MOTION & CONTROL™
NSK

BEARINGS FOR INDUSTRIAL GEARBOXES

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As one of the world's leading manufacturers of rolling bearings, linear technology components and steering systems, we can be found on almost every continent – with production facilities, sales offices and technology centres – because our customers appreciate short decision-making channels, prompt deliveries and local service.

The NSK company

NSK commenced operations as the first Japanese manufacturer of rolling bearings back in 1916. Ever since, we have been continuously expanding and improving not only our product portfolio but also our range of services for various industrial sectors. In this context, we develop technologies in the fields of rolling bearings, linear systems, components for the automotive industry and mechatronic systems. Our research and production facilities in Europe, Americas and Asia are linked together in a global technology network. Here we concentrate not only on the development of new technologies, but also on the continuous optimisation of quality – at every process stage.

Among other things, our research activities include product design, simulation applications using a variety of analytical systems and the development of different steels and lubricants for rolling bearings.

Partnership based on trust – and trust based on quality

Total Quality by NSK: The synergies of our global network of NSK Technology Centres. Just one example of how we meet our requirements for high quality.

NSK is one of the leading companies with a long tradition in patent applications for machine parts. In our worldwide research centres, we not only concentrate on the development of new technologies, but also on the continual improvement of quality based on the integrated technology platform of tribology, material technology, analysis and mechatronics. **More about NSK at www.nskeurope.com or call us on + 44 (0) 1636 605 123**

NSK Technology

Designed to Move – Day by Day

NSK stands for motion in all areas of application, all over the world. From industrial plants to household appliances. In a global technology network of more than 62 plants, more than 31.500 staff members ensure that approximately three million new bearings with the NSK trademark are produced daily. The incredibly large range of NSK bearings is employed in all sorts of application areas and this guarantees that our clients will find the perfect solution for their requirements.

We are there when you need us

Products and solutions by NSK do not only provide optimum support for gears, but their inherent control over dynamic performance delivers on client requirements. The areas of application range from computer disk drives, tunnel boring machines, wind generator plants, washing machines, plants for semiconductor production and rolling mills. NSK stands for perfect bearing performance no matter how contaminated the environment or how severe the operating conditions. NSK rolling bearings are employed in the steel industry and in machine tools. They ensure reliable operation of wind turbines and operate just as effectively in pumps for industry and household as in compressors. The NSK product range comprises of miniature bearings with a bore diameter of 1 mm up to rolling bearings with a diameter of 5 metres. No matter the size, NSK is committed to developing ever improved solutions.

Our incentive is continuous change

NSK products are not only known for their high reliability, high heat and seizure resistance and long bearing life, but they are also known to be highly economical and environmentally sound. However, in a world that is continuously changing, a company which promotes highest standards needs to aim high. NSK is permanently developing new rolling bearings that even exceed these high quality standards. Large sums of money are invested in basic research, material technology and lubrication technology. We are first when it comes to developing solutions for tomorrow.

Focus on performance of outstanding nature

The textbook says: Gearboxes are systems for converting and translating motion. The designer says: bearings for industrial gearboxes are a means of supporting the torque and speeds of the drive end to the required turning moments and speeds of the engine – according to the individual and specific operating processes. And what does the engineer say from experience? Above all, bearings for modern industrial drive systems face the most demanding and most versatile requirements. Features, including sufficient availability, long life, economy and best combination features of weight and performance, are only a few examples out of many.

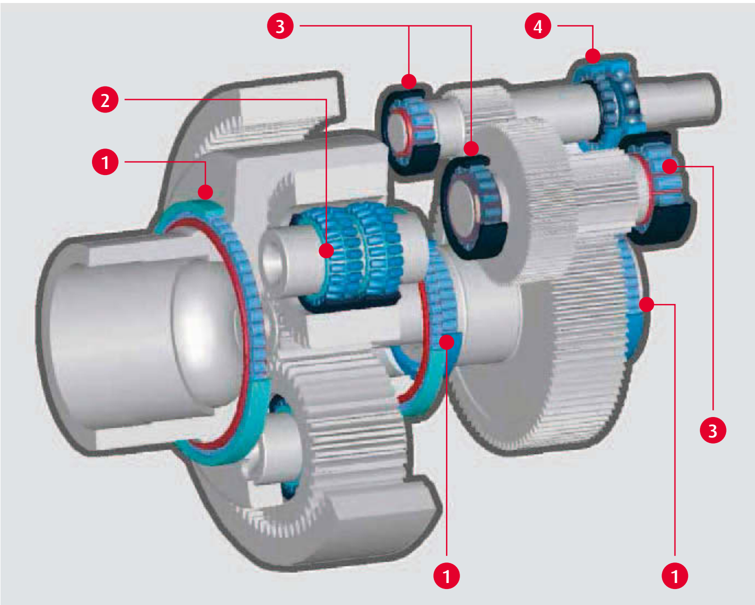
Just as versatile as their functions

To achieve the desired torque and speed, a certain degree of fatigue strength and life needs to be guaranteed for all components. In addition, sufficient cooling and noise levels need to be achieved for maximum performance. These features have always been fundamental for gear operation. Considering the various areas of application, the number of gear types is increasing, as are the demands for smooth gear operation.

