives or packaging machines, for example.

Needle roller bearings are mainly used as non-locating bearings. Typical for this type of bearing are also its very compact dimensions. Here and there, the inner and/or outer ring may be missing, and the same applies to the cage. If the cage is missing, it is also called a "full complement needle roller bearing". Needle roller bearings have a small cross-section and are therefore smaller than many other bearing types. This is because the rolling element diameter is smaller than 10 millimetres. The diameter-length ratio of the rolling elements is between 1:3 and 1:10.



The length to diameter ratio of the rolling elements in needle bearings is shown here.

Because their rolling elements are relatively long and the contact with the raceways is linear, as in cylindrical roller bearings, needle roller bearings achieve the highest load rating in the smallest installation space and can be used with high radial loads. In addition to their compactness, another advantage is that needle roller bearings are characterised by high rigidity. These bearings are also particularly well suited for applications in which they do not have to perform complete revolutions, but are only pivoted through an angle. In contrast to other bearing designs, the areas overlapped by the rolling elements on the raceways occurs even with small movements due to the small rolling element spacing. This makes it possible to counteract the poor lubrication conditions that often exist in these pivoting applications. In addition, their modular design means that they are not normally difficult to mount. Moreover, needle roller bearings are usually associated with low costs, especially in relation to their performance – pretty good, right?

The disadvantage of needle bearings is the increased noise level – especially compared to ball bearings. As mentioned before, needle bearings are ideal for radial loads, but conversely they are not suitable for axial loads. If needle bearings without an inner or outer ring are to be used, care must be taken to ensure that the bearing journals in the area of the shaft or housing have sufficient hardness and also meet high requirements for dimensional and concentric running accuracies. Another aspect that should be taken into account is that needle roller bearings are only suitable for high speeds and high temperatures to a limited extent. This is particularly important for full complement bearings, whose rolling elements rub against each other due to the missing cage. Special attention must be paid here to lubrication in order to keep friction as low as possible.

Needle cages (needle roller and cage assemblies)

It looks as if the production of the bearing has not yet been completed. In reality, however, the shaft and housing bore of needle roller and cage assemblies take over the function of the bearing raceways.

There are various needle bearing series, the most important of which are presented here. First of all, needle cages, also called *needle roller and cage assemblies,* should be mentioned. These run directly on the shaft or housing, so that the shaft and housing replace the classic bearing raceways. Needle roller and cage assemblies are a cost-effective variant of the rolling bearing, mainly because they are light and compact and require little space. At the same time, however, high demands are placed on the surface finish and hardness of the thin cages. The basic form with a highly rigid cage can be recognised by the abbreviation K, but there are numerous different forms of needle roller and cage assemblies.

Drawn Cup bearings are also called shell type needle roller bearings.

Drawn cup needle roller bearings

Drawn cup needle roller bearings are characterised by a deep-drawn outer ring that is manufactured by forming. This is characterised by a low wall thickness of sheet steel and is very thin. High precision tolerances of the housing bore are the main requirement for the use of drawn cup needle roller bearings. A characteristic feature of drawn cup needle roller bearings is that in most cases they do not have an inner ring. As with needle roller and cage assemblies, there are many different types. The basic type is called HK. Drawn cup needle roller bearings can also have a seal integrated in the deep-drawn outer ring on one or both sides. There are also variants of this type which are completely closed on one side. All types of drawn cup needle roller bearings are also known as shell type needle roller bearings.

Solid ring needle roller bearings

As you can easily see, the solid needle bearing is characterised by a solid, wide outer ring, to which it also owes its name.

Another needle roller bearing series are the solid ring needle bearings; these are characterised by a solid outer ring, which is also known from cylindrical roller bearings. The rigidity of solid needle bearings is higher than that of other needle bearing types. The bearings are therefore suitable for applications with high speeds, high loads and high demands on rotational accuracy. Solid ring needle roller bearings can also have an oil groove with holes in the outer ring.

Stud type track rollers

A stud type track roller only exists in combination with a stub shaft, it is also

Another type of needle roller bearing is the stud type track roller. Stud type track rollers have a stub shaft and perform intermittent, oscillating and continuous rotary motions with high accuracy and high speed. They are used as a cam control mechanism for drive units and are ideal for packaging machines that can roll over the outer raceway *capable of high rotational speeds.* during production.

Yoke type track rollers

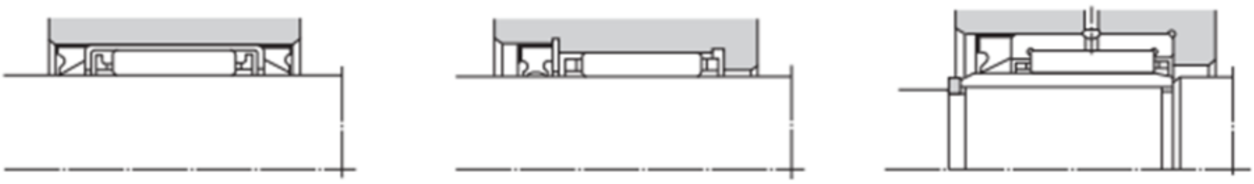
Last but not least, yoke type track rollers are important, but unlike the stud type track rollers, they do not involve a stub shaft. On the one hand, like stud type track rollers they can *also* fulfil the function of a cam mechanism, but on the other can function as a guide or support roller for straight or curved tracks. Both yoke type track rollers and stud type track rollers have a solid outer ring that can withstand impact loads. There are two types of outer surface; it can be either cylindrical or crowned.

Yoke type track rollers can take on a variety of tasks.

There are quite a few different types of needle bearings, some of which are shown here.

Sealing of needle bearings

What role do seals actually play in connection with needle bearings? Basically, open needle bearings, and thus bearings without seals, are more common than bearings with seals. Irrespective of this, it is possible to install a seal directly in both machined and deep-drawn needle roller bearings. A contact seal made of nitrile rubber is used as standard for needle roller bearings. With needle roller and cage assemblies, however, a seal must be used in the direct vicinity of the bearing. Here, the rolling bearing manufacturer NTN has seals that are directly matched to the height of needle bearings and can thus effectively protect the bearing from foreign particles. The special GD seal is particularly advantageous compared to the G seal, as it has a better sealing effect and thus retains grease. In addition, particle ingress is prevented.



Here you can see the drawings for special seals for needle bearings (left and right: G type single lip seal, centre: GD type double lip seal).

Further information on seals can also be found at bearingwizard.co.uk. In addition, you will also find other considerations that go together with the design of a bearing arrangement, including bearing mounting, the difference between a locating (fixed) and non-locating (floating) bearing arrangement and the arrangement types.

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Summary

- Bearing units are based on the design of a deep groove ball bearing
- Self-aligning bearing units enable the compensation of static misalignments
- The units consist of a housing as well as a bearing insert and can optionally be equipped with protective caps
- They are characterised by their simple design and user-friendliness
- Bearing inserts are sealed and filled with lubricant
- Housing materials: Grey cast iron, pressed steel, stainless steel, plastic
- Bearing inserts can be fixed to the shaft by means of an eccentric collar, set screw, adapter sleeve or a tight fit

Characteristics of bearing inserts

The bearing insert, which in principle is constructed like a deep groove ball bearing, has a spherical outer ring surface. The seat in the housing, on the other hand, is a spherical recess and enables the bearing insert to be held securely without the need for further fastening elements. This configuration allows the bearing to absorb loads in the radial and axial directions and to compensate for slight shaft misalignments.

Soil preparation machines are equipped with bearing units. Dust, moisture, chemicals and impacts from the solid soil layers are some of the conditions that must be withstood here.

Due to their user-friendliness and cost-effectiveness, bearing units can be found in many industrial sectors. These include, among others, agricultural machinery, woodworking and packaging machines, equipment in the food industry as well as in conveyor technology.

Bearing units can also be found in a car wash.

Bearing units are frequently used for machining processes in the food industry, for example for conveyor belts.

Bearing units

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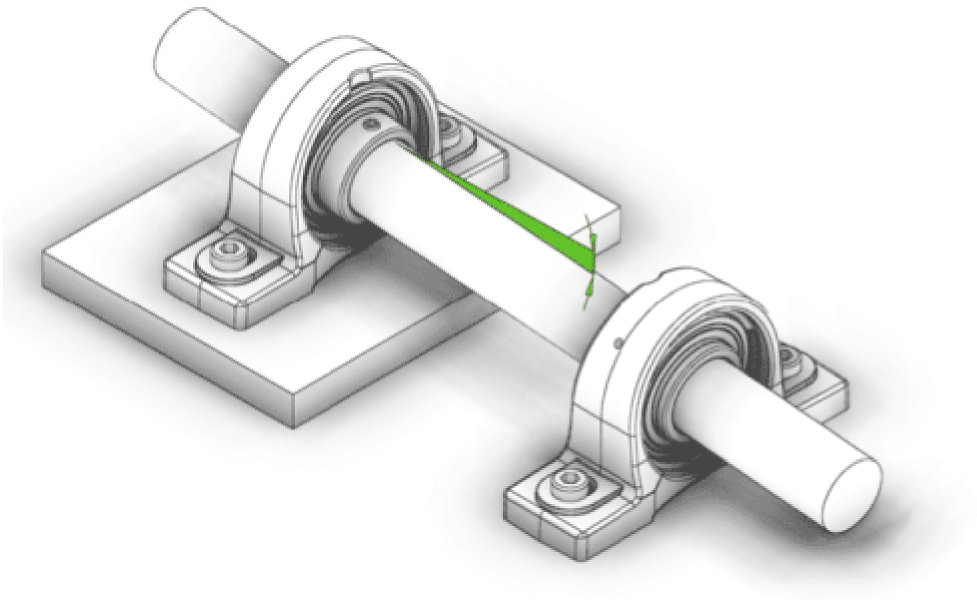
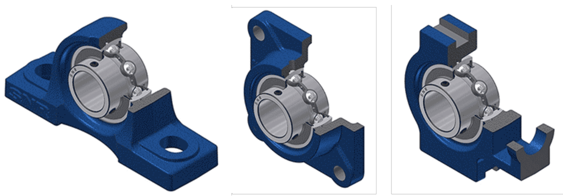


Bearing units are self-aligning and can compensate for shaft misalignment.

In contrast to deep groove ball bearings, bearing inserts generally have a seal. They are pre-greased and in most cases can be re-greased via a lubricant feed in the housing. An integrated clamping system on the inner ring allows easy mounting on cylindrical shafts.



In terms of housing designs, a distinction is made between pillow block housings, flanged housings and take-up housings (from left to right).

The assembly and disassembly of the units can be carried out without special prior knowledge and special assembly tools.

There are various methods available for mounting a bearing insert on cylindrical shafts. The most suitable fastening system is determined by the application. From a design point of view, the maximum permissible speed, the direction of rotation of the shaft and the running behaviour as well as the effect of axial loads must be taken into account. Furthermore, economic aspects, the available installation space and the ease of installation can be decisive for the choice of fastening system.

Bearing units can be mounted on drawn shafts because the bore is always 0+ tolerance (larger than the nominal diameter of the shaft). Special machining of the shaft surface is therefore not necessary.

A wide range of plummer block and flanged bearing units as well as take-up units are available for the most diverse installation situations. Construction elements, such as clamping frames and protective caps, provide further application possibilities.

The selection of the right material also plays an important role in the reliable operation of a bearing unit. NTN's portfolio includes bearing units with housings made of steel, spheroidal graphite cast (ductile) iron, grey cast iron, pressed steel, stainless steel and thermoplastic. Due to the very high variance of different designs and materials, bearing solutions can be achieved for many industrial applications.

The simple assembly of the units does not require any special prior knowledge on the part of the fitter. However, the operating conditions and mounting instructions must be observed. When planning, the loads, speeds and operating temperatures for the respective application must be considered, almost like any other bearing calculation. Furthermore, the consideration of sealing and the type of lubricant should play a role in the design of the bearing configuration. In practice, rolling bearings with ball type rolling elements are almost exclusively used for bearing units. The bearing geometry is identical to that of deep groove ball bearings of series 62 and 63. The limiting speed of bearing inserts is lower than that of comparable deep groove ball bearings due to the special mounting method on the shaft.

Bearing units

In the pictures you can see examples of the different series: The most commonly used series made of grey cast iron (top left) , the light series with housings made of pressed steel (top right), bearing units made of stainless steel (bottom left) and thermoplastic bearing units (bottom right), which are mainly used for industrial food production.

Bearing unit fixing methods

For mounting a standard deep groove ball bearing on a shaft, the inner ring is usually heated by means of an induction heating device for warm mounting. Special mounting tools are used for cold mounting. In both cases, mounting is significantly more complex and costly than for bearing inserts with an integrated mounting system.

You can find out which NTN systems are available and how they work here:

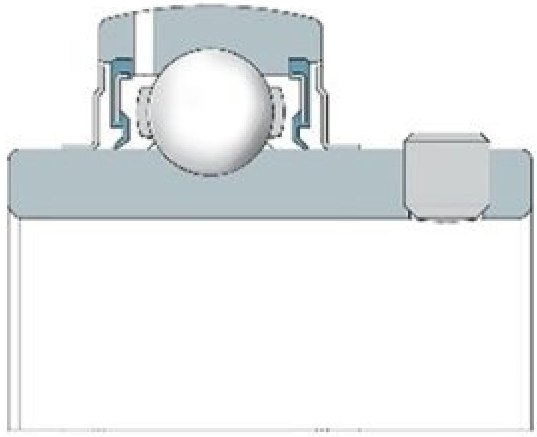
Fastening of housing bearings with:

- Set screw
- Eccentric collar
- Adapter sleeve
- Press fit
- Floating bearing screw

More detailed information on most of the listed fastening options can be found here.

1) Fastening with set screws

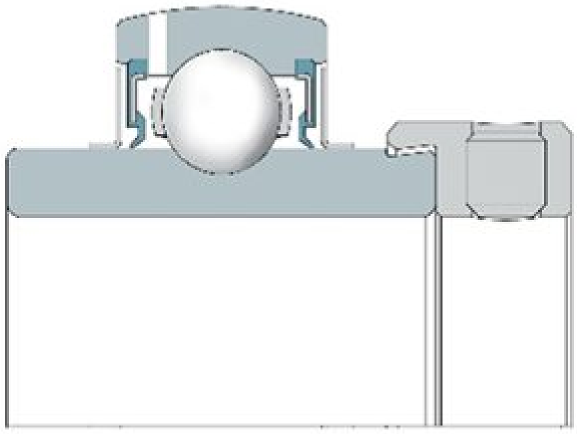
The simplest and most economical mounting method is bearing inserts with set screws. The inner ring is equipped with two set screws offset by 120°. By tightening the two hexagon socket screws, the bearing inner ring is fixed to the shaft and locates the bearing unit. The recommended tightening torque must be observed when tightening the set screws. A normal Allen key is sufficient as a tool. With this method, the axis of the bearing insert is offset slightly from the centre of the shaft axis. This slight offset can lead to vibrations at higher shaft speeds, but is not relevant for applications with normal speeds. In contrast to bearing inserts with an eccentric collar, the bearings with set screws are also suitable for alternating directions of shaft rotation.



Bearing inserts with set screws are suitable for both directions of rotation.

2) Fastening with eccentric collar

The mounting method using an eccentric collar is also very common in industrial machines. With this fastening method, the bearing insert is mounted together with an eccentric collar. The eccentrically machined collar on the inner ring and the eccentric recess on the eccentric collar are clamped together during mounting and ensure the fixation of the bearing on the shaft. The eccentric collar must be fixed in the direction of rotation of the shaft and finally secured with a set screw. This type of mounting is not suitable for quick changes in the direction of rotation, as the eccentric collar could come loose during alternating operation. The larger installation space required by the additional component must also be taken into account.

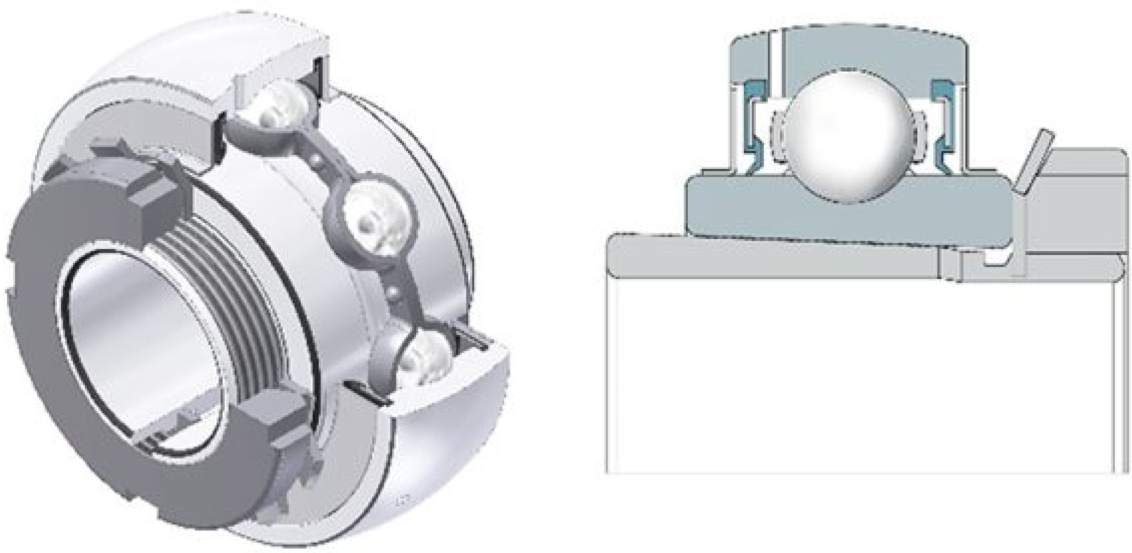



You can see the eccentric collar on the left and right side of these pictures.

3) Fastening with adapter sleeve

Just like spherical roller bearings, bearing inserts can also have a tapered bore. However, these are usually mounted on a cylindrical shaft by means of an adapter sleeve. Adapter sleeve mountings generally represent a very secure shaft connection. During mounting, the bearing is pushed onto the sleeve until the recommended reduction in radial internal clearance is achieved. Setting the correct internal clearance value is crucial for the service life of the bearing. The bearing is secured in this position with a lockwasher and locknut.

Shaft mounting with an adapter sleeve is somewhat more complex and must be carried out professionally. Due to the number of additional components, bearing inserts with adapter sleeves are also somewhat more cost-intensive. However, with this mounting method you benefit from a very high clamp force, low-vibration running and higher speeds.



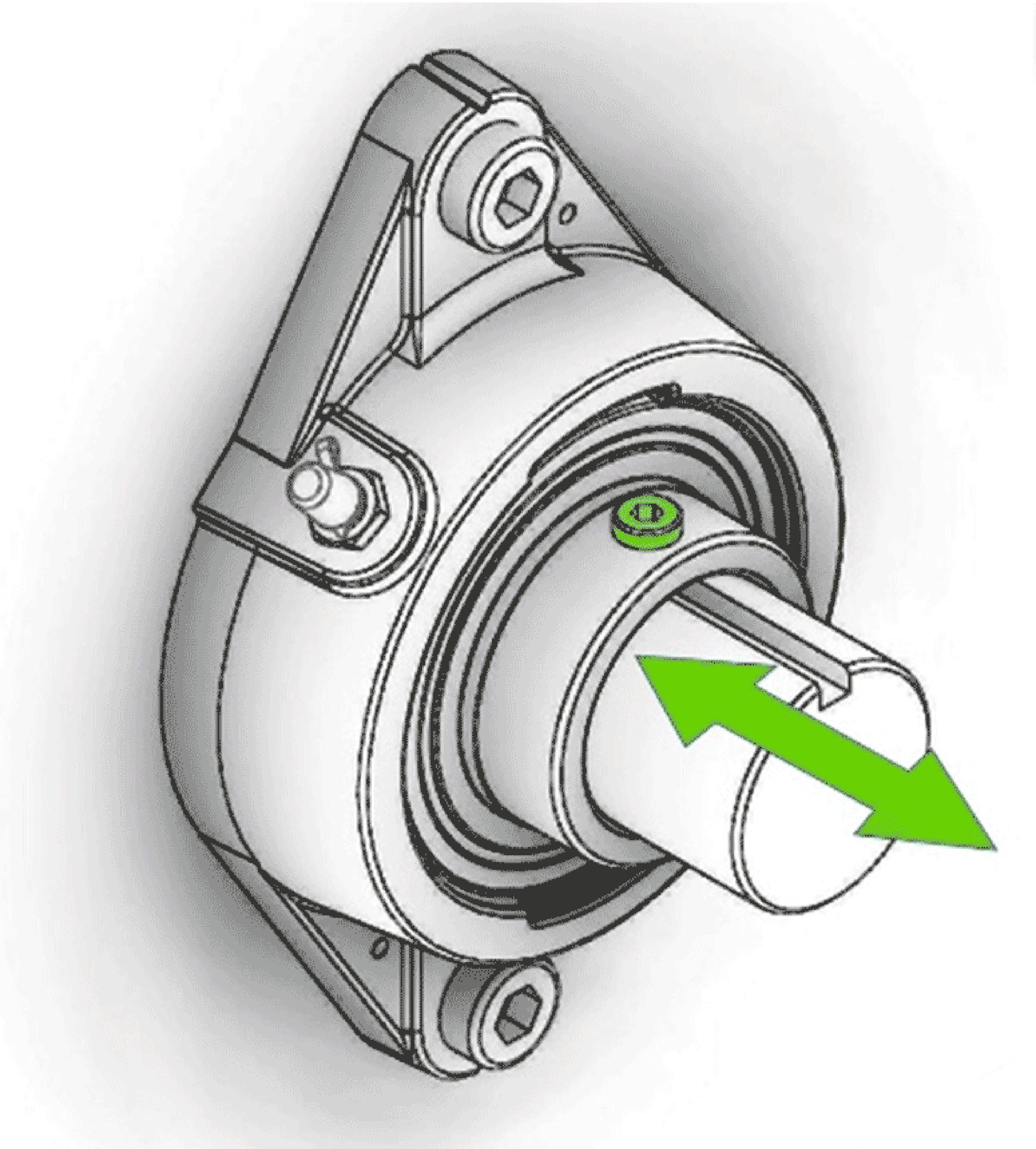
Bearing inserts with a tapered bore are typically mounted with an adapter sleeve.