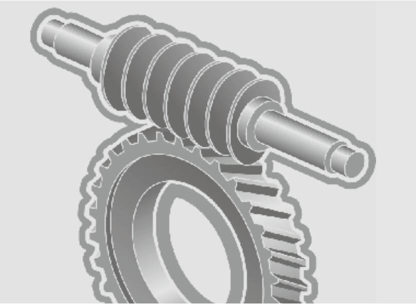
For example, environmental conditions (such as contamination, water and shock loads) affect bearing performance, as do specific operation modes, such as stop-start mode or stand-by operation. The inherent operating requirements for precision gears, such as employed in press printing machines, vary from those employed in wind generator plants, which require a high degree of maintenance free operation.

When selecting a suitable bearing type the special operating conditions at the respective bearing location is taken into consideration.

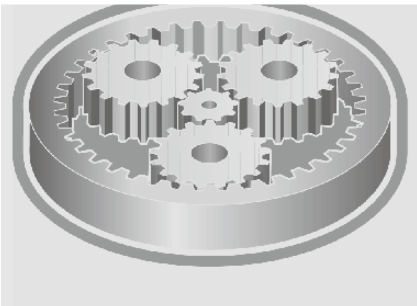
1. **Full complement cylindrical roller bearing** for low speed and high radial loads
2. **Spherical roller bearings** for ultra-high loads and components in oblique arrangement
3. **Cylindrical roller bearings** for high speed and high loads, functioning as a floating bearing
4. **Four-point bearing**, acting as the locating bearing for the high speed stage, while the cylindrical roller bearing takes the radial load



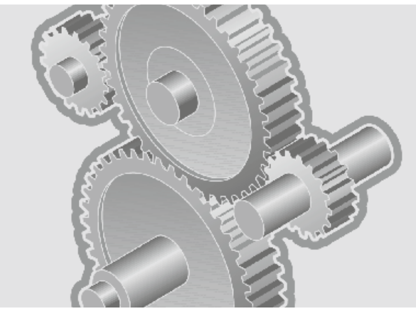
Hypoid bevel gears
The larger-sized pinion which is part of this hypoid bevel gear integrating an offset pinion shaft, facilitates lower peripheral force while the turning moment (torque) remains constant. The offset axis provides for higher strength of pinion support in both directions. Low noise generation is a further advantage. However, a disadvantage is increased friction due to additional sliding motion.



Worm gear
A particular advantage is translating motion in a single stage. In most cases the axis of worm and worm gear intersect below 90°, provided there is sufficiently high clearance between the axes. During operation vibration is absorbed to a high degree and noise generation during operation is low. However, the high friction reduces the degree of efficiency. This gear is usually employed in combination with a globoid gear with cylindrical worm made from steel, because these can be subjected to tempering and grinding.



Planet gear
Utilising planetary wheels with internal gears, epicyclic gearboxes have significant advantages over other gearbox types. Volume and weight are reduced. Due to low rolling speed and low sliding speed within the tooth system, noise generation can also be reduced. An increased degree of efficiency can be achieved due to the fact that part of the energy is translated to the coupling performance – these advantages often compensate for increased maintenance.



Spur gear
Parallel axis gears generally fall into two main types – Spur gears and Helical gears. Whilst spur gears have the advantage of ease of manufacture and accuracy, smooth operation and high load capacity are achieved through helical gears (albeit with the need to react the thrust loads). Double helical gears constitute a sub-type with increased load capacity and larger face width.

Bevel gear
There are three types of design depending on tooth traced characteristics. If spur gearing is used, tooth engagement cangenerate noise. Although Helical bevel gears also use straight tooth profiles, they have reduced noise levels, due to improved mesh characteristics. The third type of design employs spiral bevel gears and curved tooth bevel gears. This type of design operates at the lowest noise levels.

NSK rolling bearings meet tomorrow's requirements

The history of developing and designing gears is the history of continuously improving performance. Over the course of time gears have become increasingly powerful – thus the requirements for bearing performance have continuously increased. NSK rolling bearings have not only kept pace: great ideas have ensured that they have always been one step ahead. However, capacities for high performance can only be fully utilised if the correct rolling bearing is fitted in the right place. For this purpose numerous vital criteria and important features need to be systematically considered and analysed. These issues concern bearing life, static bearing capacity at maximum load, extreme load on part of the engine as well as the limiting speeds.

Load

First the input torque needs to be determined. If the torque is variable, it is important to determine the intervals at which the torque varies. Also what are the estimations for tooth loads and bearing loads? It is also necessary to determine if there are further loads that affect performance e.g. loads applied externally to either input or output shafts.

Speed

It is important to determine the level of speed and direction of rotation. Do operating modes include stand-by mode? Interaction between the level of load and the level of speed needs to be evaluated.

Space for assembly

Are certain assembly dimensions fixed? If dimensions can be altered the range of dimensions must be specified. If the space for assembly is not sufficient, problems may exist finding a solution for optimum bearing selection. In this case it needs to be determined to which extent the dimensions may be altered without causing any problems.

Shaft arrangements

Another vital issue is to determine whether the gear shafts are to be arranged horizontally, vertically, or inclined. Do the shafts change position during operation? Lubrication methods and sealing are highly dependent on the position of the shafts. Are the shafts arranged on one level? This issue is important with regard to bearing load. Another issue: Are hollow shafts or solid shafts employed? Are the bearings supported within the housing or other shafts? This issue affects load on the main shaft.