Non-locating (floating) bearing

Bearing arrangements that can compensate for heat-related changes in the length of shafts are referred to as non-locating (floating) bearings. In order to avoid bearing failures due to axial tension, the shaft must be supported via a locating and non-locating bearing.

While the locating bearing side can absorb forces in radial and axial directions, the shaft on the non-locating bearing side remains displaceable – but absorbs forces only from the radial load direction. Bearing inserts from SNR (an NTN brand) with set screws, for example, can be easily converted for use as non-locating bearings.

Despite the similar term, bearing units are not to be confused with bearing housings, about which information can also be found on bearingwizard.co.uk.



By changing the set screws, a fixed bearing unit can be converted into a floating bearing unit.

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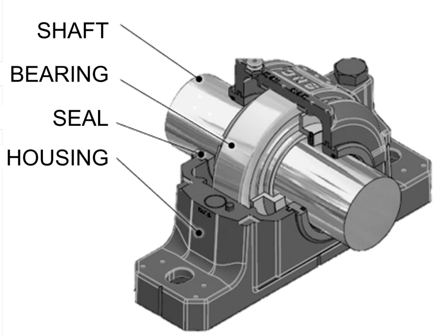
Bearing housings

Summary

- Bearing housings can accommodate rolling bearings of a wide variety of designs
- The designs include plummer block housings, flanged bearing housings and insert ball bearing housings
- The bearing housings can be separated into split and one-piece designs
- Bearing housings for special applications can withstand high temperatures
- Bearing housings can be lubricated with grease or oil, with grease often being the appropriate lubricant

We have learned about standard bearing units which are only suitable for bearings with a spherical outer surface. As a rule, these bearing units cannot accommodate rolling bearings with a cylindrical outer ring surface.

Bearing housings, on the other hand, are equipped with cylindrical bearing seating surfaces and can accommodate standard rolling bearings of various types. They can be differentiated on the basis of their design and construction. Possible designs include plummer block housings, flanged bearing housings and other special bearing housings. Plummer block housings are also available with a split or one-piece housing body. Bearing housings are suitable for



Plummer block bearing housings can accommodate rolling bearings with a cylindrical outside surface.

industrial use in a wide range of applications and machines. The right choice of bearing housing depends on the application purpose and the expected requirements in operation.

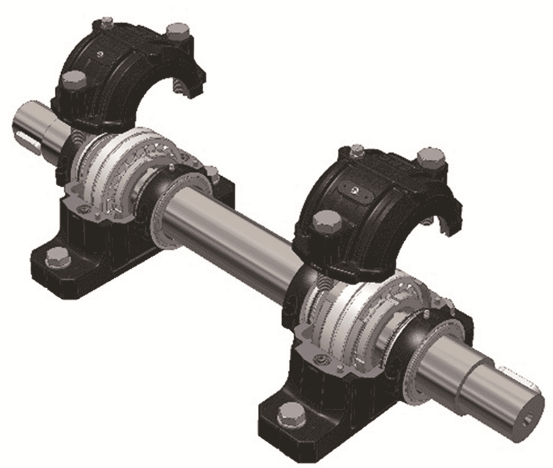
Split designs

In the split design, the upper part of the housing and the lower part of the housing can be dismantled, making it easier to mount the bearing and other components from above. Split plummer block housings are designed to accommodate a rolling bearing. This type of housing is represented in many areas of industry.

The SNC series from NTN can be described as a real all-rounder, as it can be adapted to the application in the best possible way by using different rolling bearings and seales.

Features of split versions of the SNC series:

- Simple Assembly
- Modular system
- High efficiency and economy
- Suitable for spherical roller or self aligning ball bearings of ISO dimensional series 02, 03, 22, 23 and 32
- For shaft diameters from 20mm to 160mm (Large bearing housings SNCD up to 500mm)
- Housing material: Cast iron with lamellar graphite or nodular graphite (SNCD)



Easy assembly, as split SNC housings can be separated to allow the bearings to be inserted from above.

In this application example, you can see the rotor bearings in an industrial fan.

One-piece designs

Bearing housings of this design have no split in the bearing seat surface. The bearings are mounted from the side. Flanged bearing housings and so-called block bearing housings are manufactured by SNR (a brand of NTN) in a one-piece design. Block bearing housings are suitable for the installation of two or more rolling bearings.

Block bearing housings ZLOE with oil lubrication are essential for the design of large industrial fans.

For example, at bearing manufacturer NTN (and its associated brands NTN and SNR), the designations for units with grease lubrication are ZLG and DLG, and units with oil lubrication are called ZLOE. These bearing housings have the shape of a tube, with the bearings arranged at an optimum distance from each other at the ends of the housing. Misalignment of the bearings is practically impossible, as the bearing seats are completely parallel. Bearing housings of this type are often used for industrial fans because they run very smoothly and can absorb large moment loads. Block bearing housings can be configured in a variety of ways by equipping them with different bearing combinations.

Features of one-piece designs:

- Aligned bearing seat positions for high shaft runout accuracy
- Usable bearing types: Deep groove ball bearings, angular contact ball bearings and cylindrical roller bearings (can be mixed within a block bearing)
- Housing material: Cast iron with lamellar graphite
- For shaft diameters from 30mm to 120mm
- Suitable for applications with high axial or radial forces – also in combination with high speeds
- High running smoothness due to axially preloaded bearings
- Preferred bearing for industrial fans
- Sealing system: Felt strip / V-ring seal
- Can be configured as pre-assembled, ready-to-use complete units

The one-piece designs can include flanged bearing housings and bearing housings for special applications, which are described in more detail below.

Due to the more compact housing design, flanged bearing housings require less installation space than plummer block housings. The housings, which are equipped with three or four mounting holes depending on size, are bolted to a machine wall. Slight mounting or shaft alignment errors are compensated for by the spherical roller or self-aligning ball bearings installed. The one-piece housings of series 722500 can be equipped with a closed end cover or with a cover for through shafts.

Features of flanged bearing housings:

- Housing material: Cast iron with lamellar graphite
- Usable bearing types: 12..K, 22..K, 222..K
- For shaft diameters from 20 mm to 100 mm
- Version with closed cover (type A) or open cover for through shaft (type B)
- Sealing system: Felt strip seal
- Regreasable

Flanged housings of the 722500 series make do with little installation space.

In addition to flanged bearing housings, there are also bearing housings for special applications. These include TVN housings, which are compact, one-piece bearing housings made of grey cast iron, specially developed as wheelset bearings for conveyor and hardening trolleys. For applications under normal temperature conditions, the housings can be equipped with standard deep groove ball bearings or self-aligning ball bearings. For applications in the high-temperature range, heat-stabilised high-temperature deep groove ball bearings of the F605 series from NTN can be used (maximum temperature: 350°C).

Features of high temperature bearing housings:

- Heat-stabilised bearings up to 350°C
- Special sealing
- High temperature lubricant

Wheelset bearing housing TVN for high temperature applications up to 350°C.

Bearing housings with grease or oil lubrication

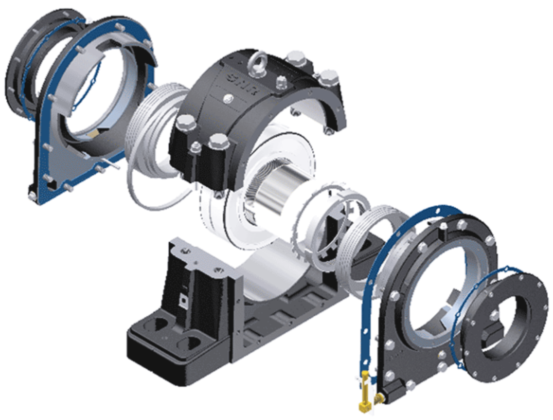
Grease is the most suitable lubricant for rolling bearings in most cases, as it is usually less expensive, can be fed into the bearing enclosure with little effort and seals do not have to be designed as elaborately.

In many cases, bearing housings do not need to be regularly supplied with fresh grease. If the operating conditions are moderate, the grease is only replaced in the event of general service maintenance.

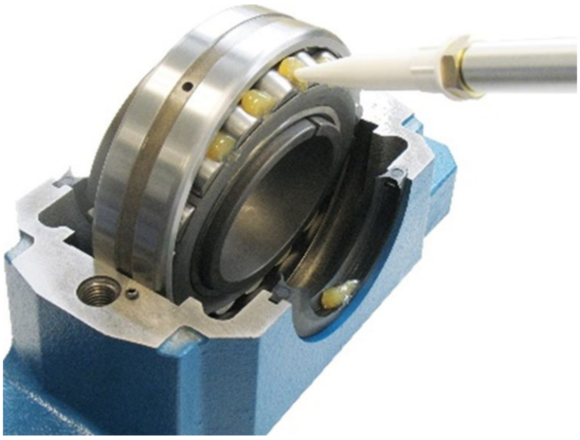
Bearing housings with oil lubrication are preferred for use in machines that are operated at high shaft speeds or where very short grease relubrication intervals are to be expected. The lubricating oil can improve heat dissipation and increase bearing operating life, by installing additional devices (such as external oil cooling). Oil bearing housings are available from SNR (a brand of NTN) as a split design (SNOE) and as a block bearing (ZLOE).

For example, labyrinth seals are used for sealing in oil bearing housings. Non-contact seals are preferable at high circumferential speeds to reduce frictional heat in the system.

Bearing housings



Bearing housings of the SNOE series operate with oil sump lubrication. The oil is conveyed to the upper area of the bearing by a rotating oil feed ring.



The initial supply of grease. Before commissioning, the bearing and the seals as well as part of the interior are supplied with lubricant.

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Summary

- The bearing life indicates the total number of revolutions or operating hours possible until fatigue damage to the rolling bearing material occurs
- L_{10} (basic rating life): Formula based on statistics; indicates the rating life of a rolling bearing
- L_{nm} (extended modified service life): This formula provides more precise information than the basic rating life, as it takes into account other influencing factors such as lubrication conditions and cleanliness

Damn, bearing damage! If you consider that rolling bearings are exposed to continuous pressure and shear stress, this is nothing unusual to begin with. What is more significant is the time of the bearing failure. For dimensioning a bearing position, and so that the bearing failure does not come as a surprise or can be prevented, the calculation of the service life is of vital importance. Here, the life of a bearing is not given in years, but with the total number of revolutions or operating hours that are theoretically possible until natural fatigue damage to the material occurs.

Basic rating life L_{10}

The probably best-known rolling bearing service life, which is often also called “basic rating life“, is designated as L_{10} and is standardised according to DIN 281:2007 (calculation formula below). The prerequisite for achieving the calculated service life is a realistic assessment of the operating conditions such as speed, load and ambient conditions.

L_{10}	Basic rating life in 10^6 revolutions
L_{10h}	Basic rating life in operating hours
C	Dynamic load rating according to dimension table; see e.g. NTN catalogue (C_r: Radial bearing, C_a: Axial bearing)
P	Equivalent dynamic load (P_r: Radial bearing, P_a: Axial bearing)
p	Service life exponent (Ball bearing: p=3, Roller bearing: p=10/3)
n	Speed of the rolling bearing in the application, min^{-1}

When calculating bearing life, you cannot avoid these variables.

Since rolling bearings differ slightly from each other due to manufacturing tolerances and material properties, a group of bearings of the same type under the same operating conditions (same speed, load and lubrication) will in reality have a varying service life. This so-called scatter range is similar to a probability value, as it is determined statistically. On the basis of the statistical service life (the basic rating life L_{10} according to DIN ISO 281:2007), the total number of revolutions in millions is given, which is reached by 90% of all bearings in an identical group until material fatigue occurs. This applies under identical operating conditions at a constant speed.

There is a simple answer to the question “Why only 90%?”: The reason is that operating a system with 100% fulfilment of the calculated service life is usually simply too expensive. The scatter range of 90% also means that the other 10% “may” fail before the specified time. The calculation of L_{10} varies by the exponent – depending on whether the service life of a ball bearing or a roller bearing is being calculated. With the help of the basic rating life L_{10h}, the number of achievable operating hours is specified (formula 1).

Formula 1

Basic rating life in 10^6 revolutions:
For ball bearings: $L_{10}=(C/P)^3$
For roller bearings: $L_{10}=(C/P)^{10/3}$
Basic rating life in operating hours:
$L_{10h} = (16\,666.\overline{6}) \times (C/P)^p$

The following applies to ball bearings: If you halve the load or double the load rating, you increase the service life eightfold.

By the way, the highest service life requirements are placed on rolling bearings, especially in wind power as well as in electric motors and machine tools. In agricultural applications, on the other hand, where some machines are only used seasonally, a shorter service life is required by calculation – here, contamination and other unfavourable environmental conditions also play a major role, which cannot always be represented by calculation.

The basic rating life in hours L_{10h}

An important basis for the calculation of L_{10h} is the bearing-specific dynamic load rating C, which indicates the load carrying capacity of rolling bearings and consequently the dynamic load that a bearing can carry. The calculation of the dynamic load rating is also standardised according to DIN 281:2007 and is specified for standard bearings by the rolling bearing manufacturer in the respective catalogue. With a load on the rolling bearing equal to the basic dynamic load rating, the bearing achieves a calculated service life of 1 million revolutions. In practice, however, further conditions should be observed or checked. Also, for radial and axial bearings, the basic dynamic load rating given is *for their primary load direction only*. For instance, a load rating given for a radial ball bearing applies only to loads perpendicular to the axis of rotation (radial), whereas the load rating for a thrust needle bearing is for loads parallel to the axis (axial). For this reason, a distinction is made between the designations C_r for radial bearings and C_a for axial bearings.

With many bearing arrangements, the load F acts at an angle on the rolling bearing. This then results in a radial force F_r and an axial force F_a. However, to calculate the basic rating life, a load of constant magnitude and direction is assumed. Therefore, the equivalent dynamic bearing load is determined from the two forces, which for radial bearings is called the dynamic equivalent radial load (P_r) for radial bearings and dynamic equivalent axial load (P_a) for axial bearings. When the bearing is loaded with this calculated equivalent load, the rolling bearing achieves the same L_{10}– service life as with the actual load conditions.

Formula 2

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

F_r	Radial load
F_a	Axial load

X	Radial load factor can be found in the catalogue for each type of rolling bearing.
Y	Axial load factor can be found in the catalogue for each type of rolling bearing.

This formula is used to calculate the equivalent dynamic load P.

In addition, rolling bearings must be operated with a minimum load to ensure safe rolling of the rolling elements and to minimise sliding motions. The latter should be urgently avoided in order to prevent smearing (the formation of material accumulation and the development of a rough raceway surface), as this can lead to premature bearing failure. The recommended minimum load varies depending on the type of rolling bearing. For example, for spherical roller bearings, it should be 0,01 x *C*0.

The lifetime exponent *p* is already fixed, so a formula is not needed. The only thing that needs to be taken into account is the design of the rolling bearing. Accordingly, the service life exponent for ball bearings has a value of *p* = 3, while for roller bearings it is *p* = 10/3.

Example calculation of L_{10} and L_{10h}
Bearing: 6206C3
$C_r = 21.6$ kN
$F_a = 250$ N
$F_r = 2000$ N
$n = 2000$ rpm
$X = 1$, $Y = 0$, since $F_a/F_r \leq e$
$P_r = 2$ kN
$L_{10} = (21.6/2)^3 = 1\,259.71 \times 106$ revolutions

L_{10h} = 10 497.6 h

The calculation of L_{10} and L_{10h} using the example of the deep groove ball bearing 6206C3.

The modified rating life L_{nm} or L_{nmh}

Although the scatter range of the basic rating life L_{10} is standardised at a reliability coefficient of 90%, there are certain areas of application in which it must be higher. This is followed by the extended service life, which is also standardised according to DIN ISO 281:2007. L_{nm} or L_{nmh} comes into play, which in some cases cannot be avoided when calculating the service life.

Formula 3

$L_{nm} = a_1 \times a_{ISO} \times L_{10}$

$L_{nmh} = a_1 \times a_{ISO} \times L_{10h}$

L_{nm}	Modified rating life in 10^6 revolutions
L_{nmh}	Modified rating life in hours
a_1	Life adjustment factor for reliability
a_{ISO}	Life modification factor for the operating conditions $a_{ISO} = f(e_c \times C_u \div P, \kappa)$ e_c = Contamination factor C_u = Fatigue load limit P = equivalent dynamic load κ = Viscosity ratio
L_{10}	Basic rating life: Reference life in 10^6 revolutions

No trick, but simple mathematics: The modified calculation of rolling bearing service life L_{nm} and L_{nmh}. However, one has to calculate a few things beforehand, especially for a_{ISO}.

Practical experience shows that under ideal operating conditions, rolling bearings can exceed the L_{10} calculated values. An example would be a load-bearing lubricating film between the rolling elements and rings without contamination and impurities. It is remarkable that even very long service lives beyond the endurance limit are possible. The prerequisites for this are optimum operating conditions and a low bearing load. At a maximum contact stress of 1500 MPa, the bearing is usually described as fatigue-resistant (bearing load below the fatigue load limit load C_u). Accordingly, the modified rating life provides more accurate and possibly also more realistic results than the basic rating life.

For a_1 a default probability of 10% is generally assumed. For this reason a_1 = 1 and thus the value of a_1 changes accordingly for a different failure probability.

Reliability	L_n	Life adjustment factor for reliability a_1
90%	L_{10}	1.00
95%	L_5	0.62
96%	L_4	0.53
97%	L_3	0.44
98%	L_2	0.33
99%	L_1	0.21

The life adjustment factor for reliability a1 decreases with a higher percentage of service life reliability.

The factor a_{ISO} is a function based on lubrication, contamination, material properties and load and can be described using the following formula:

$$a_{ISO} = f\left(\frac{e_C C_u}{P}, \kappa\right)$$

Contamination from hard particles in the lubricant can cause indentations on the raceway surface, resulting in surface-related damage and a reduction in bearing life. The contamination factor e_c takes this into account and depends on the degree of contamination, the bearing size and the lubricant viscosity (lubricant film thickness).

Contamination level	e_c	
	D_{pw} < 100 mm	D_{pw} ≥ 100 mm
Extreme cleanliness Particle size of the order of lubricant film thickness; laboratory conditions	1	1
High cleanliness Oil filtered through extremely fine filter; conditions typical of bearing greased for life and sealed	0.8 ~ 0.6	0.9 ~ 0.8
Normal cleanliness Oil filtered through fine filter; conditions typical of bearings greased for life and shielded	0.6 ~ 0.5	0.8 ~ 0.6
Slight contamination Slight contamination of the lubricant	0.5 ~ 0.3	0.6 ~ 0.4
Typical contamination Conditions typical of bearings without integral seals; course filtering; wear particles and contaminent ingress from the surrounding environment	0.3 ~ 0.1	0.4 ~ 0.2

Severe contamination Bearing environment heavily contaminated and bearing arrangement with inadequate sealing	0.1 ~ 0	0.1 ~ 0
Very severe contamination	0	0

The table describes the contamination factor e_c.

The fatigue load limit is another influencing variable and is the load applied to a bearing that results in the fatigue limit stress at the maximum loaded contact within the raceway. This depends on the bearing type, internal specifications, quality and material strength. In ISO 281:2007, 1.5 GPa is recommended as the contact stress corresponding to C_u is recommended for bearings made of commonly used high quality material and of good manufacturing quality.

Furthermore, in a_{ISO} the viscosity ratio κ is integrated, which describes the influence of the lubricant film formation. Bearings are used under the assumption that the rolling contact surface is separated by a lubricating film. However, if the viscosity of the lubricant is low, the separation becomes insufficient and solid contact occurs, resulting in damage. The viscosity ratio κ takes this effect into account and is determined by the formula given below and by the ratio of the operating viscosity v to the reference viscosity v_1 described.

Formula 4

$\kappa = v/v_1$

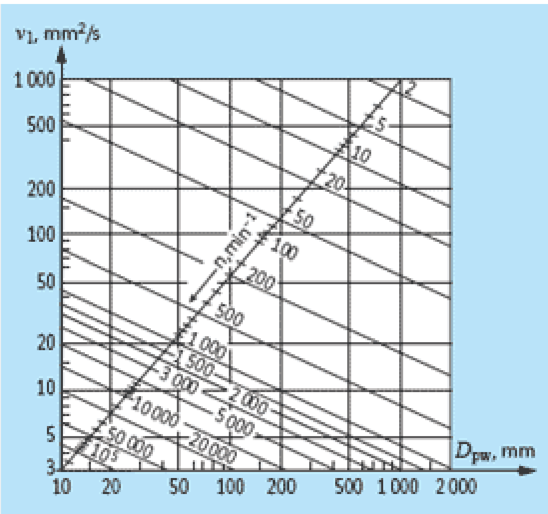
The calculation of the viscosity ratio κ.

Formula 5

If n < 1 000 min^{-1}, $v_1 = 45\,000\ n^{-0.83}\ D_{pw}^{-0.5}$

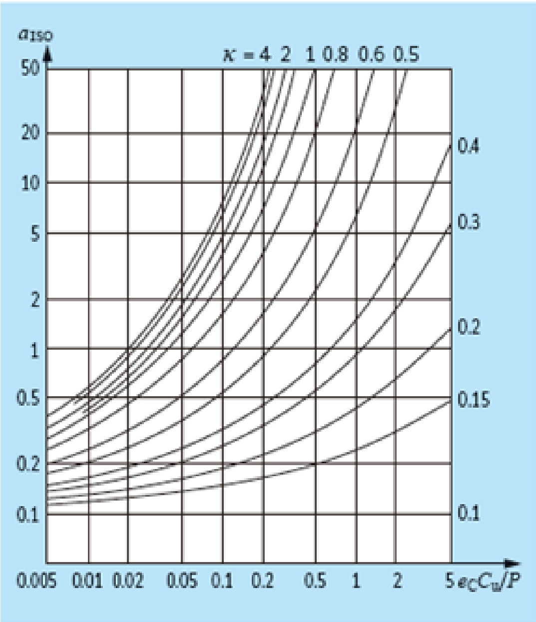
If n ≥1 000 min^{-1}, $v_1 = 4\,500\ n^{-0.5}\ D_{pw}^{-0.5}$

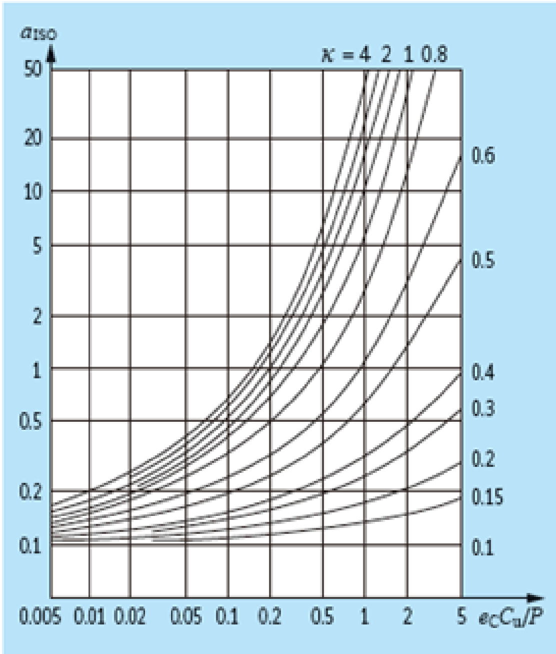
The reference viscosity v_1 depends on the speed n and the size D_{pw}.

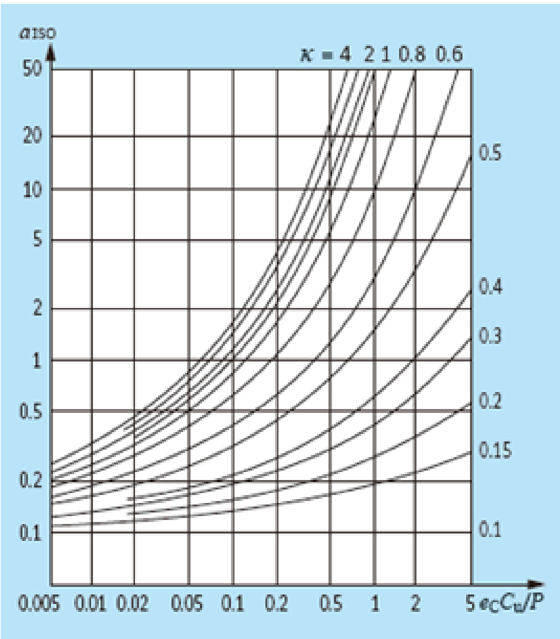


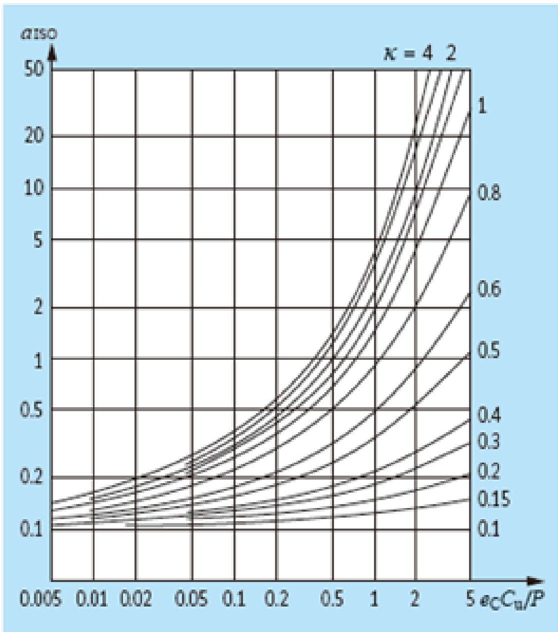
The calculation of the reference viscosity v_1 by means of a diagram.

In the diagrams shown, the relationship between $^{Cu}/_{P}$, e_c, κ and a_{ISO} of different bearing types is shown. The use of the figure is subject to the restrictions that the service life coefficient is limited to $a_{ISO} \leq 50$ and that for κ > 4 the value of κ = 4 must be assumed. The approach is also not valid for κ < 0.1.









In the illustrations, information is provided on the life modification factor a_{ISO} of (from left to *right) radial ball bearings, radial roller bearings, axial ball bearings and axial roller bearings.*

Example calculation of L_{10mh}
Same bearing and application as above: 6206C3
C_r = 21.6 kN
C_u = 0.795 kN
F_a = 250 N
F_r = 2000 N
n = 2000 rpm
High cleanliness of the surroundings
Lubricant viscosity at operating temperature 80°C of 14.37 mm²/s
$X = 1$, Y = 0, since $F_a/F_r \leq e$
P_r = 2 kN
$L_{10} = (21.6/2)^3$ = 1 259.71 x 10^6 revolutions
L_{10h} = 10 497.6 h
With D_{pw} < 100 mm follows e_C = 0.6 – 0.8
With formula 5 it follows for v_1 = 14.76 mm²/s
From this follows κ = 0.9
From the diagram for radial ball bearings, an a_{ISO} value of approx. 8 can be seen
From this follows for L_{10hm} = 83 981 *h*

The calculation of L_{10mh} using the example of the deep groove ball bearing 6206C3.

Other methods for calculating bearing life

In addition to the methods described here for determining the service life of a rolling bearing, there are other methods for calculating failure due to material fatigue. For example, when calculating the reference service life according to ISO TS 16281, the load distribution of the rolling element over its length is considered using a disc model. This method takes into account other influencing variables such as the operating clearance and misalignment of the bearing, but also the existing contact stresses of the respective rolling contacts. However, due to the immense computational effort, such a method is only suitable when using a calculation programme.

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Nothing works without lubrication: Every bearing runs with grease or oil lubrication, which is the basic prerequisite for avoiding metallic contact of the bearing components,

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Summary

- Rolling bearings are lubricated with grease or oil
- It serves to reduce friction and wear and tear
- The lubrication method chosen must be adapted to the operating conditions
- No or insufficient lubricant in the bearing leads to rolling bearing damage and / or premature bearing failure
- Grease is used more often than oil as a lubricant (easier handling)
- In special cases, solid lubricants are used instead of grease or oil

Nothing works without lubrication: Every bearing runs with grease or oil lubrication, which is the basic prerequisite for avoiding metallic contact of the bearing components, (rolling elements, bearing rings and cage). In special cases, bearings can also be lubricated with a solid lubricant. Along with friction and wear, lubrication belongs to the field of *Tribology*. Probably the most important function of lubrication is to keep friction and wear as low as possible. In addition to this, lubrication also brings other advantages, which can be seen in the list.

Functions of lubrication:

- Reduction of friction and wear
- Dissipation of frictional heat
- Extending the bearing life
- Prevention of rust
- Protection against contaminant ingress

Optimal lubrication is the basic prerequisite for long bearing life.

The lubricant selection

Depending on the bearing, the lubrication method varies between grease and oil. It is also important to ensure that there is not too much or too little lubricant in the bearing. Did you know that, statistically, problems with lubrication are the main cause of failure of rolling bearings?

The lubrication method chosen must be adapted to and satisfy the operating conditions (especially the speed and operating temperature of the bearing) to ensure the lubrication is most effective. It is also important that the lubricant used is a quality lubricant and that the correct amount of lubricant is used. Another key requirement is that the bearing design is resistant to contaminant ingress while also preventing leakage of lubricant. For this purpose, rolling bearing manufacturers such as NTN offer types with contact seals for some series. Another configuration is that bearings are sealed externally, with various seal types available. When selecting the seal type, the resulting change in limiting speed must be taken into account (frictional heat of the seal).

	Grease lubrication	Oil lubrication
Handling	Very good	Acceptable
Reliability	Good	Very good
Cooling effect	Unsuitable	Good*
Sealing variants	Good	Acceptable
Friction loss	Good	Good

Environmental impact	Good	Acceptable
High speed	Acceptable	Good

The choice of lubricant must always be weighed up. Generally what one lubrication method can’t do, another one can do better.

** Oil recirculation circuit required*

Grease lubrication

Grease is the most widely used lubricant and is generally relatively simple and inexpensive to use. The properties of all greases are mainly determined by the type of base oil used and by the combination of thickeners and various additives. The base oil used is mainly mineral oils, synthetic oils (such as ester oil), synthetic hydrocarbon oil and essential oils. A distinction is made between greases with low viscosity base oil, which are suitable for low temperatures and high speeds, and greases with high viscosity base oil. The latter are used in applications with high temperatures and high loads. Thickeners added to the base oil can be divided into the two basic types of metal soaps and non-metal soaps. The different properties of a grease, such as temperature range, mechanical stability, water resistance, etc. depend mainly on the type of thickener used. Depending on the intended use, various additives are included to further adjust its properties. Typical additives are antioxidants, high pressure additives (EP additives), rust inhibitors and corrosion inhibitors.

The amount of grease the bearing is filled with also depends on the speed. However, the quantity of grease to be used under the respective operating conditions generally depends on several factors at once, relating to the size and shape of the housing, the space available and the type of grease used. As a rule of thumb for most applications, bearings should be filled to 30% to 40% of the bearing internal free space and the housing to 30% to 60%. At high speeds and minimal temperature rises, it is advisable to use a reduced amount of grease. However, too high a grease quantity can lead to a rise in temperature, which softens the grease and as a result, grease leakage can occur. Also, oxidation and deterioration can lead to an impairment of the lubricating effect.

When using grease lubrication, it is extremely important to observe the relubrication schedule, as the lubricating performance of a grease decreases over time. This means that bearings must be regreased at certain intervals. Relubrication intervals are not uniform, because they sometimes depend on the type of grease, the type of bearing, the temperatures and the speed. It is also possible to fill with grease once (lifetime greasing) if the relubrication interval is longer than the lifetime of a bearing, for example, or if the bearing is sealed and relubrication would be too costly. With regard to the miscibility of different greases, the manufacturer's instructions must be observed. As a rule, however, mixing is not advisable due to different basic substances and additives of individual greases, as there is a risk that a chemical reaction of the different components will occur.

Oil lubrication

The most common alternative to grease lubrication is oil lubrication. This is the ideal, but more expensive choice and is preferred to grease lubrication, especially for rolling bearings with line contact. Oil lubrication is mainly used in applications where the heat generated by the bearing or other sources must be dissipated from the bearing and discharged to the outside. At the same time, high demands are often placed on the sealing and filtering of the oil, which is associated with greater design effort. In the context of rolling bearings, mineral oils such as machine oil, spindle oil or turbine oil are used in the temperature range -30°C to 150°C. At other temperatures, bearings are lubricated with synthetic oils such as ester oil, silicone oil and fluorinated oil. It is also generally true for oils that a mixture of different oils should be avoided or a detailed compatibility analysis should be carried out. An important property of lubricating oils is the kinematic viscosity v which is used to measure the lubricity of an oil.

Bearing type	Kinematic viscosity mm^2/s
Ball bearings, cylindrical roller bearings, needle roller bearings	≥13
Spherical roller bearings, tapered roller bearings, axial needle roller bearings	≥20
Axial spherical roller bearings	≥30

Generally, higher viscosity oils are used for roller bearings than for ball bearings, as the former run at lower speeds and carry heavier loads.

If possible, lubrication should reach an elastohydrodynamic (EHD) state, which leads to a complete separation of the rolling surfaces. The rolling of the rolling elements on the raceway with EHD lubrication can be compared, for example, with a water skier who needs a certain speed to glide on the water instead of sinking. Thus, the lubricity of the oil must not be too high or low, because, for example, if there is insufficient oil film between the rolling elements and raceway, then damage is usually not too far away.

Formula 6 is used to calculate the required oil quantity.

Formula 6

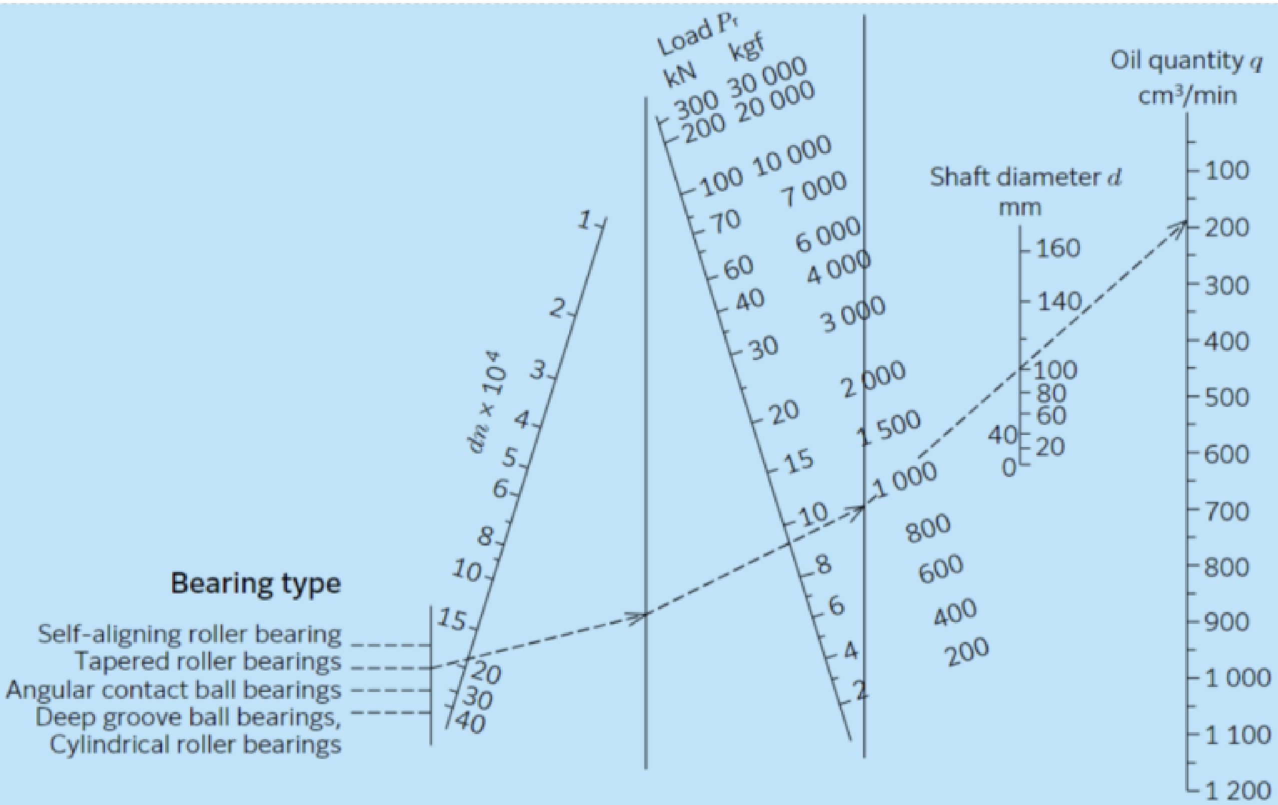
$$Q = K \times q$$

Q	Oil quantity per bearing (cm^3/min)

This is the key to determining the required oil quantity, for this the permissible oil temperature rise factor is multiplied by the lubricant quantity.

K	Permissible oil temperature rise factor
q	Lubricant quantity according to diagram (cm^3/min)

The amount of oil required must be calculated to ensure that the heat dissipated by the lubricating oil is approximately equal to the amount of heat generated by the bearing and other sources. In practice, the calculated quantity is then multiplied by a safety factor of 1.5 to 2.0 because the radiated heat of the housing varies depending on the design.



The diagram shows the guidelines for oil quantity: The lubricant quantity varies depending on the bearing *type. Procedure: Start on the left with the bearing type and then go through the diagram using the parameters dn, P_r and d (from left to right). The intersection with the vertical line with no scale always represents the new starting point.*

Regular checking of the oil quantity and cleanliness is essential. The intervals for replacing the lubricating oil vary depending on the operating conditions, oil quantity and type of oil. As a rough guideline, the oil should be changed once a year at operating temperatures of up to 50°C and at three-monthly intervals at temperatures between 80°C and 100°C. In addition, it must be noted that the lubricant service life decreases by approximately 50% every 10°C from temperatures of 80°C onwards.

Solid lubrication

In special cases, for example when grease or oil lubrication is not possible, solid lubricants are used as an alternative. Solid lubricant consists of a oil, which has the same viscosity as a conventional oil, and an ultra-high polymer polyethylene. The two components are mixed in a liquid phase. After heating and cooling, this substance solidifies so that a large amount of lubricant is absorbed into the polymer structure. Even with strong vibrations or centrifugal forces, the lubricant does not escape from a rotating bearing. In addition, solid lubrication is used in applications where dirt can enter the bearing or ordinary lubricant is simply washed out, because this way the dirt is blocked by the solid lubricant as it fills the available bearing internal free space. Solid lubrication is also used in the food industry, where there would otherwise be a risk of escaping lubricant contaminating the food. So far quite advantageous, isn’t it? On the other hand, solid lubrication is not suitable for applications with high speeds due to the increased friction in the bearing. Therefore, it is crucial speed is taken into account when considering a solid lubricant.

The Kappa value

To conclude this chapter, we’ll explore the kappa value, another important parameter in the field of lubrication. This has to be determined individually for each lubricant and the operating conditions and is also required for the determination of a_{ISO}, the life modification factor for the adjusted rating life of a rolling bearing. The Kappa value represents the viscosity ratio of actual kinematic viscosity v and nominal viscosity v_1 and describes the lubrication conditions in a rolling bearing during operation. The type of rolling bearing, size, lubricant, speed and temperature play a role here.

The Kappa value can be divided into three lubrication conditions. A value of $\kappa \leq 0.1$ indicates boundary lubrication where an EHD lubricating film is not formed. This leads to solid body contact and increased friction or wear. A kappa value of $0.1 < \kappa \leq 4$ is referred to as mixed friction. Due to insufficient lubricant film thickness, there is still partial solid body contact, so that the roughness peaks interlock sporadically. In this case, however, the friction is already reduced. Only at $\kappa > 4$ is there so-called “full lubrication“ and thus a full EHD lubricating film is present, which completely separates the contact surfaces of the solid bodies.

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Fit selection

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Summary

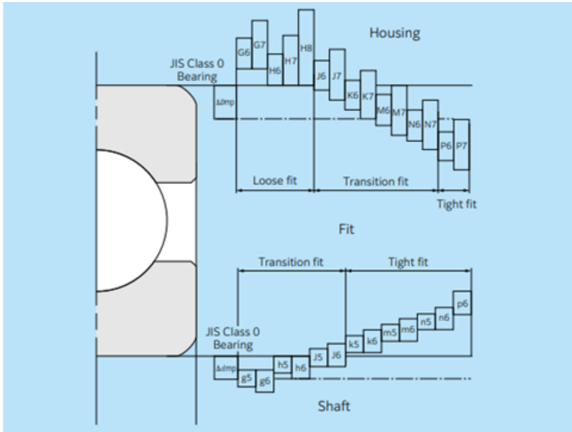
- Fit selection is made before calculating the bearing clearance
- The selection of the correct fit is intended to prevent relative movements between the inner ring and shaft or outer ring and housing during operation
- Incorrect bearing fits can cause bearing damage
- Types of fit: Interference, transition and clearance fits
- In some applications, the calculation of a minimum and maximum interference between inner ring and shaft or housing and outer ring is required

Interference fit, transition fit, clearance fit. You should know and be able to define these three types of fit after reading this article. But before that, it is useful to understand what fitting is and what you have to consider.