Shaft guidance

The selection of the bearing type, design and arrangement are issues that are highly dependent on the operational requirements which the shaft guiding function needs to fulfil. It is important to determine the effects that internal clearance and bearing stiffness may have on tooth engagement. In addition, it has to be determined to which degree axial movement of the shaft is permissible or whether shaft guidance is to be performed free of clearance.

Strength of connecting parts

Does deformation of the housing need to be taken into consideration? Does misalignment at the bearing position caused by shaft bending affect performance? Such issues can cause distinct additional loads within the bearings and therefore need to be fully understood.

Friction

One issue is to determine whether specific friction performance is required to maintain accurate motion. Another issue is to determine whether support is to be provided for a special gear that requires a low level of heat generation during operation.

Bearing life

This issue is quite simple: What are the actual requirements for bearing life? This is driven by the area of application intended for gear operation. If proven and historically reliable calculation methods for determining bearing life are applicable, dimensioning can be based on standard values. If such data is not available, more complex calculations for determining bearing life need to be performed.

Safe static capacity

It is important to analyse whether certain operating routines require particular focus on safe static bearing operation, e.g. if the bearing is employed in excavators which have to cope with sudden, strong impacts. Significant plastic deformation has to be minimised to prevent premature damage and to guarantee smooth operation.

Environmental conditions

This is a complex issue. Environmental conditions, i.e. whether the machine has to operate in a roofed building or whether it is exposed to dust, sand, strong insulation, high humidity or rain, all affect lubrication and selection of the bearing type, sealing and fits. Are there any aggressive agents? What is the ambient temperature? Is the bearing exposed to separate heating or cooling? Do other machines cause vibrations when the gear is in standstill operating mode?

Lubrication

It needs to be determined whether there are certain conditions stipulated for lubrication of the rolling bearings or if oil lubrication is required in individual cases. Is centralised oil lubrication feasible for all bearing locations? Does leakage of lubricant (even in very small quantities) affect operation of the plant or the overall production process?

Assembly

It is vital to understand whether mass production is planned or whether products are to be individually hand built. As a rule rolling bearings made to bespoke designs need to be assembled with the help of special gauges. Costs for such devices are more likely to be amortised in series production. It is not only essential to determine the complexity of bearing design for initial assembly. If the gears are to be disassembled at regular intervals due to maintenance, easy handling is highly dependent on the assembling and disassembling of the bearing.

Economy

Is increased complexity of bearing design justifiable in terms of the benefit of increased bearing performance and operational reliability? Above all, it needs to be determined whether increased costs for the bearing are acceptable in view of easier handling during maintenance.

Vital features affecting performance

All elements of a machine, for example components of a wind generator plant, have to cope with high stress factors where arduous environmental conditions prevail. Maximum reliability is required while maintenance is to be reduced to a minimum. We have learned from experience that the fatigue life of a gear, and fatigue life of the total plant is to a high degree dependent on the correct selection of bearing type. This decision has to be taken prior to calculation and design of the bearing.

The right selection makes the difference

Of course, this preview can only deal with the most important factors, i.e. basic bearing types, without considering further important parameters such as size, internal clearance, cage material and design. Our product range gives an insight to the scale of the application spectrum of our products: You can select from more than 35.000 different types of ball bearings and roller bearings, which fulfil practically any requirement from engineers from all branches of industry and for all sorts of applications. Yet in our global company engineers keep working on new developments to implement customised applications promptly and efficiently.

Bearing types

Design and Classification

Rolling bearings generally consist of two rings, rolling elements and a cage, and they are classified as radial bearings or thrust bearings depending on the direction of the mainload. In addition, depending on the type of rolling elements, they are classified as ball bearings or roller bearings, and they are further segregated by differences in their designor specific purpose. The most common bearing types are shown on the next pages.

Single-Row Deep Groove Ball Bearings
- Suitable for small and moderate radial loads and minor axial loads in both directions
- Extremely high speed possible
- Excellent noise performance
- Also available in pre-lubricated sealed versions

Double-Row Deep Groove Ball Bearings
- Suitable for moderate radial loads and minor axial loads in both directions
- Suitable for moderatespeed
- Sensitive to misalignment

Maximum Type Ball Bearings
- Only suitable for moderate radial loads and small axial loads in one direction
- High speed is possible
- Separable

Single-Row Angular Contact Ball Bearings
- Suitable for moderate radial loads and moderate axial loads in one direction
- High speed is possible. Certain design versions are also suitable for ultra-high speed

Angular Contact Ball Bearings, single row, paired
- Suitable for high radial load and high axial load
- Depending on arrangement axial loads are possible in one or two directions
- Suitable for high speed. Certain design versions are also suitable for ultra-high speed

Double-Row Angular contact Ball Bearings
- Suitable for moderate radial loads and low to moderate axial load in both directions
- Moderate to high speed possible
- Sensitive to misalignment

Legend

Speed Range
Loads
Angular Misalignment

Self Aligning Double Row Ball Bearings
- Suitable for moderate radial loads and minor axial load in both directions
- Moderate and high speed possible
- Can take small degrees of misalignment
- Mounting with adaptor sleeve possible