Why is the choice of fit important?

It is wise to select a fit before calculating the bearing clearance, as the fit choice has a direct effect on it. Understanding this is an important aspect of mechanical engineering. The choice of fit, also called *bearing fit*, is very important in order to prevent or enable relative movements between the inner ring and shaft or outer ring and housing during operation.

If the interference is too small, unwanted relative movements potentially occur between the mating surfaces of the bearing and the shaft or housing. These movements can occur in a radial, circumferential or axial direction. These relative movements can cause damage to the shaft, housing and bearing, which then leads to expensive or complex repair measures. In addition to the bearing itself, the shaft and housing may also have to be replaced. There are cases, however, where the bearing should move freely, for example in the case of non-locating bearings. In this case, it must be ensured that there is sufficient clearance between the mating surfaces of the bearing and the shaft or housing. If there is no clearance, there is a risk that the bearing will jam in the event of temperature fluctuations with accompanying longitudinal expansion of the housing and/or the shaft.



When choosing the fit, always take a look at the operating conditions (especially influences such as temperature fluctuations and bearing loads).

With regard to the choice of fit, it should be noted that some bearings with line contact (roller bearings) can potentially also run directly in the housing and/or on the shaft. The bearing fit is also very important in such cases, as it has a direct influence on the bearing clearance.

Correct fit selection is imperative. Particular attention must be paid to the geometric shape of the shaft and housing bearing seats, because all geometric errors can be transferred to the inner ring and outer ring. They can lead to vibrations, noise during operation and ultimately to bearing damage (see list “Bearing damage due to incorrect fit”). To avoid this, it makes sense to choose an interference, transition or clearance fit only after careful analysis of the operating conditions (and the surrounding components). In doing so, one should strictly adhere to the recommendations of the rolling bearing manufacturer according to the catalogue.

Bearing damage due to incorrect fit

- Cracks in the ring, early flaking and misalignment of the raceway
- Abrasion on the ring and shaft or housing due to creep and fretting-corrosion
- Seizure caused by excessive negative bearing clearance (preload)
- Noise generation and loss of concentricity as a result of raceway deformation

Types of bearing damage from incorrect fits are many and varied, but fortunately also avoidable.

Important criteria for consideration are the shaft and housing material, the wall thickness and the surface finish. In addition, there are the operating conditions of the rolling bearing – these include factors such as the load type, size and direction, the speed and temperature.

Interference fit

In general, interference fit is an effective method of fixing the mating surface of the bearing rings with shaft or housing. As the illustration for “Radial load and bearing seat” shows, an interference fit is required for bearing rings with rotating loads – this applies to both the inner ring and the outer ring. “Bearing rings with rotating loads” refers to bearing rings that are subjected to rotating loads relative to their radial direction. Strong interference fits are also recommended for operating conditions with high vibration or shock loads, for hollow shafts and thin-walled housings, as well as for applications with housings made of plastic. Furthermore, fits with low interference are sometimes recommended for applications with high running accuracy requirements or when using small or thin-walled bearings. In most cases, the bearing must be pressed onto the shaft or into the housing in the case of an interference fit, which is why mounting and dismounting can be quite time-consuming. The prerequisite is that the shaft is slightly larger than the inside diameter *d* of the inner ring of the rolling bearing. Another general disadvantage of the interference fit is the reduction of the bearing clearance or operating clearance.

Transition fit

In addition to the interference fit, there is also the transition fit, which is used when there are tolerances ranges in an application that allow for both a clearance as well as an interference.

Clearance fit

For non-separable bearings, such as deep groove ball bearings, a clearance fit is recommended for either the inner ring or the outer ring. In this case, the bearing ring that is subjected to a point load is provided with a loose fit. The outside diameter *D* of the bearing outer ring is smaller than the minimum inside diameter of the bearing housing seat; or the inner ring inside diameter *d* is larger than the maximum shaft outside diameter. The relationship between the bearing seat and the type of load is shown in the next table.

Load type	Bearing rotation	Ring load	Bearing seat

Fit selection

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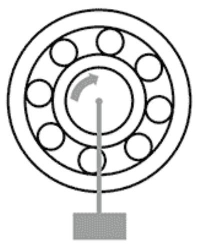
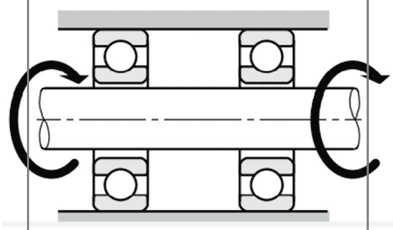
<tr>
<td>Fixed load
</td>
<td>
Inner ring rotates
Outer ring static</td>
<td rowspan="2">Circumferential or rotating load for the inner ring
Point or static load for the outer ring</td>
<td rowspan="2">Inner ring: Tight fit
Outer ring: Loose fit</td>
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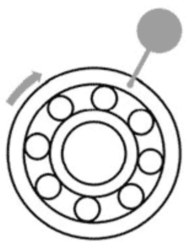
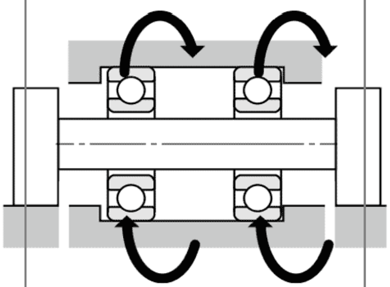
<td>Rotating load
</td>
<td>
Inner ring static
Outer ring rotates</td>
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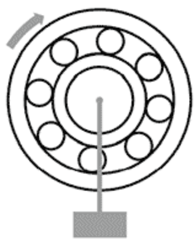
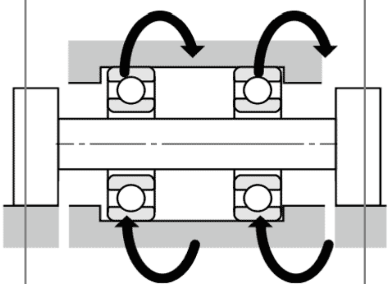
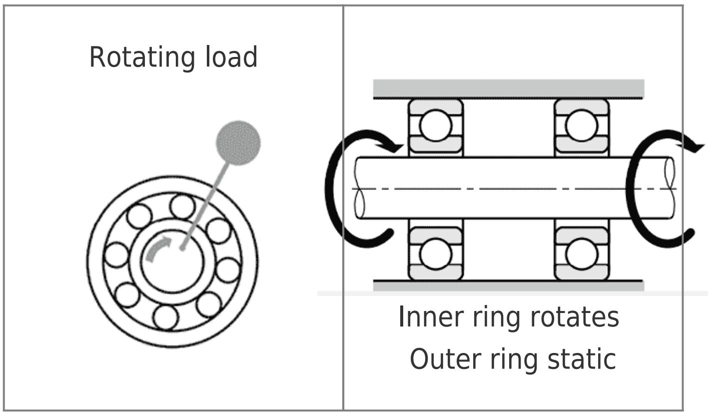
<tr>
<td>Fixed load
</td>
<td>
Inner ring static
Outer ring rotates</td>
<td>Point or static load for the inner ring
Circumferential or rotating load for the outer ring</td>
<td>Inner ring: Loose fit
Outer ring: Tight fit</td>
</tr>
</table>



Radial load and bearing seat: Here you can see the connection between the load type and bearing fit.

Determination of the bearing fit

The interference can be determined on the basis of the diameter tolerances of the shaft and housing bores and the tolerances of the bearing rings. Recommended values for the interference and possible fits for various applications can usually be found in corresponding tables, for example in the NTN catalogue.

Minimum and maximum interference

In some applications it is necessary to calculate a minimum and maximum interference between inner ring and shaft or outer ring and housing. With regard to minimum interference, the following factors should be considered:

Reduction of the interference due to:

- Radial loads
- Differences between operating temperature and ambient temperature
- Change of shape/surface of the mating surfaces

- Deformation

Inner and outer ring tension must be taken into account when selecting fits.

The first factor considered in detail is therefore the fact that the interference between the inner ring and shaft is reduced when a radial load acts on the rolling bearing. This influence, which will be referred to below as the required effective interference corresponding to the radial load Δ_{dF} can be calculated using formula 7 and formula 8.

Formula 7

$F_r \leq 0.3\ C_{or}$

$\Delta_{dF} = 0.08\ (d \times F_r/B)^{1/2}$ N

Formula 8

$F_r > 0.3\ C_{or}$

$\Delta_{dF} = 0.02\ (F_r/B)$ N

The formulas are used to calculate the reduction of interference due to radial load Δ_{dF}.

A handful of variables are used for the calculation of Δ_{dF}.

Δ_{dF} = Required effective interference relative to radial load µm

d = Bearing bore diameter, mm

B = Inner ring width, mm

F_r = Actual radial load, N

C_{or} = Basic static load rating, N

The interference between inner rings and steel shafts is reduced by temperature increases (difference between bearing temperature and the ambient temperature, ΔT) due to bearing operation. The calculation of the minimum required interference in such cases is shown in formula 9.

Formula 9

Δ_{dT} *is calculated with this formula.*

$\Delta_{dT} = 0.0015 \times d \times \Delta T$

Δ_{dT} = Required effective interference for the temperature difference in µm

ΔT = Difference between bearing inner ring temperature and the ambient temperature in °C

d = Diameter of the bearing bore in mm

Furthermore, when selecting the fit, it must be taken into account that the fitting surface may be smoothed as a result of press fitting – in contrast to heat fitting. This also means that the interference is reduced. The extent to which the interference decreases depends on the roughness of the mating surfaces. In general, a reduction of the interference must be expected (see “Reduction of the interference“).

Reduction of the interference:

- For ground shafts: 1.0~2.5 μ m
- For turned shafts: 5.0~7.0 μ m

How much the interference reduces depends on the type of machining used.

The previous criteria referred to the minimum interference, but now an aspect is added that concerns the maximum. The use of bearing rings with interference leads to tensile stresses and compressive stresses on the mating surfaces. If the interference is too large – the specified upper limit of approx. 127 MPa must always be observed – one should not be surprised about damage to the bearing rings and the subsequent reduced service life. The consequences of excessive interference can be cracks in the inner ring and breakage of the guide ribs.

Fit selection for materials with high thermal expansion

Shafts and housings can be made of materials other than steel. Particularly in the case of materials with high coefficients of thermal expansion (e.g. aluminium), it must be taken into account that the fit of inner ring and shaft or outer ring and housing changes when the temperature rises during operation of the bearing. Because materials such as aluminium expand faster than steel, for example, this can only be compensated for to a limited extent by tighter fit for alloy housing. If the temperature fluctuations are too extreme, the housing should be made of materials with comparable expansion coefficients such as cast steel.

Formula 10

$$\Delta d_{TE} = (\propto_1 - \propto_2) \times d \times \Delta T$$

Δd_{TE} = Change in interference due to different expansion coefficients, mm
$\propto_1$ = Coefficient of expansion of the rolling bearing, 1/℃
$\propto_2$ = Expansion coefficient of the shaft or housing, 1/℃
d = Reference diameter of the relevant fit, mm
ΔT = Temperature difference between ambient and operation

Coefficients of expansion of individual materials must be taken into account when choosing *the fit. The reason for this is that materials other than steel have different coefficients of expansion.*

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Summary

- The internal mobility of the rolling elements and the rings in the axial and radial direction is referred to as *bearing clearance*
- *Bearing clearance* refers to an unmounted rolling bearing
- *Operating clearance* refers to a mounted rolling bearing in operation
- Typical bearing clearance classes (values for a deep groove ball bearing 6008): C2 (1->11µm) -> CN -> C3 -> C4 (28->46µm)
- Preload is defined as either a negative radial operating clearance or the axial preloading of a rolling bearing by means of a spring or a clamping system

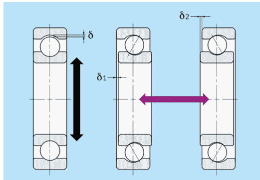
Bearing clearance and operating clearance, isn't that the same thing? And preload, I've heard that before, but what is that supposed to be?! How do I calculate all these values and what criteria are important when choosing the right operating clearance? Perhaps you are confronted with such questions – you will find the answers and more detailed information in this article.

Definition of bearing clearance and operating clearance

The bearing clearance refers to an uninstalled rolling bearing and can be described as the internal mobility of the rolling elements and the rings in both axial and radial directions. The operating clearance can also be described as the internal mobility of the rolling elements and the rings in both directions, but it refers to an installed bearing in operation.

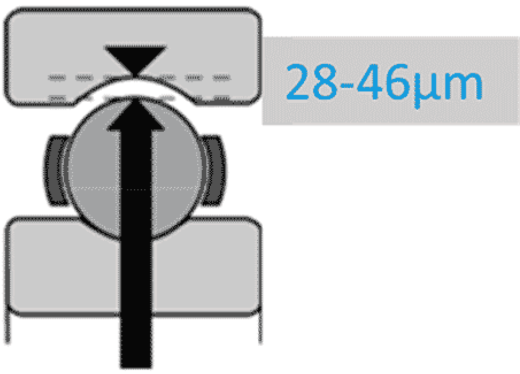
Bearing clearance, operating clearance and preload

Internal clearance



The bearing clearance is characterised by displacements in both radial and axial directions.

The most practical way to explain internal clearance is to imagine a bearing (for example, a deep groove ball bearing) that you are holding in your hand. If you try to move the inner ring of this bearing up and down or to the left and right while holding the outer ring, you will notice a small displacement in the radial (black arrow) or axial direction (purple arrow). This displacement is called bearing clearance. Conversely, the inner ring can also be held and the outer ring moved up and down or to the left and right. This is also referred to as bearing clearance.



The bearing clearance of the deep groove ball bearing 6008C4, which uses the following example calculation, is shown here graphically.

But enough theory. What about the bearing clearance in a practical example? For a bearing 6008C4, for example, the radial internal clearance is 28-46µm (= C4). In the first step, bearing 6008C4 is mounted once on a steel shaft that has, for example, a k6 tolerance (+2 -> +18µm). Since bearing 6008C4 has a tolerance on the inner ring of 0/-12µm the resulting fit between the inner ring and the shaft gives 2 to 30 microns of interference. This value is obtained by looking at the tolerances on the bearing inner ring and the shaft.

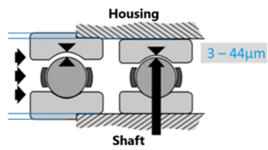
Only extreme values are taken into account, which cover the range when the “largest” bearing is mounted on the “smallest” shaft or the “smallest” bearing is mounted on the “largest” shaft. In this example, this would be the following cases:

- Shaft with 40.002 mm outside diameter (OD) and bearing with 40.000 mm inside diameter (ID) = 2 µm interference
- Shaft with 40.018 mm OD and bearing with 39.988 mm ID = 30 µm interference

Some force is needed to mount the 6008C4 on the shaft to overcome the interference. Due to this interference, the bearing clearance is reduced so that after mounting on the shaft it becomes +3µm -> +44µm. Now the shaft is mounted with the 6008C4 inside a steel housing. In this example, the housing has a H6 (0µm/+19µm) tolerance and the outer ring of the bearing has a tolerance of 0/-13µm.

Comparable to the shaft, the housing bearing fit and outer ring tolerance are considered. Here, the following applies:

- Housing with 68.000 mm inside diameter (ID) and bearing with 68.000 mm outer diameter (OD) = 0 µm
- Housing with 68.019 mm ID and bearing with 67.987 mm OD = 32 µm

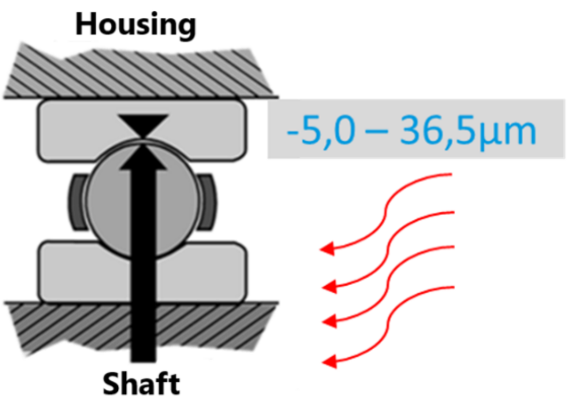


Reduction of bearing clearance due to fits.

As you can see, the resulting fit between the outer ring and the housing is a clearance of 0µm – 32µm. This does not change the clearance in the bearing: +3 -> +44µm.

The shaft is then rotated at 8,000 rpm, for example. The bearing 6008C4 now has a

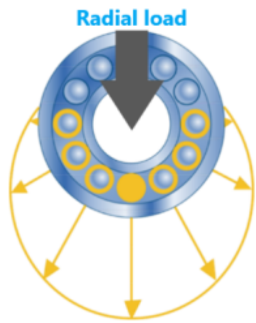
Bearing clearance, operating clearance and preload



Due to the fact that the inner ring expands more than the outer ring, the bearing clearance is reduced.

temperature of 100°C on the inner ring and 90°C on the outer ring. But what is actually happening now? Well, the inner ring and the outer ring expand due to the heat, but the inner ring expands more than the outer ring due to the temperature difference. Because of this, the clearance in the bearing is reduced from +3 -> +44µm to -5.0 -> +36.5µm. This reduction of about 7.5µm is calculated with a computer programme or alternatively with the help of catalogue formulas.

If a radial force is now added, this increases the radial internal clearance again. The reason for this is that some of the rolling elements absorb the radial load while the other rolling elements are relieved. The rolling elements under load will deform slightly (elastic deformation). In the illustration of radial load, this is shown for a deep groove ball bearing. The length of the yellow arrows indicate the magnitude of the force acting on the rolling elements where the elastic deformation is proportional to the force.



In this illustration you can see the magnitude of the force acting on the rolling elements. In short: Small arrow = low load, large arrow = high load on the rolling element.

There are different groups of radial internal clearance for rolling bearings. These can be seen in the table. (Note: The axial internal clearance can be calculated from the radial clearance using formulae, for example for deep groove ball bearings).

Internal clearance	Meaning	Possible applications
C2	Bearing clearance is smaller than normal	• Small motors • Shaft journals of compressors
CN	Standard bearing clearance	• Most common applications
C3	Bearing clearance is larger than normal	• Axle bearings for rail vehicles • Paper machines and dryers
C4	Greater than C3	• Traction motor bearings for rail vehicles • Paper machines and dryers
C5	Greater than C4	• Special applications

You will certainly not come across CN, C3 and C4 for the last time. The other bearing clearance classes are only used under special operating conditions.

Operating clearance

We can now say that the bearing clearance in the operating state is -5.0µm to 36.5µm. This bearing clearance during operation is also called operating clearance. The corresponding changes to the bearing clearance depending on the assembly condition can be seen in the table.

Bearing clearance, operating clearance and preload

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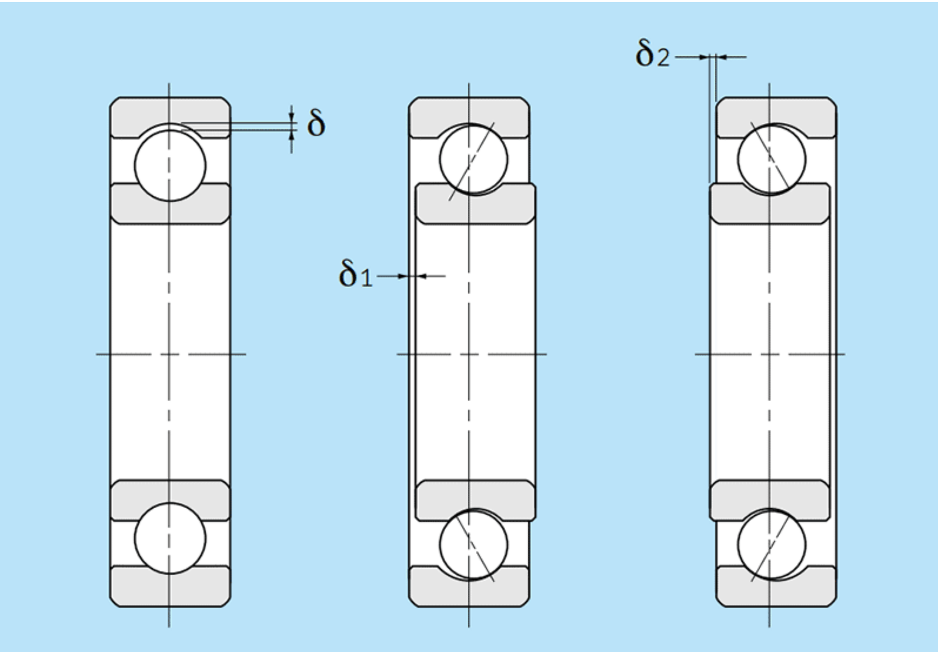
Summarised results		
Step	State	Radial internal clearance/operating clearance
1	**Before assembly**	28µm – 46µm
2	**After assembly on the shaft (k6 tolerance)**	3µm – 44µm
3	**After assembly into the housing (H6 tolerance)**	3µm – 44µm
4	**In operation, 8,000rpm, Inner ring temperature: 100°C, Outer ring temperature: 90°C**	-5.0µm – 36.5µm
5	**Radial force of 1,000 N**	+7,3µm -> +48,7µm

This table summarises the most important factors affecting radial clearance.