Spherical Roller Bearings
- Suitable for very high radial loads
- Axial load in both directions possible
- Moderate speed possible
- Can take small degrees of misalignment
- Mounting with adaptor sleeve possible

Cylindrical Roller Bearings
- Suitable for high radial load
- Depending on bearing type, axial loads in one or two directions are also possible
- Suitable for high speed
- Normally separable

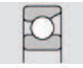
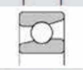
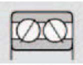
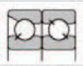
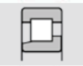
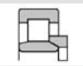
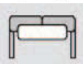
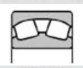
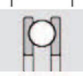
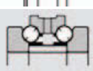
Tapered Roller Bearings
- Suitable for high radial load and axial load in one direction
- When arranged in pairs axial load in both directions possible
- Suitable for moderate speed
- Separable

Thrust Ball Bearings – Single Direction
- Suitable for moderate axial load in one direction
- Radial load is not permissible
- Suitable for lower speed
- Minimum axial load required
- Separable

Thrust Ball Bearings – Double Direction
- Moderate axial load in both directions possible
- Suitable for low speed
- Minimum axial load required
- Separable

Spherical Thrust Roller Bearings
- Suitable for very high axial load in one direction. Radial load only permissible up to 55 % of axial load
- Only suitable for lower speed
- Accommodates misalignment
- Oil lubrication is recommended
- Separable

Bearing types

	Bearing Types/Features	Radial Loads	Axial Loads	Combined Loads	High Speeds	High Accuracy	Low Noise and Torque	Rigidity	Angular Misalignement	Self-Aligning Capability	Fixed End Bearing	Free End Bearing	Tapered Bore in Inner Rings	Comments
	Deep Groove Ball Bearings	••	↔ ••	••	••••	••••	••••		•••		Δ	*		
	Magneto Bearings	•	← •	•	•••				•					A
	Angular Contact Ball Bearings	•••	← •••	•••	••••	••••			•					B
	Double-Row Angular Contact Ball Bearings	•••	•••	•••	••				•		Δ	*		
	Duplex Angular Contact Ball Bearings	•••	← •••	•••	•••	••••		•••	•		Δ	*		C
	Four-Point Contact Ball Bearings	•	← •••	••	•••	•••			•		Δ	*		D
	Self Aligning Ball Bearings	••	↔ •	•	•••				••••	Δ	Δ	*	Δ	
	Cylindrical Roller Bearings	•••	x	x	••••	••••	•••	•••	••			Δ		E
	Double-Row Cylindrical Roller Bearings	••••	x	x	•••	••••		••••	•			Δ	Δ	F
	Cylindrical Roller Bearings with Single Rib	•••	← ••	••	•••			•••	••					G
	Cylindrical Roller Bearings with Thrust Collars	•••	••	••	•••			•••	••		Δ			H
	Needle Roller Bearings	•••	x	x	•••			•••	•			Δ		
	Tapered Roller Bearings	•••	← •••	•••	••	•••		•••	••					I
	Double- and Multiple-Row Tapered Roller Bearings	••••	← •••	••••	••			••••	•		Δ	*		J
	Spherical Roller Bearings	••••	↔ ••	•••	••				••••	Δ	Δ	*	Δ	
	Thrust Ball Bearings	x	← •••	x	x	•••			x					
	Thrust Ball Bearings with Aligning Seat	x	← •••	x	x				••••	Δ				
	Double-Direction Angular Contact Thrust Ball Bearings	x	↔ •••	x	••	••••		•••	x					
	Cylindrical Roller Thrust Bearings	x	← ••••	x	•			••••	x					K
	Taperded Roller Thrust Bearings	x	← ••••	x	•			••••	x					
	Sperical Thrust Roller Bearings	•	← ••••	•	•				••••	Δ				L

Characteristics of Rolling Bearings

Compared with plain bearings, rolling bearings have the following major advantages:

› Their starting torque and friction is low and the difference between the starting torque and running torque is small
› With the advancement of worldwide standardization, rolling bearings are internationally available and interchangeable
› Maintenance, replacement, and inspection is easy because the structure surrounding rolling bearings is simple
› Many rolling bearings are capable of taking both radial and axial loads simultaneously or independently
› Rolling bearings can be used under a wide range of temperatures
› Rolling Bearings can be preloaded to produce a negative clearance and achieve greater rigidity

Comments

A In general two bearings are mounted face-to-face
B Contact angle of 15°, 25°, 30° and 40°. In general two bearings are mounted in opposition
C Combination of DF and D bearings is feasible, however not used at the free end. Desired clearance needs to be adjusted
D Contact angle of 35°
E Including N-Type
F Including NNU-Type
G Including NF-Type
H Including NUP-Type
I In general two bearings are mounted in opposition. Desired clearance needs to be adjusted
J KH and KV-Types are also available; however, not suitable for use at thefree end
K Including needle roller thrust bearing
L Oil lubrication recommended

Key to the symbols

•••• Excellent
••• Good
•• Suitable under certain conditions
• Poor
x Not suitable
Δ Applicable
✻ Applicable, but it is necessary to allow shaft contraction/elongationat fitting surfaces of bearings
⟵ One direction only
⟷ Two directions

Bearing position in gears

We hold much in store for you

A rotating gear shaft requires at least two bearings for optimum support and guidance with regard to the stationary element. NSK rolling bearings do not only accommodate the respective radial and axial loads, but they also ensure accommodation of shaft expansion. A fundamental issue concerns the arrangement of a thrust (fixed) bearing and floating bearing and any necessary set-up adjustments.