Formula 11
Radial clearance = δ
Axial clearance = $\delta_1+\delta_2$

The determination of

radial and axial clearance.



In the illustration you can see that the operating clearance is split into radial and axial clearance. Radial and axial clearance are determined differently.

Example: Relationship between operating clearance and service life

A targeted and careful selection of the bearing clearance is elementary, as the subsequent operating clearance has an effect on the service life (not the L_{10h} service life), the temperature curve, the bearing performance as well as the running noise. The effects of the operating clearance on the service life are shown in the graph.

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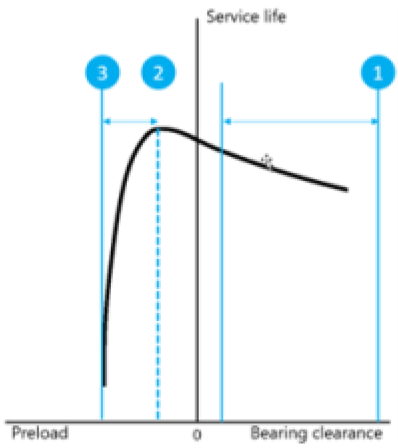
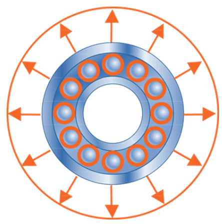
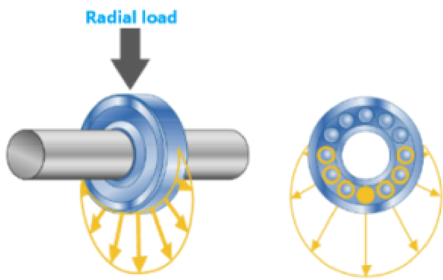


Lifetime depending on the operating clearance.

As you can see in the figure, the life span drops rapidly in areas 3 and 1. But why does the service life decrease so much? Let's assume that the bearing 6008C4 mentioned in the example above has 12 balls (rolling elements). However, if the temperature difference between the inner ring and the outer ring now always increases, the operating clearance will continue to decrease (range 3). As a result, all 12 rolling elements are now in contact, increasing resistance to rotation until eventually sliding occurs (rolling no longer takes place). This reduces the service life to the point of total failure!

If the table for the bearing clearance classes mentioned above is extended by a further column, the balls which "bear" the radial force (for example the weight of the shaft) are shown in the fourth column (load bearing).

Step	State	Bearing clearance/ Operating clearance	Load bearing balls	Service life area (see graph above)	Note
1	Before assembly	28µm – 46µm	–	–	–

2	After assembly on the shaft (k6 fit)	3µm – 44µm	3 – 12	1–2	–
3	After assembly into the housing (H6)	3µm – 44µm	3 – 12	1–2	–
4	In operation, 8,000rpm, Inner ring temperature: 100°C, outer ring temperature: 90°C	-5,0µm – 36,5µm	12 – 12	2–3	 The bearing 6008C4 has an inner ring temperature of 100°C and outer ring temperature of 90°C at n= 8,000rpm.
5	Radial force of 1,000 N	+7,3µm -> +48,7µm	7 – 12	2–1	 Bearing 6008C4 is in operation with a radial load of 1,000N.

This table shows how many balls or rolling elements bear the load depending on the operating clearance.

The calculation of the operating clearance

Even though the operating clearance should (theoretically) ideally be slightly negative in order to achieve maximum bearing life, in practical everyday life under normal operating conditions, operating clearance is usually targeted at just above zero. The reason for this is that this negative operating clearance (preload) could increase if a rolling bearing is exposed to changing operating conditions. This would in turn lead to the reduction in service life already described.

To calculate the operating clearance, factors such as fits as well as temperature differences that occur between the inner and outer ring must be taken into account.

Formula 12
$\delta_{eff} = \delta_o - (\delta_f + \delta_t)$
δ_{eff} = Effective interference (due to fits), mm
δ_o = Bearing clearance, mm
δ_f = Decrease in bearing clearance due to interference caused by fits, mm
δ_t = Decrease in bearing clearance due to temperature differences between inner and outer rings, mm

The calculation of the operating clearance δ_{eff} requires three variables.

The interference δ_f

The bearing clearance is reduced due to interference δ_f between the inner ring and shaft or outer ring and housing. Due to the interference δ_f between the inner ring and the shaft, the inner ring expands or the outer ring contracts (interference between the outer ring and the housing) during mounting.

Formula 13 can be used to calculate the reduction in bearing clearance. For the sake of simplicity, factors such as the shape of the bearing, shaft and housing as well as the materials used are taken into account by a numerical value of 70%-90%. In general, the larger the interference, the more the bearing clearance is reduced.

Formula 13
$\delta_f = (0,70 \sim 0,90)\ \Delta_{deff}$

Δ_{deff} denotes the effective interference in mm.

The temperature difference δ_t

The calculation of the value δ_f is not the whole picture. The next step is to calculate the variable δ_t which takes into account the reduction of the operating clearance due to a temperature difference in the bearing. An important piece of information: When the bearing is in operation, the outer ring is typically 5 to 10°C cooler than the inner ring, for example. Under certain conditions, such as above-average heat dissipation of the housing, this difference can be even greater.

Formula 14
$\delta_t = \propto \times \Delta T \times D_o$
$\propto$= Temperature coefficient of expansion of the bearing material, 12,5× ((10)*6/℃)
ΔT= Temperature difference (inner/outer ring) in °C
D_o= Outer ring raceway diameter, mm

When calculating the reduction in operating clearance due to a temperature difference, you must take several factors into account.

The raceway diameter of the outer ring D_o

In order to determine the raceway diameter of the outer ring again D_o (approximately), one must use formula 15 or formula 16, depending on the type of rolling bearing.

Formula 15
For ball bearings and spherical roller bearings:
$D_o = 0{,}20\ (d+4{,}0D)$

Formula 16
For roller bearings (except spherical roller bearings):
$D_o = 0{,}25\ (d+3{,}0D)$

The calculation of the raceway diameter of the outer ring D_o is different for ball bearings and roller bearings.

Preload

So far, this article has been about bearing clearance classes and how they change during operation. But depending on the application, it may be necessary to preload bearings axially.

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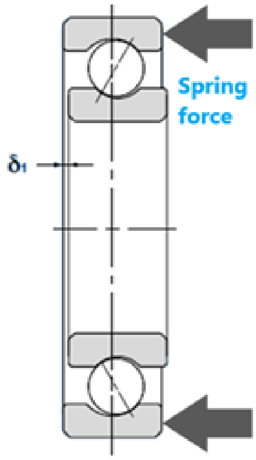
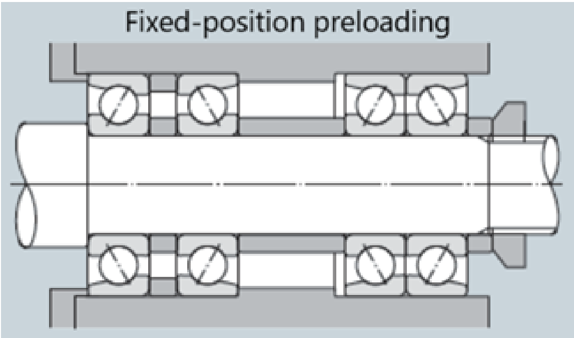
One possibility, which is often used in electric motors, for example, is axial preloading of the rolling bearings by means of a spring (preloading by means of a constant sprung preload force). This is shown symbolically in the illustration. The spring force acts around the entire circumference.



Spring force fixed-pressure preloading in a deep groove ball bearing.

Why is this done? The spring preload force causes all the balls to fit snugly against the raceways of the deep groove ball bearing (axial bearing clearance = 0µm). The preload thus causes a tension at the contact points of rolling elements and raceways. This reduces the operating noise and improves the vibration behaviour.



Spindle bearings are typically preloaded.

Another application is the bearings in a machine tool spindle (hence the name spindle bearing). Here, the spindle bearings are axially preloaded either by means of a spring, as with the electric motor, or alternatively via a fixed–position clamping system.

Preload is most likely to occur in angular contact ball bearings and tapered roller bearings, and a slight preload also has a positive effect on the overall service life. In the context of preload, one should always consider the purpose and the goal, because preload also carries risks, especially if preload is excessive. Therefore, it shouldn't be overlooked that this can lead to increased surface pressure, extremely high heat generation and a shortening of the bearing service life.

Effects of preload:

- Increase in rigidity
- Only conditionally recommended for highest speeds (applies to fixed-position preload)
- Concentricity and positioning accuracy are improved
- Positive influence on vibrations and running noise
- Lower risk of skidding

- Forced guidance of rolling elements on the guide rib (for example with tapered roller bearings)

Preload has several effects.

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Fit selection

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Fixed and floating bearings

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Summary

- Fixed/locating bearing: Prevents axial movement of the shaft in relation to the housing and absorbs radial and axial forces
- Floating/non-locating bearing: Axial relative movements are permitted as well as absorption of radial forces, precise axial guidance is not required
- Adjusted bearing: Bearing rings of two opposed bearings are preloaded against each other; precise guidance is required in the application
- Fully floating arrangement: characterised by axial play; no tight axial guidance required
- O-arrangement: Low misalignment of the bearings, wide support base
- X-arrangement: High misalignment of the bearings, low support base

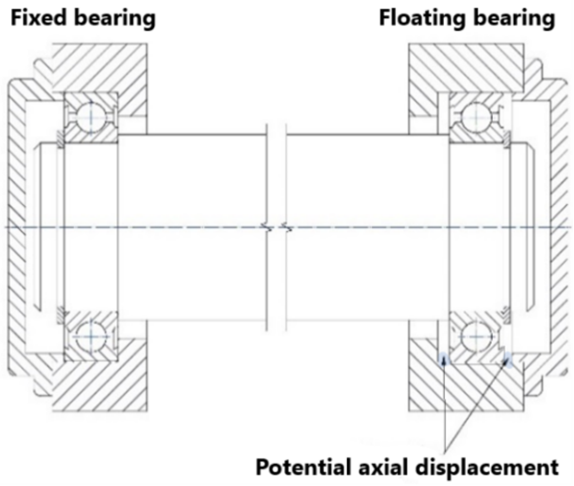
Do I choose a fixed bearing arrangement, an adjusted bearing arrangement or a floating bearing arrangement? This question is important when designing a shaft system. The three variants naturally have their advantages and disadvantages.

Definition of fixed/floating bearing arrangement

First of all, it is important to know that shafts or axles are basically supported by at least one pair of bearings in the axial as well as in the radial direction. The bearing that is to prevent axial movement of the shaft in relation to the housing is called a fixed or locating bearing. For this purpose, the bearing must always be secured axially on the shaft and in the housing using suitable abutments. This axial securing can sometimes be done by means of a locknut or circlip.

Fixed and floating bearings

In order to compensate for thermal expansion and manufacturing tolerances, another bearing, a so-called floating bearing, is required. As can be seen in the illustration of the fixed and floating bearing, the axial displacement occurs in the housing. However, this axial displacement can also be made possible on the shaft or within the bearing itself (for example in the case of a cylindrical roller bearing of the NU or N design). In each case, the axial securing takes place on the shaft or in the housing. In the case of a cylindrical roller bearing (NU or N design from NTN), where the axial displacement occurs within the bearing, both the inner ring and the outer ring are axially secured.



The illustration of a fixed and floating bearing arrangement

Bearing arrangement (differentiation between fixed and floating bearing side)			
Arrangement		Comment	Application examples
Fixed bearing side	Floating bearing side		

Fixed and floating bearings

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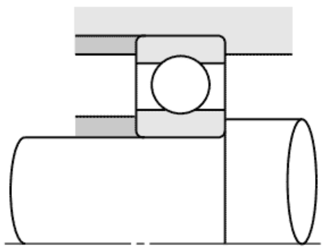
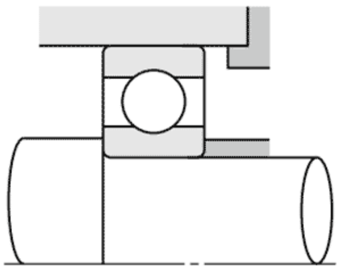
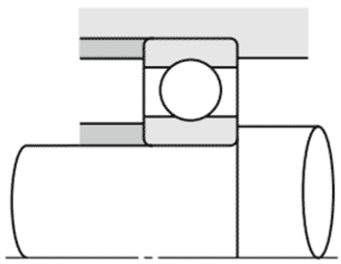
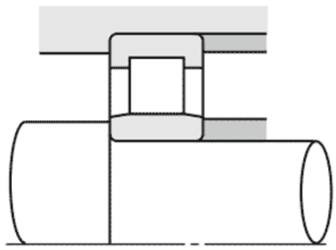
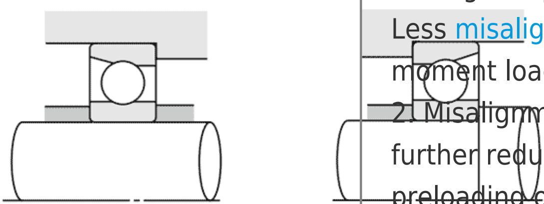
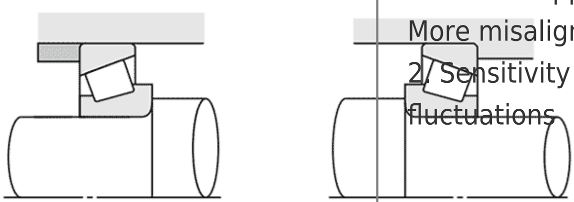
Bearing arrangement (differentiation between fixed and floating bearing side)			
		1. General arrangement for all machines. 2. For radial loads, but also supports axial loads.	• Small pumps • Motor vehicle gearboxes
		1. Suitable for low installation errors and shaft deflection or for high speed applications. 2. The floating bearing side is easily movable, even with expansion and contraction of the shaft.	• Medium size electric motors • Fans

Here you will find a general overview of fixed and floating bearing arrangements

The adjusted bearing arrangement

In addition to the fixed and floating bearing arrangement, there is also the adjusted bearing arrangement. Adjustment means that the rings of two bearings are displaced until either the desired preload or the desired clearance is achieved. This results in more accurate guidance and higher bearing stiffness. Tapered roller bearings and angular contact ball bearings are mainly used for this “adjustment“, but many other rolling bearing types (such as deep groove ball bearings) are also suitable for an adjusted bearing arrangement. In order to align two bearings against each other, there are three possible bearing arrangements: The O, X and tandem arrangement. The table shows the O and X arrangements.

Bearing arrangement (adjusted bearings)		
Arrangement	Comment	Application examples
 O-arrangement (Back to Back)	1. Larger support width → Less misalignment under moment load 2. Misalignment can be further reduced by additional preloading of the bearings.	• Machine tool spindles
 X-arrangement (Face to Face)	1. Lower support width → More misalignment possible 2. Sensitivity to temperature fluctuations	• Reduction gear • Front and rear differential of motor vehicles

You can find more information on the O and X arrangement here.

However, it has to be taken into account that adjusted bearings also have disadvantages. For the “adjustment“, considerably more time is needed during assembly than for a fixed/floating bearing. The reason for this is, for example, the setting of a defined clearance or preload.

The fully floating bearing arrangement

Another bearing arrangement that essentially has a lot in common with the adjusted bearing arrangement is the fully floating bearing arrangement. In contrast to the adjusted bearing, this always involves some axial play, which is why there is no precise axial guidance with the floating bearing. The amount of axial clearance *s* is predetermined by the designer in the case of a floating bearing arrangement, so that the bearings are not subjected to axial distortion under any circumstances. A floating bearing arrangement is chosen for gearboxes, for example, if the gearing requires a free axial position or the axial guidance accuracy does not have to be particularly high.

Angular contact ball bearings and tapered roller bearings, both of which must be adjusted, are conversely unsuitable for the fully floating bearing arrangement. The most prevalent rolling bearing types that are suitable for a floating bearing arrangement are summarised in the list.

- Spherical roller bearing
- Deep groove ball bearing
- Cylindrical roller bearing

In addition to the three bearings, other rolling bearing types can of course also be used to create a fully floating bearing arrangement.

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Summary

- Applies to angular contact ball bearings and tapered roller bearings
- O-arrangement: Only small misalignment of the bearings possible, wide support base
- X-arrangement: Larger misalignment of the bearings possible, low support base
- Tandem arrangement: Unlike the other two arrangements, bearings can support axial loads from only one direction
- All arrangement types can be combined with each other

If you have already read the articles on angular contact ball bearings or tapered roller bearings, you may already have come into contact with different types of bearing arrangements. Specifically, these refer to the arrangement of the rolling elements in multi-row or matched bearings. There are three main types – O, X and tandem arrangements.

The O, X and tandem arrangement is about how several bearings are arranged in relation to each other. If you look at the contact angles of the force application in the technical drawings and sketch them further in your mind, you will notice that they take on an O-shape in the O-arrangement and a – surprise! – X-shape in the X arrangement. The tandem arrangement can be visualised insofar as the contact angles in the drawing work in the same direction. Also, the tandem bicycle can serve as a mnemonic. Before you read about specific characteristics, you should know that there are several names for the different arrangements.

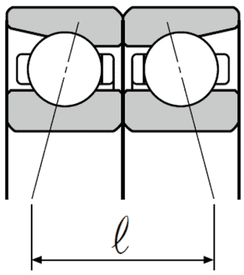
Name	Abbre-viation	Descrip-tion

In the text, only the designations O, X and tandem arrangement are used for simplicity.

O arrangement	DB	Back to Back
X arrangement	DF	Face to Face
Tandem arrangement	DT	Tandem

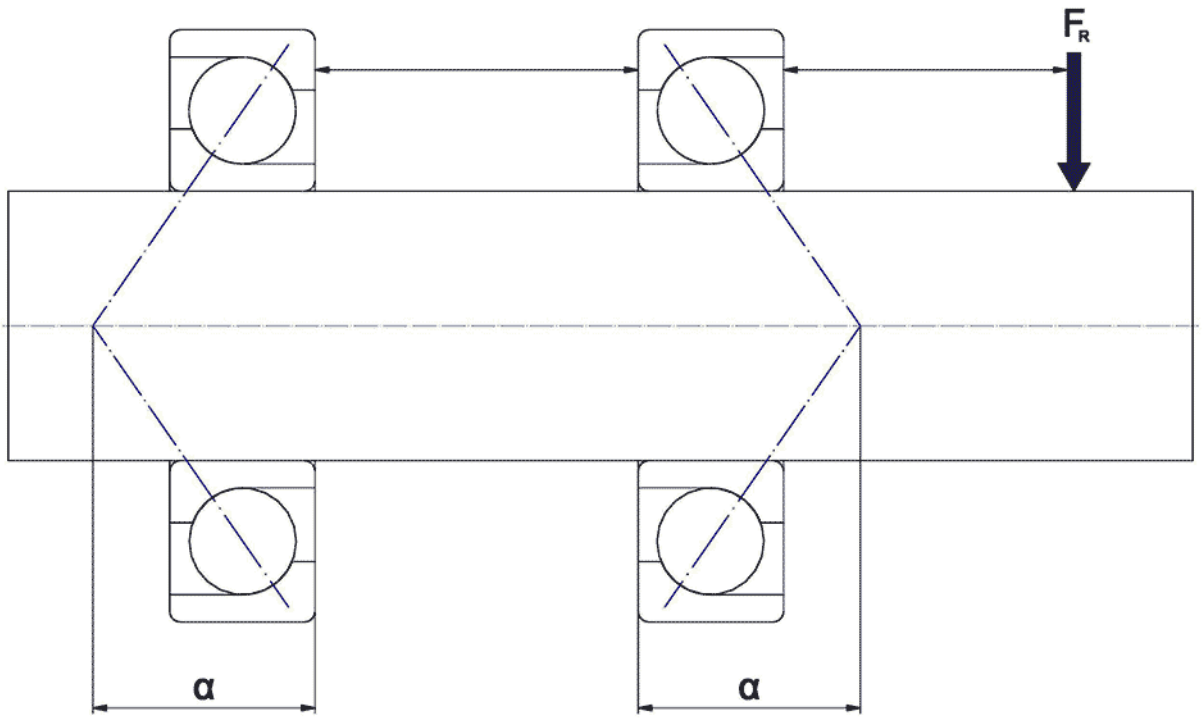
O arrangement

Let's start with the O arrangement, the questions of what it can do and when you should use it. In the article on adjusted bearings, it was already mentioned that angular contact ball bearings and tapered roller bearings can be "adjusted" to form an O arrangement. This means that in addition to high radial loads, axial forces from both directions can also be accommodated.



The O arrangement of rolling elements concerns angular contact ball bearings and tapered roller bearings.

To explain when to use the O arrangement, the following example can be given: In an application, two 6212 deep groove ball bearings were previously used, but a more rigid support of the shaft is now required. What is the best way to proceed? In the sketch you can see two angular contact ball bearings. The value a must be used, which indicates the support span. For a 7212 angular contact ball bearing (30° contact angle) the value is a = 36 mm. For a 7212B angular contact ball bearing (40° contact angle) the value is a = 47,5 mm. In comparison, the previously used 6212 deep groove ball bearing only has a span of 11 mm (half the bearing width). If the two 6212 deep groove ball bearings are now replaced by angular contact ball bearings 7212B, this results in a considerably larger support span and consequently also a more rigid support of the shaft.



The O arrangement using the example of two angular contact ball bearings.

In the following, the three temperature effects that exist in the O arrangement and the so-called rolling cone peak R will be discussed. The latter can be seen in the three case studies shown.

O, X and tandem arrangement

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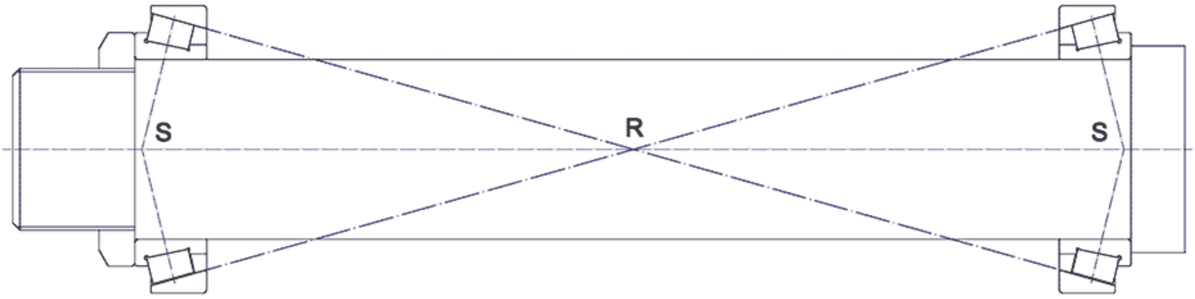
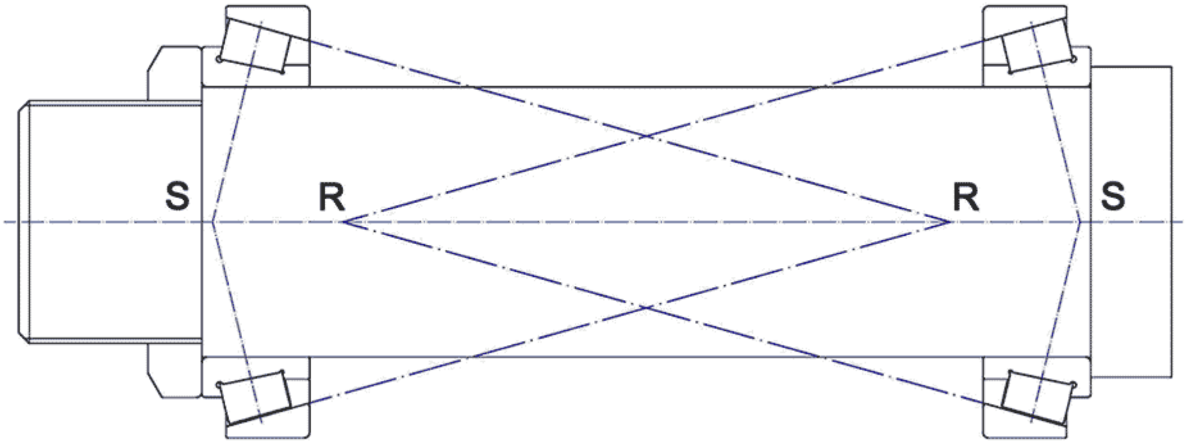


If the rolling cone lines meet at their apexes, then the axial and radial thermal expansion balance out and the set clearance is maintained.



If the rolling cone lines overlap, the radial expansion has a greater effect on the bearing clearance than the axial thermal expansion. The set clearance becomes smaller.

O, X and tandem arrangement

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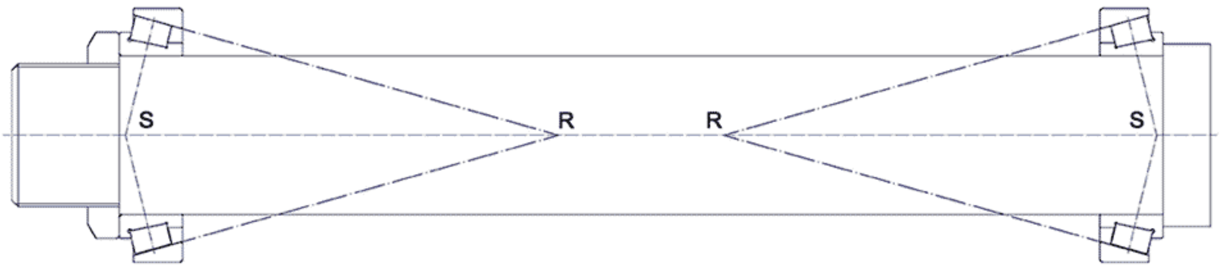
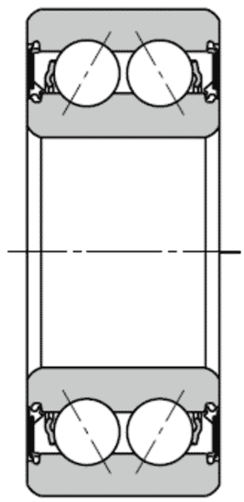


If the rolling cone lines do not overlap, the axial thermal expansion has a greater effect on the bearing clearance than the radial expansion. The set clearance becomes larger.

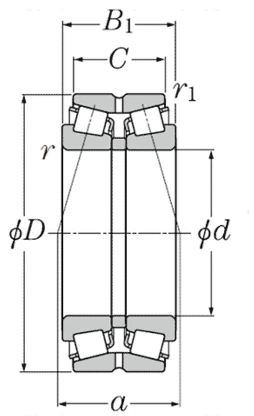
OK, and what does that mean? The bearing has been designed and deflections, bending lines, gear corrections etc. have now been calculated. However, if the temperature effects have not been taken into account, the consequences can be serious. In the worst case, bearing damage can be the result. Should this occur in practice, it is advisable to contact the bearing manufacturer for support.



Double row angular contact ball bearing with seals (LLD).

In addition to single-row angular contact ball bearings, which can be arranged in an O arrangement, there are also double-row angular contact ball bearings, for example. These are supplied in an O arrangement and have a common outer ring and inner ring. The advantage of these double-row angular contact ball bearings is their width.

A 7200B bearing (B = 40° contact angle), for example, has a width of 9mm, so the O arrangement thus has a bearing width of 18mm. The double-row angular contact ball bearing 5200S has an overall width of

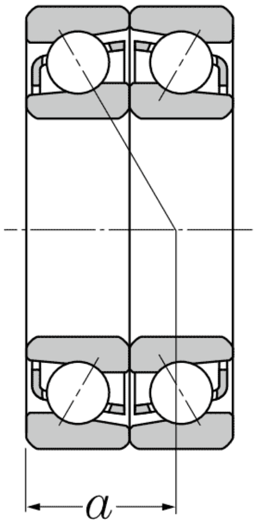


Here you see a double-row tapered roller bearing in O arrangement.

14.3mm with the same bore and outer diameter and is thus narrower in design. However, the load ratings are lower compared to the single-row angular contact ball bearings, so a compromise must be found. In addition, there are also double-row tapered roller bearings.

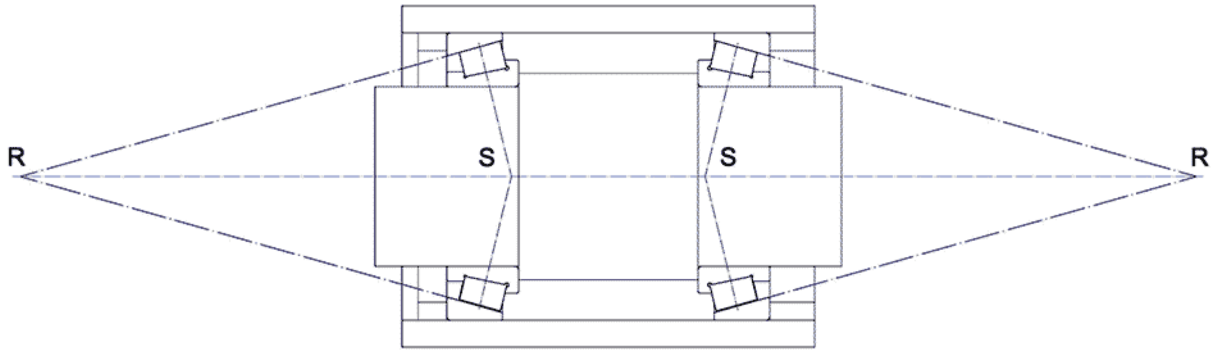
X arrangement

Angular contact ball bearings as well as tapered roller bearings with rolling elements in X arrangement can support axial forces running in both directions in addition to high radial loads (just as with O arrangement). Bearings with an X arrangement have a smaller support span between the load application points compared to bearings with an O arrangement. The load directions therefore intersect on the shaft axis, which is why bearings in this arrangement have a lower moment rigidity. At the same time, the X arrangement has a lower tilting rigidity, which means that larger misalignments are possible. The use of such bearing arrangements is suitable, for example, in the case of shaft deflection or in the case of predominant radial force application between the bearing points.



Compared to bearings of the O-arrangement, the X-shaped structure can lead to higher misalignments of the rolling bearings.

What about the temperature effects here? In contrast to the O arrangement, there is only one possibility here: A temperature difference between the inner ring and the outer ring leads to a reduction of the clearance or to an increase in the preload in the bearings. The extent to which these effects are critical for the bearing arrangement can be determined either from empirical values or through extensive and costly tests. In practice, costly tests can be avoided by asking the bearing manufacturer for advice.



X arrangement with tapered roller bearings.

Tandem arrangement

Sometimes a simple O or a simple X arrangement is not sufficient (for example due to low lifetime or rigidity).

O, X and tandem arrangement

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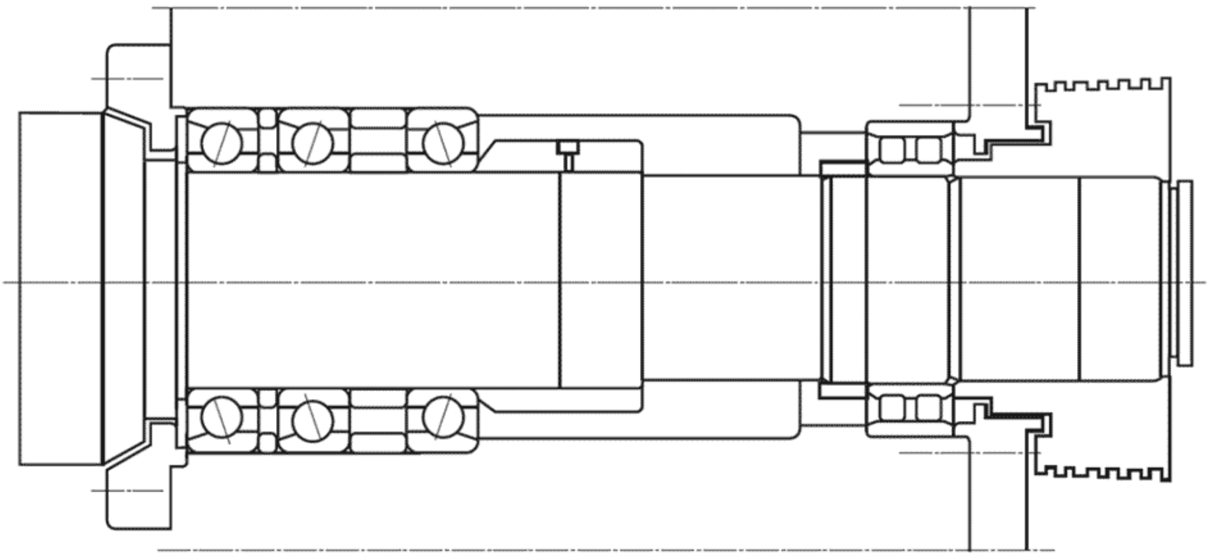
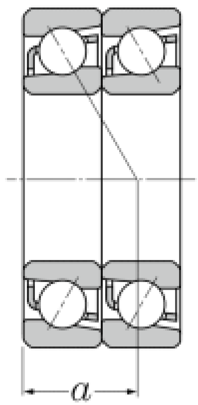


Bearing of a CNC milling machine spindle.

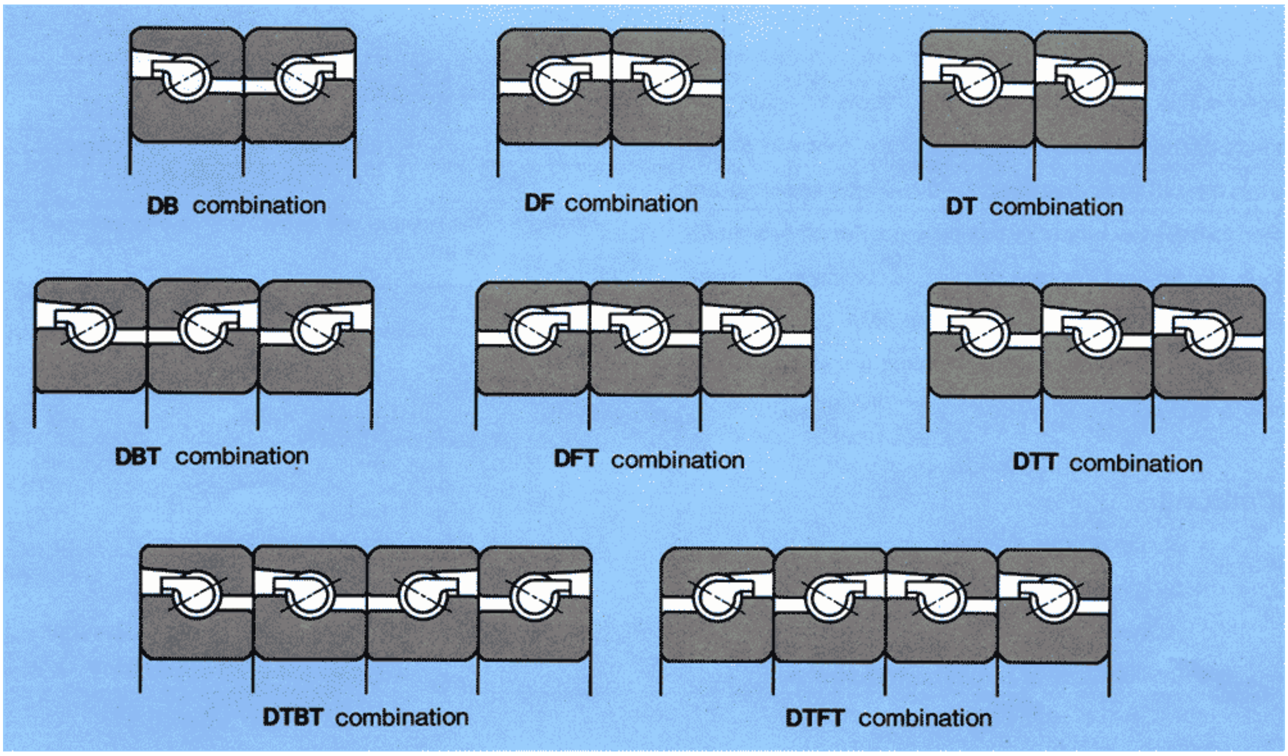
In such cases, one adds one or two bearings to an O-arrangement (see illustration of the bearings of a CNC milling machine spindle). The two bearings on the left are in tandem. The bearing arrangement shown is therefore called a tandem O arrangement. In contrast to the "simple" O or X arrangements, such tandem arrangements can support a greater axial load in one direction (acting from left to right in the picture). This reduces the axial deflection compared to the simple O-arrangement.

With regard to temperature effects, the same rules apply as with the O and X arrangement.



The term tandem arrangement can serve you as a mnemonic, since both rolling elements lying next to each other point in the same direction.

For some applications (especially for bearings in machine tools), several bearings are needed to “absorb” the acting forces and to achieve the desired properties (service life, rigidity, etc). This is why you also come across various combinations of individual bearings. In order not to have to write long, almost complicated designations such as Tandem-O or Tandem-O-Tandem arrangement every time, the whole thing is abbreviated with initials (like with O and X arrangement).



No limits: All arrangement combinations are possible.

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Characteristics of tapered roller bearings Here you see an NTN tapered roller bearing. As the name suggests, tapered roller bearings are roller bearings, whereby the

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Summary

- After calculation and selection of the bearing arrangement, the design of surrounding components must be carefully considered.
- Rolling bearings are secured with the aid of mechanical elements such as locknuts, circlips (snap rings) or adapter sleeves.
- The choice of the correct fits with shaft and housing depend on the operating conditions
- In the context of bearing abutment dimensions, shoulder height and fillet radii are important

Generally speaking, a bearing is only as good as its environment. Who can perform at their best if they don't feel comfortable in their surroundings? Have you already read our article on fixed and floating bearings? This chapter provides a good basis for bearing mounting and surrounding component design.

Shaft and housing design

After the correct bearings and bearing arrangement have been selected, the surroundings must now be considered. The most important criteria that need to be taken into account are listed below.

- Selection of the bearing arrangement

- Correct bearing mounting
- Ensuring the mountability of the bearing (Important if you don't want to make enemies during mounting).
- Choosing the right fit
- Determination of the correct bearing abutment dimensions (shoulder heights and corner radii)
- Geometric accuracy of shaft and housing (Attention: The more accurate, the higher the costs!)
- Determination of the maximum bearing misalignment in comparison to the permissible misalignment

At all times, the rolling bearing manufacturer's specifications should be observed with regard to these criteria.

Securing of rolling bearings with mechanical elements

Information on choosing the right bearing arrangement can be found in the corresponding article. Let's start with the correct mounting of the bearings on the shaft and in the housing. Rolling bearings can be secured with the help of various mechanical elements, including, for example, the use of lock nuts or retaining bolts or the use of a retaining ring (snap ring). For bearings with tapered bores, other bearing-specific accessories such as adapter sleeves and withdrawal sleeves can be used.

Inner ring lock	Outer ring lock	Snap ring

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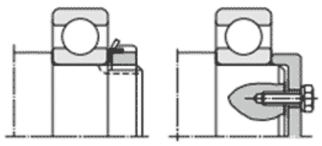
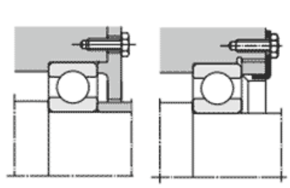
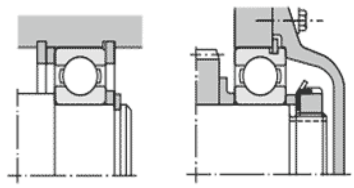
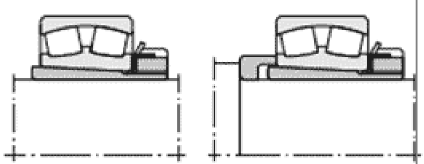
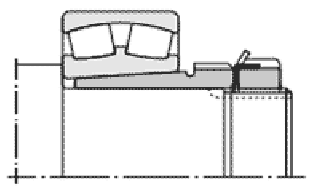
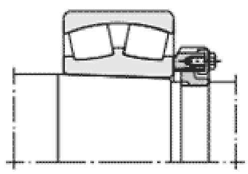
		
Rolling bearings can be fixed with the help of lock nuts or retaining bolts.		Above is a classic fastening with lock nut, lock washer, snap ring, bearing cover and spacer ring.

In this table you will see the fastening methods of rolling bearings that are generally in use.

With regard to the use of a retaining ring (snap ring), special attention must be paid to potential sources of error such as limit radii and bearing connection dimensions. Circlips simplify the construction. It is also important to know that retaining rings (snap rings) have certain disadvantages. They are not suitable for precision applications and equally unsuitable for absorbing high axial loads.

Mounting with adapter sleeve	Mounting with withdrawal sleeve	Mounting with tapered shaft
		
Adapter sleeves and withdrawal sleeves are used for axial location of the bearing on cylindrical shafts.		A split ring inserted into a groove on the shaft holds the rolling bearing in position with a split ring nut.

Further mounting options for rolling bearings are shown here for you.

The adapter sleeve is fixed by the frictional force between the shaft and the inner diameter of the sleeve. In addition, the position of the bearing on a cylindrical shaft can be freely selected when mounting with an adapter sleeve or withdrawal sleeve; both mounting variants are considered simple and process-safe. Mounting bearings with a tapered shaft is also an option. In this case, the split retaining ring is secured with a locknut or screw. The bearings (such as the spherical roller bearing in the illustration) can also be mounted easily and reliably by hydraulic means. According to the manufacturer's instructions, the displacement path must be measured and, at the same time, always checked, just like the bearing clearance.

Selection of the correct tolerances for shaft and housing

After this brief overview of the various fixing options, we now come to the importance of tolerances for the shaft and housing. On the subject of bearing clearance and preload, terms such as bearing clearance and operating clearance have already been mentioned and it has also been explained how to calculate them. This chapter is now about choosing the right fits. The choice of the "right" fit depends on the following considerations:

- Shaft and housing material
- Wall thickness
- Surface texture
- Operating conditions of the machine

So, let's get straight to the first important question: Tight fit or loose fit?