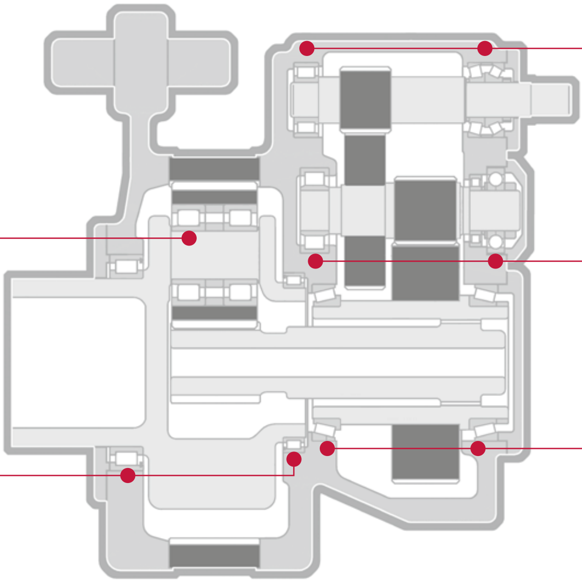
Support by means of fixed and floating bearings

The position of the thrust bearing on the shaft and in the housing has to be set in anaxial direction, i.e. it needs to guide the shaft axially and it needs to accommodate the axial loads of the gear mesh. Fit variations of bearing positions on the shaft and in the housing, as a result of production tolerances and operating temperatures, are compensated and balanced by the floating bearing. These compensating and balancing features are vital for preventing strain on the bearing. The floating bearing takes the radial loads and accommodates axial movement.

The selection of the bearing type employed as a thrust bearing is dependent on the axial load levels and the requirements put forward for precise axial guidance of the shaft. Bearing types suitable for accommodating combined stress factors may be employed as a thrust bearing. These include deep groove ball bearings, spherical roller bearings and double row angular contact ball bearings. Single row angular contact ball bearings mounted in pairs and tapered roller bearings may also serve as fixed bearings, as do thrust bearings that are assembled in combination with a radial bearing.

Floating bearing support with two **cylindrical roller bearings** NJ type. The two cylindrical roller bearings accommodate radial load and are arranged in pairs for uniform and balanced load distribution. To ensure sufficient axial clearance axial adjustment is performed by means of spacers.

Floating bearing support with two full complement **cylindrical roller bearings**, suitable for high radial and moderate axial loads.



Combination of thrust bearing and floating bearing arrangement with a **cylindrical roller bearing** and a **tapered roller bearing** arranged in asymmetric pairs, suitable for high radial loads and high axial loads from one direction.

Two **cylindrical roller bearings** and one **four-point contact bearing**. The two cylindrical roller bearings take the radial loads while the four-point contact bearing takes axial loads only.

Bearing with two **tapered roller bearings** in X-**Arrangement**, suitable for high radial and axial loads.

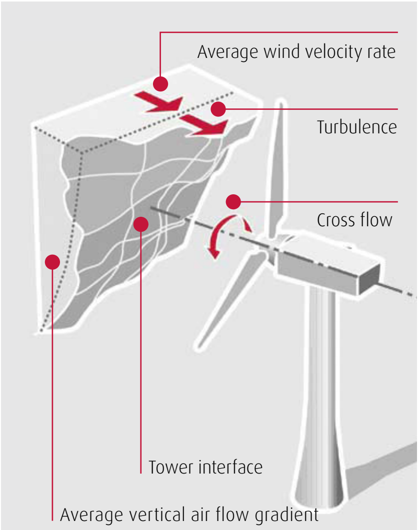
Cylindrical planet gears with different bearing arrangements

Adjusted bearing support

This arrangement does not provide for a particular thrust bearing. The shaft is guided axially in one direction by each of the two bearings. However, there is the risk of mutual strain impacts with this bearing type. Basically all bearing types, which are in a position to accommodate axial loads in at least one direction, as well as accommodating radial loads, can be used. These include deep groove ball bearings, spherical roller bearings, angular contact ball bearings and tapered roller bearings. If accurate shaft guidance is required as, for example, with pinion support integrating spiral bevel gears, adjusted bearing support is of particular advantage.