Load visualisation	Bearing ring rotation	Bearing ring load	Bearing seat fit

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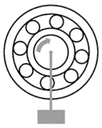
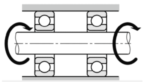
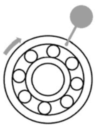
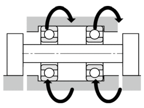
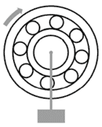
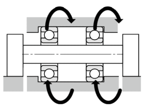
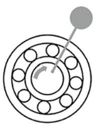
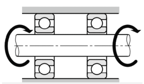
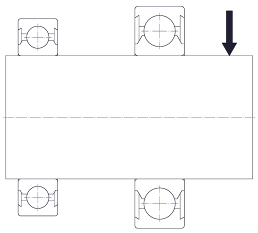
Fixed load 	 Inner ring rotates Outer ring static	Circumferential load for the inner ring Point load for the outer ring	Inner ring: Tight fit Outer ring: Loose fit
Circulating load 	 Inner ring static Outer ring rotates		
Fixed load 	 Inner ring static Outer ring rotates	Point load for the inner ring Circumferential load for the outer ring	Inner ring: Loose fit Outer ring: Tight fit
Circulating load 	 Inner ring rotates Outer ring static		

This table shows you under what circumstances a fixed or loose fit is necessary.

First it has to be clarified which of the two rings is rotating and which is static. Then it is checked which load is applied to the inner ring and which to the outer ring. An example: For the bearing unit shown, the fits for the two roller bearings are to be selected. Finally, the pulley is mounted on the shaft. The two bearings in question are a 6320C4 and a 6318C4 (manufacturer NTN).

You can visualise the bearing block in the example given like this.



Example bearing arrangement.

Which ring rotates? Correct, both inner rings. The outer rings, on the other hand, should not rotate. Does the inner ring have a point load? No, it has a circumferential load. Circumferential load means that the direction of the radial load acting on the inner ring is circumferential for the ring. Point load is present on both outer rings and means that the load only acts on a small point of the outer ring. The recommended fit is therefore: Inner ring = tight fit and outer ring = loose fit. Suggestions for suitable fits can be found in the catalogues of the rolling bearing manufacturers, for example at NTN. For the current case, for example, taking into account a "normal load", both shaft seats should have a k5 tolerance and an H7 tolerance should be selected for the housing seats.

Meaning of the bearing abutment dimensions

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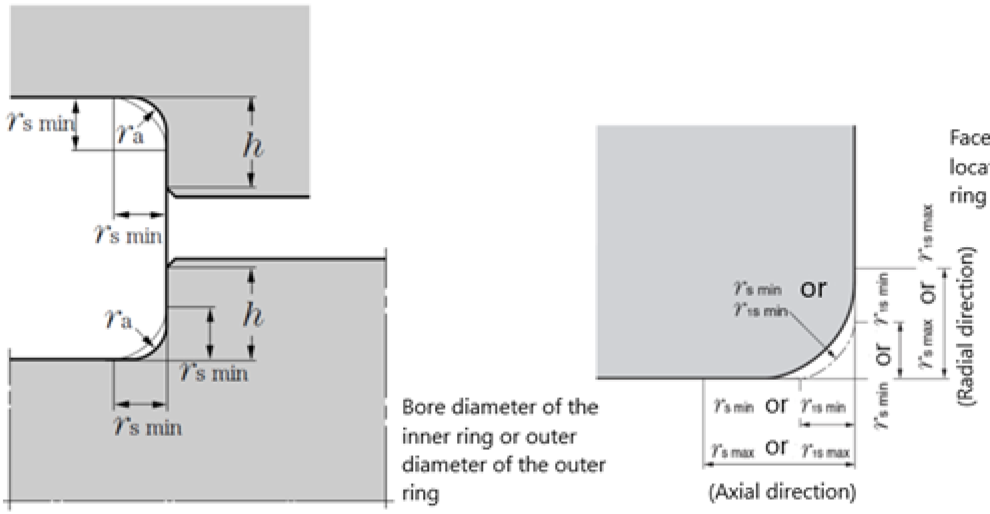
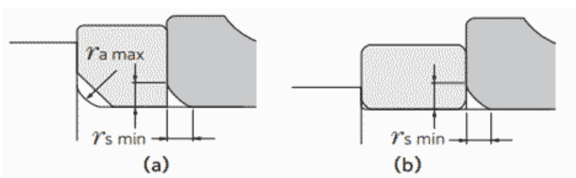
In addition to the bearing mounting itself, attention to the bearing abutment dimensions is crucial, with the shoulder height and corner radii playing a particularly important role.



Shoulder height and corner radius are important parts of the bearing abutment dimensions.

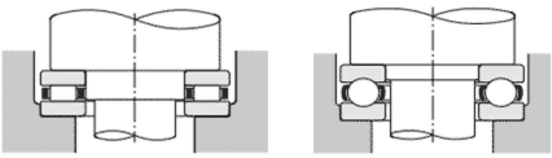
It is important that the height *h* of the bearing ring against the shaft and housing (left side of the illustration) is greater than the maximum permissible edge radius r_s max of the bearing (right side of the illustration). Otherwise, the support of the bearing on the shaft and housing is not sufficient. It must also be taken into account that the fillet radius r_a has a smaller value than the smallest permissible edge radius of the rolling bearing r_s min.

There are situations in which the corner radius r_a max is larger than the edge radii of the bearing. Among other things, this occurs when the shaft is to be strengthened or the contact height is not sufficient as a support surface for the bearing. In such cases it is appropriate to use spacer rings. Spacer rings



In the illustration you can see technical drawings of a spacer ring. This is drawn in light grey.

are individually manufactured in such a way that correct contact between the ring and the rolling bearing on the shoulder of the shaft or housing is guaranteed.



The general rule for shafts and housing abutment heights is that both are always designed to be greater for axial bearings than for radial bearings.

When using thrust bearings, it must be ensured that the supporting surfaces of the bearing rings are sufficiently wide, taking into account the criteria of load and rigidity. For this purpose, there are corresponding dimension tables, for example, in NTN's catalogue.

Accuracy of the shaft and housing bearing seats

Another key area for design of surrounding parts is the accuracy of the mating surfaces for the shaft and housing. In addition, the surface roughness and the perpendicularity of the bearing shoulders are taken into account.

Property	Shaft	Housing
Dimensional accuracy	IT6 (IT5)	IT7 (IT5)
Roundness (max.) Cylindricity	IT3	IT4

Abutment squareness		IT3	IT3
Fitting surface roughness R_a	Small bearings	0,8 µm	1,6 µm
	Medium ~ large bearings	1,6 µm	3,2 µm

In the table you will find useful specifications regarding shaft and housing tolerances. This table applies to normal operating conditions. (IT = basic tolerances).

Permitted inclination and misalignment

Shaft deflections, deviations in the finishing of shaft and housing as well as the smallest installation errors lead to a certain misalignment between the inner and outer ring of a rolling bearing. It is therefore important that in applications where misalignments can be comparatively high, adjustable-angle bearings such as self-aligning ball bearings, spherical roller bearings or insert bearings are used. Basically, it should be noted that the permissible misalignment depends on factors such as the bearing type, load conditions and operating clearance and thus varies depending on the application. The specified guide values should not be exceeded, otherwise there is a risk of bearing damage or problems with the cage.

Allowable bearing misalignment			
Deep groove ball bearing	1/1 000 ~ 1/300	Tapered roller bearing: Single-row (standard) Single-row (Ultage)	 1/2 000 1/600

Angular contact ball bearing Single-row	1/1 000	Needle bearing	1/2 000
Cylindrical roller bearing Bearing series 10, 2, 3, 4 Bearing series 22, 23 Ultage Double-row	 1/1 000 1/2 000 1/500 1/2 000		

The permissible misalignment of various types of rolling bearings.

Permissible bearing inclination			
Self-aligning ball bearing Normal load	1/15	Thrust spherical roller bearing Normal load	1/60 to 1/30
Spherical roller bearing Normal load or more Light load	1/115 1/30	Insert bearing	1/60 to 1/30

Self aligning bearings are used in applications with relatively high misalignments.

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O, X and tandem arrangement

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If you have already read the articles on angular contact ball bearings or tapered roller bearings, you may already have come into contact with different

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Point and line contact

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What is meant by “point and line contact”? You may have already heard that rolling bearings can be split into two types. The classification depends

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Sealing

5. April 2022

During the design of a bearing assembly, the topic of sealing will always accompany you. In the following material, we will cover both integrated and

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Summary

- Seals are to prevent lubricant from escaping from the rolling bearing
- Seals should prevent ingress of contaminants
- When choosing the seal, aspects such as the type of lubricant and the circumferential speed of the bearing rings must be taken into account
- There are two seal variants: Integrated and external seals
- The external seals can be divided into non-contact seals and contact seals
- Non-contact seals are suitable for high-speed applications
- Contact seals have a sealing lip made of rubber and have greater sealing capacity as well as a higher frictional torque

During the design of a bearing assembly, the topic of sealing will always accompany you. In the following material, we will cover both integrated and external sealing concepts. Both are used to prevent lubricant from escaping and to prevent contaminants (such as dust and water) from entering the rolling bearing.

Sealing variants for rolling bearings

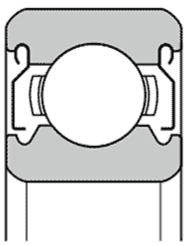
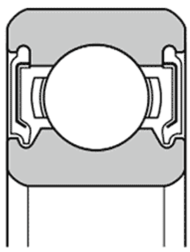
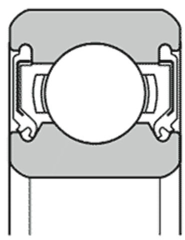
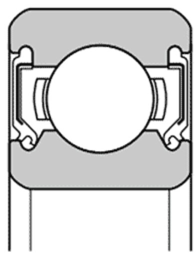
Integrated seals are integrated into the rolling bearing and pressed into the inner or outer ring. Integrated seals are mainly used in deep groove ball bearings. External seals, on the other hand, must be planned during the design phase. They are used in bearing types where no integrated seal is provided (mainly in roller bearings) or if an integrated seal is not sufficient and the bearing still needs additional protection. The functions of integrated and external seals are identical.

Sealing

Certain factors should be taken into account when choosing a seal. These include the type of lubricant, the circumferential speed at the seal lip, fitting errors of the shaft, spatial limitations, the seal friction and the associated temperature increase. The seal material also plays an important role in the choice of seal. Of course, the costs incurred must also be considered.

Integrated seals

The integrated seals can be divided into different types, some of which are defined in more detail in this section. All seals listed below are used for dust protection and sealing on both sides. The main integrated seals of rolling bearing manufacturer NTN are the seals ZZ, LLB, LLU and LLH (with low frictional torque).

Type, designation	Version with metal shield	Version with elastomer seal		
	Non-contact shield ZZ	Non-contact seal LLB	Contact seal LLU	Contact seal LLH with low friction torque
Design				
	– A metal plate shield is located in outer ring groove; a V-groove with a labyrinth gap runs in the inner ring	– A rubber-moulded pressed steel plate is clipped into the outer ring; the sealing lip runs close to the inner lip in the V-groove, but without contact	– A rubber-moulded pressed steel plate is clipped into the outer ring; the inner sealing lip touches the V-groove on the inner lip	– The basic design is the same as LLU, but the contact of the inner sealing lip is reduced. This results in a lower frictional torque

Performance comparison	**Frictional torque**	Low	Low	Relatively high	Relatively low
	Dust tightness	Very good	Better than ZZ	Excellent	Much better than LLB
	Waterproofness	Bad	Bad	Very good	Very good
	Permissibility of high speeds	Like open type	Like open type	Limited by circumferential speed	Higher than LLU
	Permissible temperature range	Depends on the lubricant	-25 °C ~ 120 °C	-25 °C ~ 110 °C	-25 °C ~ 120 °C

Here are examples of integrated seals for ball bearings and their design and properties.

External seals

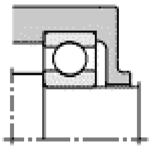
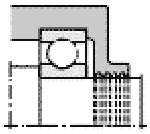
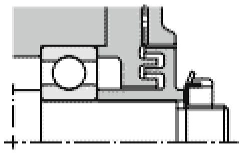
Unlike integrated seals, external seals are not integrated into the rolling bearing and must be added separately. They can be divided into two types, namely non-contact seals and contact seals.

Non-contact seals

The most important feature of non-contact seals is that in this variant there is a small gap, or labyrinth, between the seal and the rotating part. Seals of this type are suitable for high-speed applications as there is no high seal friction. In addition, oil or grease is usually applied to any remaining gaps to provide improved sealing capability.

Examples of non-contact seals

In general, lubrication (oil or grease) between the contact point of the sealing lip and the inner or outer ring of the bearing is indispensable. In the case of oil lubrication, suitable sealing concepts are required that prevent oil leakage during operation. In addition, the most important seal designs, their properties and other criteria for choosing the right seal can be found in the following tables.

Non-contact seals		
Seal structure	Designation	Sealing properties, design criteria
	Gap seal	• Simplest type of seal • Has a small, radial gap
	Gap seal with oil grooves at the housing opening	• Several concentric oil grooves are present in the inside of the housing, thereby significantly improving the seal • If the grooves are filled with a lubricant, foreign particles are also prevented from entering the bearing from the outside
	Labyrinth seal (axial example)	• Labyrinth seals have a gap labyrinth (in this case in an axial direction) • Types: axial labyrinth seal, radial labyrinth seal, self-adjusting labyrinth seal

Relevant examples of non-contact seals are the gap seal and the labyrinth seal.

Labyrinth seal

While the gap seal is considered the simplest seal variant, the labyrinth seal can be considered the most important non-contact seal type. It offers maximum flexibility in manufacturing as well as a very good sealing performance and is also an inexpensive solution when choosing a seal. As is typical for these non-contact seals, labyrinth seals can be operated almost at the limiting speed of the rolling bearing, depending on the design. There are three main types of labyrinth seals, including an axial, a radial and a self-adjusting version. Self-adjusting labyrinth seals are used, for example, in bearing housings.

Contact seals

Contact seals are seals with a moulded sealing lip made of synthetic rubber that seals against the shaft, housing, inner ring or outer ring. The rubber is vulcanised onto a sheet metal plate. The big advantage of contact seals compared to non-contact seals is their sealing capacity, which is significantly greater. Nevertheless, aspects such as the frictional torque and the temperature increase are also considerably higher with contact seals. Because the sealing lip of the contact seals rubs against the shaft, the permissible circumferential speed depends on the seal type. In addition, the sealing lip must be lightly pre-greased before assembly so that it does not run dry or wear out during the first few minutes of use.

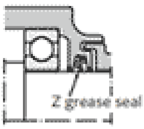
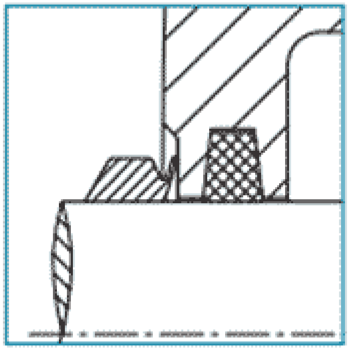
There are manufacturers who have specialised in producing different sealing concepts. This means that there are seals made of various materials (including metal and plastic) and in a wide range of variants that have individual properties in terms of thermal variability and sealing performance.

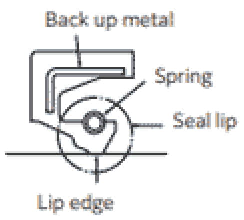
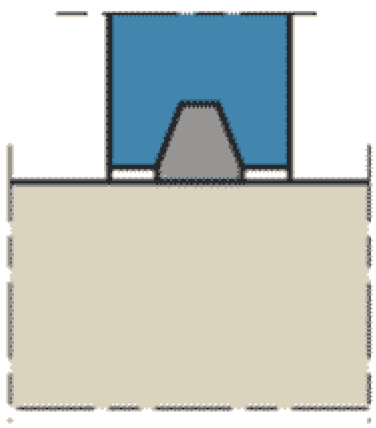
Examples of contact seals

All seals listed in the table are examples of contact seals, but are also external seals. In the case of external seals, the shaft should be ground free of twists in the contact area of the seal in order to prevent lubricant from being ejected from the bearing.

Contact seals

Sealing

Seal structure	Designation	Sealing properties, design criteria
	Z-grease seal	• The cross-section, which resembles a Z, gives this seal its name • The free space around the Z is filled with sealing grease • Often used in conjunction with split plummer block housings
	V-ring seal	• Improves sealing efficiency with an axial sealing lip • V-ring provides effective sealing against external contamination (e.g. dust or water) by utilising the centrifugal force • Usually used with grease lubrication • In the picture: Felt strip seal (pre-greased) in combination with V-ring seal. This combination is often used for bearing housings.

	Radial shaft seal	• A spring is located near the seal lip. This ensures a pre-tension of the sealing lip and thus a suitable seal • As the sealing edge is pressed firmly against the shaft, the sealing effect is high • Observe information for pretensioning according to manufacturer's instructions
	Felt ring seal	• Felt is soaked with oil at 80°C before assembly • Standardised recesses • Used for bearings with a split housing • Lubrication with grease recommended

The Z-grease seal, the V-ring seal, the rotary shaft seal and the felt ring seal are all contact seals.

Relief holes for contact seals

All contact seals should have a relief hole to ensure pressure equalisation between the bearing and the bearing environment at all times. This must be placed in such a way that there is no excess pressure in the housing that could result in lubricant leakage. The choice of relief hole should take into account the mounting position of the drive unit to prevent lubricant leakage. During the painting process, it must be ensured that the relief hole is not closed unintentionally. With regard to the radial shaft seal, the permissible circumferential speed for the seal lip should be observed. Furthermore, the installation direction of the rotary shaft seal determines its function. The rotary shaft seal can either prevent ingress of contaminants or the escape of lubricant.

Seal/material		Permissible peripheral speed m/s *V(m/s)= (π×d(mm)×n(r/min))/(60 000)*	**Permissible temperature**
Radial shaft seal	NBR	16 or less	-25 ~ +120℃
	ACM	26 or less	-15 ~ +150℃
	FKM/ FPM	32 or less	-30 ~ +200℃
Z-grease seal	NBR	6 or less	-25 ~ +120℃
V-ring	NBR	40 or less	-25 ~ +120℃

In the table you will find information on the permissible speed depending on the seal material and temperature.

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- Fatigue damage is a “natural” rolling bearing damage that occurs when the fatigue life of the material has been reached
- Fatigue damage can originate either below (subsurface) or at the surface
- Fatigue below the surface: Formation of microstructural changes and microcracks that extend to the surface, causing material to flake away.
- Fatigue on the surface: For example due to contamination, which eventually results in cracks or chipping
- Rolling bearing damage can be detected at an early stage with the help of vibration analysis

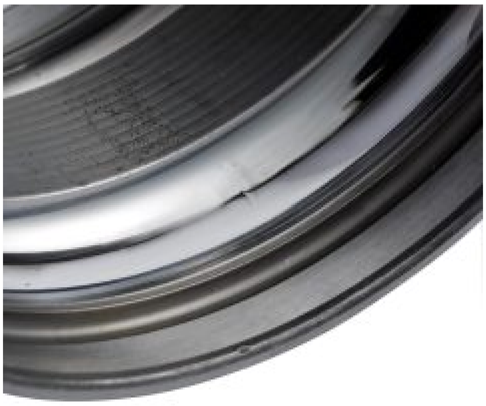
If a rolling bearing “packs up” after some time despite correct bearing selection, lubrication and handling, it is very likely to be fatigue damage. Fatigue damage occurs when the fatigue life of a rolling bearing has been reached. Even with greater loads, the occurrence of classic fatigue damage is possible after a certain period. Nevertheless, such “natural“ fatigue damage occurs relatively rarely. Experience shows that bearing damage due to insufficient lubrication or faulty mounting occurs much more frequently.

Probably the main feature of fatigue damage is rolling contact fatigue, which is caused by the repetitive stress between rolling elements and the bearing raceways. Structural changes that can be observed in a sectional view are typical with rolling contact fatigue. Also, rolling contact fatigue leads to cracking under the surface and material chipping on the surface (also called spalling or flaking). Flaked rolling bearing material is another sign of fatigue damage. There are two types of fatigue damage: Subsurface-initiated fatigue and surface-initiated fatigue.

Fatigue below the surface

With regard to subsurface fatigue, the shear stress hypothesis of Lundberg and Palmgren should be mentioned, which provides an explanation for its occurrence. Depending on the material, the applied load, the temperature, the material purity and the microstructure; structural changes and microcracks form. These cracks then expand to such an extent that they reach the surface and material flakes at the surface. The resulting material flaking usually runs parallel to the surface.

On this bearing ring, deep flaking (peeling) originating from the surface is visible. Peeling is caused, for example, by foreign particles in the lubricant that are rolled over by rolling elements, which can later develop into bearing damage.



In this example, a deep flaking (peeling) starting below the surface is shown. Such deep peeling starts with subsurface structural changes and microcracks.

Fatigue damage

Fatigue originating at the surface

Lubrication is essential for a long rolling bearing life. However, insufficient lubrication leads to metallic contact between rolling elements and the raceway. Nevertheless, even with generally perfect lubrication, indentations with raised edges higher than the lubricant film thickness (< ≅ 1µm) can occur due to contamination, overloading and raceway damage. In addition to the rolling contact between the rolling elements and the raceways, these indentations also cause metallic contact between them. This metallic contact leads to smoothening of the surfaces (plastic deformation), which in turn results in bearing damage.