Floating bearing support

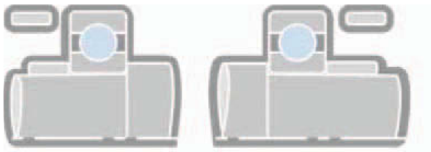
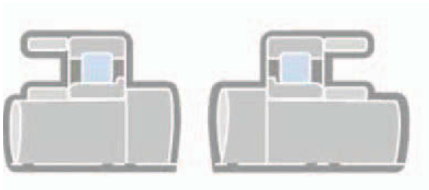
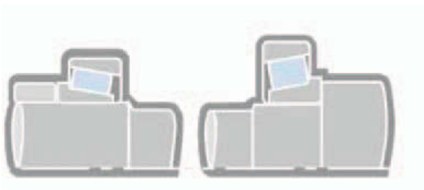
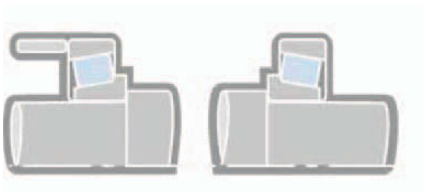
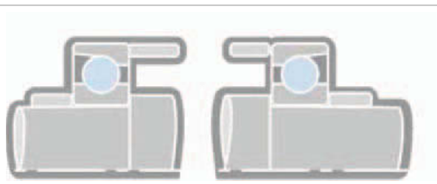
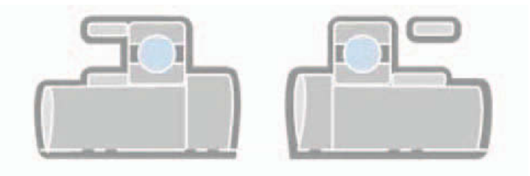
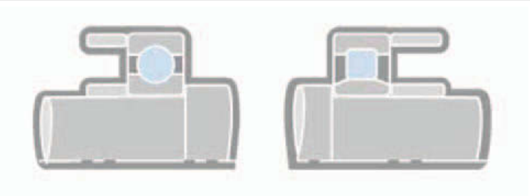
The conditions applying to floating bearing support are similar to that of adjusted bearing support. However, axial adjustment of the shaft is feasible to a certain extent. On measuring the extent of axial adjustment, negative thermal conditions are taken into consideration in order to avoid that the bearing is exposed to axial strain impacts. The extent of axial clearance is subject to clearance tolerances. Generally floating bearing support is selected if toothing requires released axial setting or if highly accurate axial shaft guidance is not of particular importance.

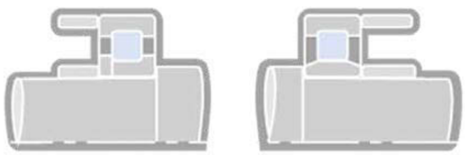
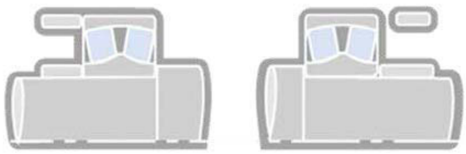
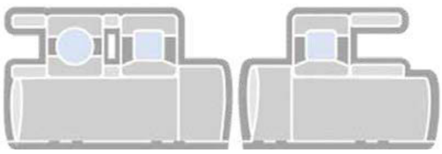
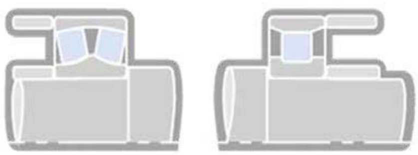
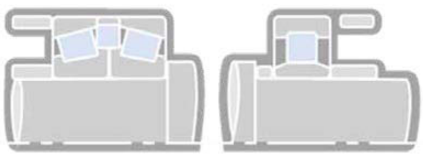
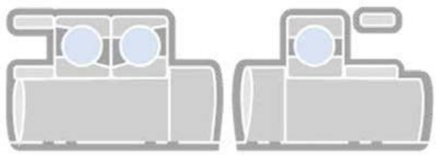
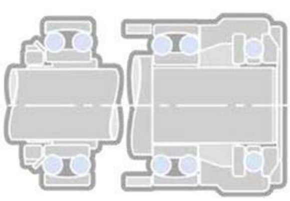


Air Flow Profile of a Wind Generator Plant
Partial wind velocity depends on rate, place and time and results in considerable dynamic load impacts affecting the plant as well as subassemblies including the rolling bearings.

Bearing position in gears

Preview of Bearing Arrangements

Arrangement		Comments	Fields of application
Bearing arrangement – adjusted or floating		Floating bearing support for moderate radial loads. Outer rings are often adjusted by means of springs	Small electric motors and gears
		Free end bearing for high radial loads. Press fit for inner and outer ring feasible. Care must be taken so the axial clearance does not become too small during operations	Small and medium-sized gears, vibration engines
		Standard bearing arrangement for high loads. Suitable for short distance between the bearings, because the distance between the bearings increases due to back to back arrangement. Adjusting internal clearance is possible during assembly	Bevel pinion with integrated shaft in gears, wheel bearings in vehicles
		Arrangement is selected if press fit for inner ring is required. Easy handling of assembly and positioning. Face to face reduces bearing support clearance. Adjusting bearing clearance is required on assembly	Small and medium-sized gears
		Suitable for high speed and moderate radial and axial loads. If certain design versions are used,preload (e.g. by means of spring support) is possible. Adjustment of bearing clearance and preload is required on assembly	Small gears, machine tools
Combination of thrust bearing and floating		The bearing arrangement is often used if the load at the bearing positions is uniform and balanced. Lower axial loads to reduce noise the bearings are often adjusted by means of springs	Small electric motors, gears
		This is a common arrangement. Loads on the bearings vary. Lower axial loads	Medium-sized electric motors, ventilators, gears