Micro Pitting

One type of surface-induced fatigue is micropitting, which can also be regarded as a preliminary stage of chipping and cracking. Typically, pitting appears as a matt grey colour on the affected rolling bearing components. It is characterised by shallow, tiny pits and occurs when a rolling bearing is subjected to a relatively low load and the components slide against each other rather than rolling. These sliding components can be avoided – provided that ball rolling elements are subjected to a minimum load of 0.01 *C* and cylindrical rolling elements (the rolling elements of roller bearings) are subjected to a minimum load of 0.02 *C.* In general, the higher the loads and the poorer the lubrication condition, the more significant cracks can occur on the rolling bearing.

Micropitting not only has a negative impact on the bearing's service life, but also on the noise generation. Furthermore, micropitting leads to a loss of material, deteriorated profiling and ultimately to excess pressure near the surface. Furthermore, the development of flaking is preceded by micropitting. It can therefore be said that micropitting occurs first, which later develops into flaking and finally cracks.

Rolling bearing damage can be detected at an early stage by determining and measuring the rolling frequencies. This is done with the help of vibration analysis, which should ideally be combined with temperature monitoring. Early detection of bearing damage means that machine downtime and repair time can be planned. Rolling bearing manufacturers such as NTN offer suitable equipment and advice for vibration analysis as a service.

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Summary

- The term wear includes worn components of the rolling bearing such as raceway surfaces or rolling elements
- Reasons for wear are lubrication faults, inadequate operating conditions and fitting errors
- Abrasive wear is largely caused by hard particles that are trapped in the rolling bearing
- Adhesive wear occurs under frictional heat, which is caused by insufficient lubrication
- Prevention of wear can be achieved through an adequate lubrication method and improved seal efficiency

Rolling bearings, like other mechanical components, encounter problems such as wear. Wear describes the progressive removal of material from surfaces and is caused by two contact surfaces acting on each other during operation.

In rolling bearings, “wear“ can refer to various components such as worn raceway surfaces, cages, guide lips, rolling elements and seals. A worn surface, for example, is usually characterised by scratches and increased roughness. One often hears that the bearing in the respective machines can become increasingly noisy over time and that vibrations become stronger. A possible cause could be a worn roller bearing. To determine these causes, vibration measuring devices are used, among other things, to identify specific frequencies of rolling or static damage on the bearing.

Reasons for the development of wear

Similar to the formation of cracks and fractures, it can be stated that the occurrence of wear can be traced back to various triggers. Possible reasons can be lubrication errors (for example, insufficient or excessive lubricant, or an incorrectly selected viscosity). One consequence of insufficient lubrication is mixed friction. The increase in friction leads to an increased temperature in the rolling bearing, an increased noise level and an increase in vibrations. Other causes of a worn bearing can be, for example, the operating conditions (overloading, external vibrations, excessive load changes) or assembly errors (jamming, inadequate fastening, incorrect choice of tolerance and fit).

You can see wear on the ring raceway of this rolling bearing as an example.

Abrasive wear

This example shows abrasive material on

Wear can be differentiated into two types, abrasive and adhesive wear. Abrasive wear occurs with the presence of hard particles. In this case, the particles rub against another surface. In the process, material is removed from the surface, causing it to become increasingly damaged. It must be noted that this surface appears increasingly matte when exposed to larger particles, but tends to appear polished when exposed to fine *the raceway surface.*

particles. In abrasive wear, the number of particles in the rolling bearing usually increases progressively before bearing failure finally occurs.

Adhesive wear

Adhesive wear is characterised by the transfer of material from one surface to another. It is important to note that the energy for this process is generated by the slip between the moving parts. Investigations on the surface of a worn bearing show that the surface burnishes or new hardening zones form. Both lead to local stress concentrations and mean an increased risk of cracking or chipping occuring in the contact area. In books, this is typically referred to as “smearing” or “seizure”. Both words describe the same failure mechanism. They can only be distinguished on the basis of the failure pattern or – in other words – smearing *becomes* a seizure.

Adhesive wear can very often be observed in large cylindrical and spherical roller bearings that are only lightly loaded. When entering the load zone, as the rolling elements are accelerated to the kinematic speed, the separating lubricating film can break off and a brief welding of the surfaces can occur. However, this connection is separated again in the next moment. After a certain running time, this can result in bearing damage.

Furthermore, relative movements between inner ring and shaft or outer ring and housing can lead to adhesive wear. The reason for this is the “creeping” of the rings, for example due to the slightly different diameters of the respective components or also if the bearing rings are too loosely fitted.

Wear prevention

Wear

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There are several ways to prevent potential wear of rolling bearings:

- Correct lubrication (lubricant quantity, method and quality)
- Suitable operating conditions (alignment, vibration, checking the load)
- Checking the assembly (installation, fastening of the bearing, choice of fit)

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Summary

- Plastic deformation is a permanent deformation caused by exceeding the yield point
- Causes include overload by shock loading (for example hammering a bearing into place without adequate load distribution), exceeding the static load rating C_0 and inadequate lubrication
- Overload: Plastic deformations form due to overloading or impacts
- Indentations due to particles: Particles penetrate the rolling bearing and are rolled over by the rolling elements, resulting in plastic deformation

You may have already learned interesting facts about damage types such as fatigue damage or wear in our other articles. This article concerns another type of damage: Plastic deformation. Plastic deformation can be defined as permanent deformation caused by exceeding the yield point. This can usually happen in two different ways:

- Overload
- Particle indentations

Overload

An overload occurs when the Hertzian pressure in the rolling contact exceeds the permissible contact stress. Mishandling of the rolling bearing can also lead to plastic deformation (for example striking directly with a hammer during assembly). Mounting errors, which are mainly due to human error, can never be completely ruled out. In practice, it is advisable to attend a mounting training course at a rolling bearing manufacturer. There, it is explained how and with which tool a rolling bearing is best mounted. Overload can occur not only with a stationary bearing, but also during dynamic operation. A plastic deformation can occur here due to a dynamic overload (see: dynamic load rating *C*) or as a result of shocks.

Here, deformations can be seen on a bearing ring.

Basic static load rating C_0 and static safety factor S_0

The calculation of the static safety factor S_0 represents a decisive factor to prevent plastic deformations due to the operating conditions. Depending on the application, rolling bearing manufacturers such as NTN recommend certain values for the static safety factor S_0. Recommendations for this can be found in the manufacturer's catalogues). It can be calculated using the following formula.

Formula 17:

$S_0 = C_0 / P_0$

Formula 2 (see also: Contribution service life calculation)

$P_0 = X_0 \text{ x } F_r + Y_0 \text{ x } F_a$

The basic static load rating C_0 can be found in the bearing dimension table in the manufacturer's catalogue. This refers to a defined static load limit at which a certain degree of permanent deformation occurs.

The static equivalent load P_0 can be calculated for radial bearings using the following formula.

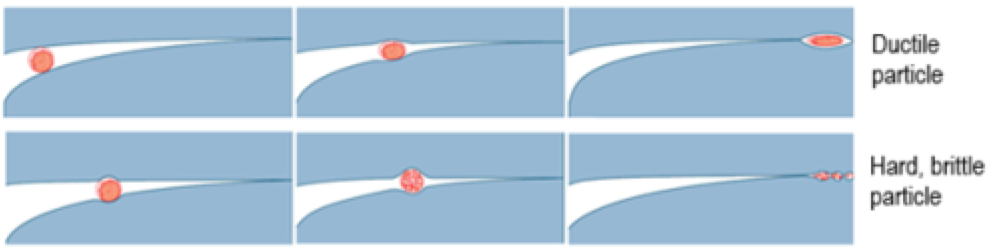
S_0 = Static safety factor

C_0 = Basic static load rating

P_0 = Static equivalent load

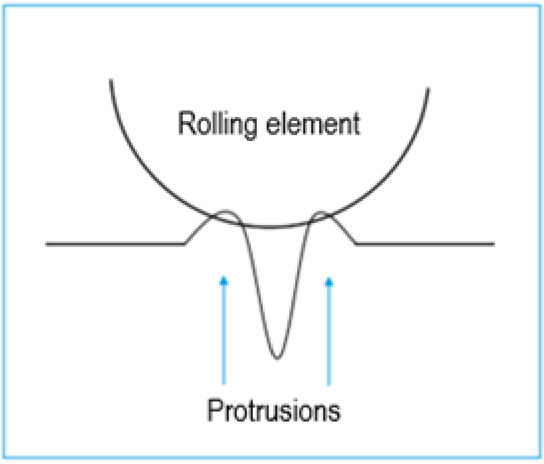
Particle indentations

Rolling elements can roll over particles which, may have penetrated the bearing due to a lack of cleanliness or incorrect handling or have arisen from wear. Plastic deformations are found both on the raceways of the bearing rings and on the rolling elements (see illustration).



Rolling over foreign bodies of all sizes causes plastic deformation.

Material is displaced from the raceway by the penetration of the particles into the surface. The rolling element that follows rolls over these protrusions again. If the height of the lubricating film is not sufficient, direct contact occurs between the protrusion and the rolling elements. In addition, stress peaks occur in the protrusions. This leads to material fatigue at these points and to spalling of the protrusion. The result is fatigue damage. The whole thing can be compared more vividly with a marathon runner (the roller bearing) who has a stone (foreign particle) in their shoe. In this case, the runner would also give up early.



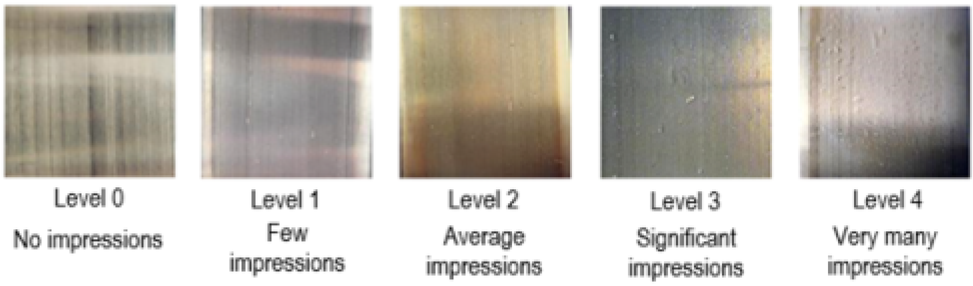
In this graphic representation, you can see how a rolling element rolls over raceway protrusions.

The size and shape of this plastic deformation depends on the type, size and hardness of the particles. A distinction is made between soft particles, particles made of hardened steel and hard, mineral particles. Examples of the three types of indentations caused by particles can be found in the table.

Type of particles	Examples
Soft particles	Fibres, elastomers/plastics
Hardened steel particles	From gearings or bearings
Hard, mineral particles	Sand (silicate)

Hard particles cause the biggest indentations compared to the other types.

Even the smallest particles in the µ range have serious effects, which is why absolute cleanliness is required when mounting and using rolling bearings. The lubricant should be stored properly and only opened before greasing. Improved sealing can also be a solution to minimise contamination in the lubricant.



The intensity of the deformations can be divided into several levels.

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Summary

- Cracks and fractures are one of the most common types of bearing damage
- Reasons for the development of cracks and fractures include insufficient lubrication, extreme loads and impacts
- Cracks form primarily on bearing rings, rolling elements and guide lips
- Fractures mostly develop from smaller cracks, which generally occur in specific locations

Cracks and fractures are not only extremely annoying, they are also one of the most common types of rolling bearing damage. The reasons for such damage can often be found in insufficient lubrication or incorrect mounting of the rolling bearing. In this article, you will learn how crack and breakage damage occurs and which methods can be used to prevent it.

Cracks

The reasons for the occurrence of cracks are numerous. Among others, an excessively tight fit, extreme loads, excessive impact loads, repeated flaking, heat generation/overheating due to gradual and rapid cooling, an excessively loose fit and incorrect shaft shapes or radii can potentially be the cause.

The formation of cracks is as follows: Initially, fine cracks form in the surfaces of the rolling bearing. Only during continuous operation of the bearing do these subtle cracks develop into larger cracks or fractures. Cracks, are most likely to form on the bearing rings, the rolling elements and guide lips. Several countermeasures exist to reduce the risk of cracks forming. In general, the first step can be to improve the identification of the causes of very high levels of stress. Also, it is recommended to check tolerances and loading conditions, improve the assembly process, coat the rolling elements and raceways (burnishing) and use an improved fit.

Fractures

Fractures – comparable to cracks – are usually caused by excessive loads, shocks (including impact loads during installation), incorrect choice of fit or poor handling. At the beginning, these usually occur individually, with small flaked areas forming. These later lead to breakage. Fractures can be avoided by an optimised installation process, correct loading conditions, suitable choice of fit and sufficient support of the bearing shoulder.

This ring fracture, using the example of a cylindrical roller bearing, can be caused by impacts, overloading or bending loads, among other things.

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Summary

- Corrosion is the result of a chemical reaction
- Corrosion occurs, for example, due to a damp environment, insufficient packaging or inadequate corrosion protection
- There are two types: Corrosion due to moisture and fretting corrosion
- Corrosion due to moisture means rust and can lead to peeling (“spalling”) in the late stage
- According to DIN 50900, fretting corrosion is the “localised corrosion of metal surfaces caused by friction without external heat”
- Fretting corrosion can in turn be divided into fretting and false brinelling

Have you ever heard of corrosion? Corrosion is basically divided into two main forms according to ISO 15243: Corrosion by moisture and fretting corrosion. Fretting corrosion can in turn be divided into fretting corrosion and false brinelling.

The most common type is probably corrosion caused by moisture. This occurs as a result of a chemical reaction on a metallic surface and due to the presence of moisture and/or aggressive media (e.g. acids). Possible causes can be, for example, poor, damp storage, insufficient packaging or inadequate corrosion protection. Rolling bearing manufacturers such as NTN therefore provide recommendations in their catalogues for the correct storage of rolling bearings. Furthermore, handling without hand protection can lead to corrosion (recognisable, for example, by fingerprints on the outer ring).

Corrosion due to moisture

Corrosion

Corrosion due to moisture occurs most frequently and arises after contact of the rolling bearing with moisture or aggressive (chemical) elements such as acids. This type of corrosion can occur, for example, due to excessive humidity. In some instances, a rolling bearing that has been running without problems can suddenly make noise after a long static period, for example. In this case, the lubricant may have absorbed water, resulting in corrosion damage due to the inactivity.

The ring of a deep groove ball bearing is affected by corrosion in the form of rust – caused by the penetration of corrosive media such as water into the rolling bearing.

Fretting corrosion

Fretting corrosion, also called tribo-corrosion or tribo-oxidation, can be divided into two subtypes: Fretting and false brinelling. These two types are discussed below.

1. Fretting

Various translations of "fretting corrosion" can be found, such as "contact erosion", "frictional corrosion", "fretting" and also "wear oxidation". Following ISO 15243 and in order to simplify readability, the word "fretting" is used below.

The picture shows the inner ring of a deep grove ball bearing. The black-brown trace is called fretting. The cause was micro-sliding movements between the shaft and the inner ring. These micro-sliding movements are caused by vibrations or loads acting on the bearing, which resulted in slippage between the shaft and the inner ring. In combination with oxygen, the detached particles oxidise. The result can be bearing damage.

This inner ring is affected by fretting corrosion.

Of course, fretting can be found not only on the inner ring of a rolling bearing, but also on the outer ring and on other mechanical elements (for example shaft-hub connections, etc). In the case of rolling bearings, it must be checked whether factors such as the surface finish, fit quality and the geometric and position tolerances of the rolling bearing seats meet the quality specifications of the rolling bearing manufacturer. If these are insufficient, they can promote the formation of fretting.

2. False Brinelling (standstill markings)

For the second type of fretting corrosion, so-called “false brinelling”, one can also find several translation variants, for example “standstill markings”, “ripple formation” or also “trough formation”. To simplify matters, only one term is used in the following, namely “false brinelling”.

False brinelling occurs at the rolling contacts of bearings. These are caused by micromovements under cyclic vibrations. Depending on the intensity of the vibrations, loads and lubrication conditions, indentations form on the raceways. Furthermore, these micromovements cause the lubricant film to be displaced from the contact area. The unprotected surface can now corrode. Consequently, the resulting particles from the corroded areas can lead to abrasive wear.

The example of this bearing ring shows false brinelling. These were caused by vibrations while the bearing was static.

Corrosion prevention

Corrosion can be reduced/prevented by various adjustments. A few points are listed below:

Design

- Improvement of the sealing properties
- Use of a suitable lubricant (with corrosion protection additives)
- Rolling bearing seat
  - Correct surface finish
  - Fit quality and the geometric and position tolerances in accordance with the recommendations of the rolling bearing manufacturer

Delivery/storage conditions

- VCI Paper/Foil
- Control of temperature and humidity levels (see bearing manufacturer’s storage

instructions)

Assembly

- Wearing gloves
- Removal of the rolling bearing from the packaging shortly before mounting
- Clean assembly environment

Delivery

- Elimination of vibration sources
- Preload the bearing to prevent false brinelling

In operation

- Elimination of vibration sources or no standstill of the machine
- Regular testing of the lubricant
- Compliance with relubrication intervals
- If necessary, change the lubricant

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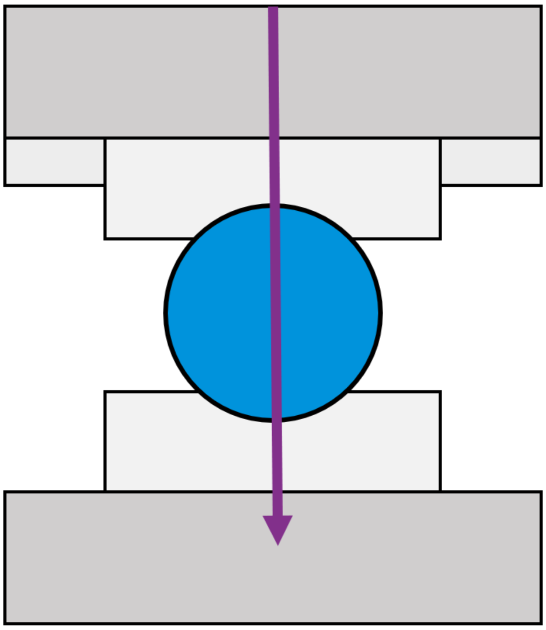
Electro-erosion

Summary

- Electro-erosion refers to a local structural change and removal of material from the contact surface, caused by electrical currents
- Electro-erosion is divided into two forms: Current passage and leakage currents
- Current passage occurs when the electrical voltage is very high and is identifiable as a series of craters on the rolling bearing components
- Creepage currents are characterised by grooves on the raceways

This article (based on ISO 15243) is all about electro-erosion – but what is it? Electro-erosion is understood to be a local structural change and removal of material from the contact surface. This structural change is caused by damaging electrical currents.

Electro-erosion is always the starting point for an increasing noise level of the machine and potentially causes early bearing failures and unplanned machine downtimes. It should not be confused with false brinelling because of the visual similarity. Overall, electro-erosion occurs particularly frequently with deep groove ball bearings because they are often installed in electric motors and generators. So, where does the current come from? Possible causes are, for example, an asymmetrical magnetic flux in the motor, unshielded cabling or a fast-switching frequency converter. According to ISO 15243, there are two forms of electro-erosion: Current passage and leakage currents.



Here is a simplified illustration of a deep groove ball bearing with current flow.

Current passage

When the electrical voltage exceeds the insulation resistance of the rolling bearing components, an electric current is generated which flows from one ring, over the rolling elements and through the lubricating film onto the other ring. Usually a concentrated electrical discharge occurs. The localised heating that forms, which takes place within an extremely short period of time, leads to melting of the contact area and welding of the mating parts. The resulting connection is separated again shortly afterwards, as the bearing continues to rotate. This process happens continuously. Finally, the passage of current can be seen in the form of craters lined up on the surface. The craters can reach a diameter of up to 500 µm.

Leakage currents

A leakage current is an uncontrollable and undesirable current flow that is permanently present. Leakage currents are typically characterised by the formation of craters on the raceway surface, which are close together and only have very small diameters of a few µm. These craters form grooves on both the raceways and rolling elements, because the current is transmitted over the entire contact area. This is referred to as a contact ellipse in ball bearings and a line in roller bearings. Balls show dark discolouration and the surface appears matt. If you then examine the balls under a microscope, you will find molten craters. In addition, the lubricant condition deteriorates.

In electro-erosion, a passage of current in the rolling bearing is responsible for causing damage, as you can see from this angular contact ball bearing.

Prevention of electro-erosion

The risk of electro-erosion can be reduced if the shaft, housing and/or bearing(s) are provided with appropriate insulation. One possibility is to use ceramic or plastic-coated bearings that are encased in one of the said materials, for example NTN's 7MC3 bearing series with ceramic-coated outer ring. Such coated bearings can then sometimes be used in generators in the wind power sector. In general, the use of ceramic rolling elements is also advisable in order to avoid welding of the mating parts.

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Nothing works without lubrication: Every bearing runs with grease or oil lubrication, which is the basic prerequisite for avoiding metallic contact of the bearing components,

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