	Arrangement	Comments	Fields of application
Combination of thrust bearing and floating bearing arrangement		Intended for higher radial loads and lower axial loads. Due to the separability of the cylindrical roller bearings, these are suitable for assembly requiring a press fit of the inner ring and outer ring	Gears, traction motors
		Intended for high radial loads at both bearing positions with moderate axial loads. Not sensitive to misalignment	Gears, roller conveyors, paper machines
		Intended for high radial and moderate axial loads at high speed. (To avoid radial loading of the deepgroove ball bearing, which is employed as an axialbearing in the housing above, the deep groove ball bearing needs to be relieved)	Gears, ventilators
		Intended for high radial and moderate axial loads	Gears, paper machines
		Intended for high radial and axial loads. Face to face of the tapered roller bearing allows misalignment to a slightly higher extent compared to back to back	Pinion shafts in gears
		Intended for moderate axial loads. The angular contact ball bearings need to be used in universal combination (BG) or paired design. Often acylindrical roller bearing is used instead of the radial bearing	Fields of application with high requirements on axial guidance
		Bearing employed when misalignment and high axial loads in one direction are present. The combination of spherical roller bearings and thrust spherical roller bearings is also often used. The spherical centre of the self-aligning seat must coincide with that of the self-aligning ball bearing. Axial minimum load is to be observed. Also suitable for vertical assembly (post cranes)	Thrust bearing blocks, post cranes

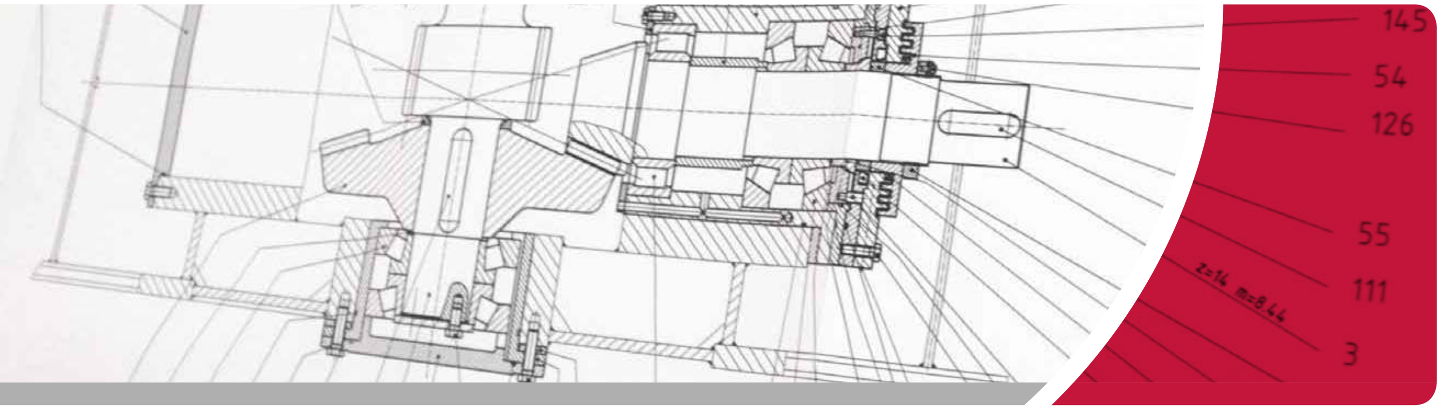
Calculation Methods

The key to the perfect solution

Having selected the bearing type, the next step is to determine the required bearingsize and bearing design to come to a solution that considers all aspects for high capacity and efficient design. One criterion is of paramount significance: estimating bearing life. For a long time experts have been aware of the fact that many features are to be considered for providing a reliable estimation. NSK's latest developments include optimised methods and calculation procedures that increase accuracy for estimating bearing life.

A host of features to be considered

Numerous influencing features are to be considered when determining bearing life. In the individual area of application, the type and bearing load capacity as well as speed are just as important as the design surrounding the bearing, i.e. the properties of the shaft and the housing, their material and tolerances. Outer sealing, lubrication method, operating temperature and ambient temperature: all these forces which affect the gear system need to be taken into consideration, calculated and assessed. Further influencing factors are, for example, load evolving from coupling, cardan shafts and belt drives, and loads evolving from the shaft and gears, and many more, all of which are just as important as the environmental conditions prevailing on the site. Briefly put: We are dealing with complex calculations. NSK has developed numerous methods and procedures for assessing and analysing these complex calculation issues.



Conventional calculation methods

Conventional standardised calculation methods for determining bearing life are also referred to as the catalogue method. These are stipulated in ISO 281. The parameters involved are: bearing load, speed, load rating and bearing type. The bearing life figures that result are: L10 or L10h. The extended standardised calculations according to ISO 281, go further and take the limiting loads for fatigue life of the bearing, the lubrication parameter, and the degree of lubrication purity into account and thus provide a more accurate outline of the bearing operating condition and performance. The bearing life figures that result are: L10a or L10ah. Both are generally approved methods, but as seen before, there is always potential for improvement.

Standard conventional methods

$$L_{10} = \left(\frac{C}{P}\right)^{p} \quad \text{or} \quad L_{10h} = \frac{10^6}{n \cdot 60} \left(\frac{C}{P}\right)^{p}$$

- **C** Dynamic load rating
- **P** Dynamic equivalent load
- **p** Exponent (3 for ball bearings, 10/3 for roller bearings)
- **n** Speed

Modified calculation for bearing life

$$L_{na} = a_1 \cdot a_{DIN} \cdot \left(\frac{C}{P}\right)^{p}$$

or

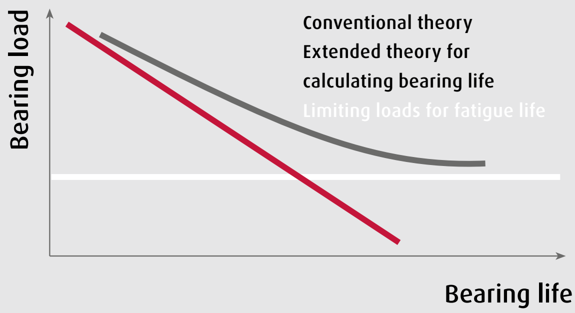
$$L_{na} = a_1 \cdot a_{DIN} \cdot \frac{10^6}{n \cdot 60} \left(\frac{C}{P}\right)^{p}$$

a_1 Coefficient for anticipated bearing life
a_{DIN} Coefficient for operating conditions

The ABLE-Forecaster

The ABLE-Forecaster (Advanced Bearing Life Equation) is the latest software which NSK has developed for increased accuracy in estimating bearing life. The standardised calculations according to ISO 281 have been extended: the main difference (and progress) is the fact that this method is based on information resulting from actual applications and tests performed over a period of several decades. In addition, this avanced calculation method, which NSK has developed, considers a great variety of features, including environmental conditions, limiting loads for fatigue life, lubrication parameters as well as contamination factors and material.

The ABLE-Forecaster



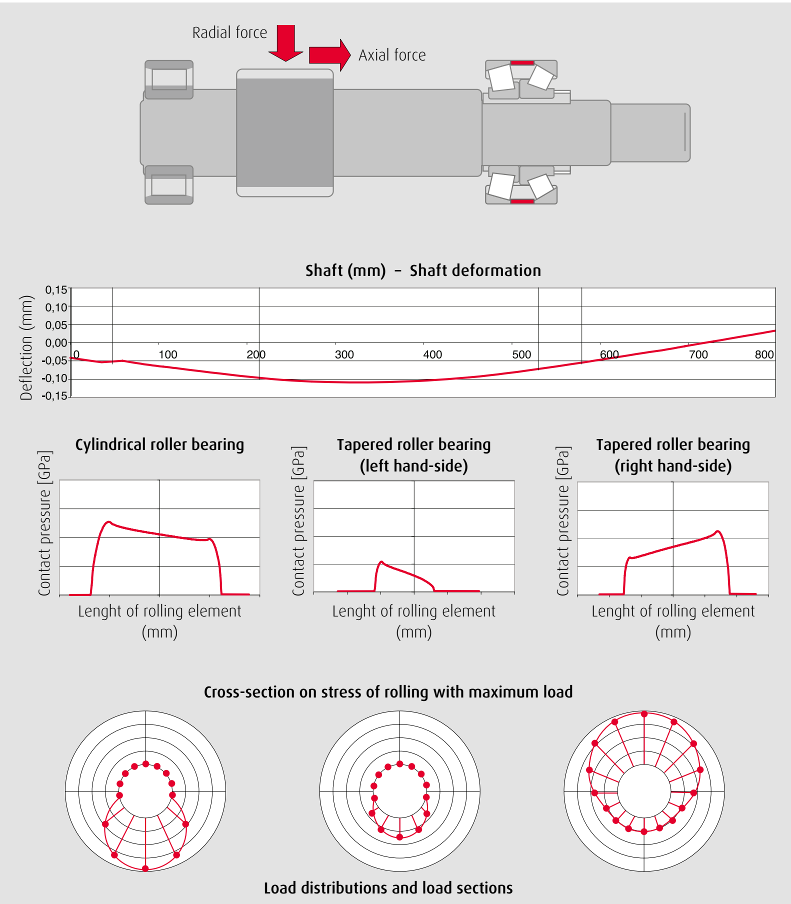
$$L_{NSK} = a_1 \cdot a_{NSK} \cdot L_{10h}$$

a_1 Coefficient for anticipated bearing life
a_{NSK} Coefficient for operating conditions

STIFF

A further invention: STIFF

STIFF is a program developed by NSK that considers important parameters such as deformation of the shaft and housing, misalignment, displacement of the bearing itself (and adjacent bearings) as well as internal operating cycles. The conventional methods merely analyse the rolling bearing itself, regardless of other features affecting bearing life. STIFF works from the principle of a bearing-shaft-housing-system. The software is outstanding due to its calculation scope and provides results that allow several analyses within a short period of time. Additionally it eliminates many time intensive tests of special rolling bearings and adjustments with regard to the individual application conditions.



Calculation procedures on estimating bearing life – STIFF-Program

Estimating strength

Analysis of component deformations

Parameter:

- Load on components and component deformation
- Loads on bearings and resultant bearing deformations

Estimating factors affecting performance

Analysis of internal friction conditions

- Kinematic aspects of the rolling elements
- Tilt and skew motion of the rolling element
- Thickness of lubrication film supplied
- Heat generation and dynamic torque

More accurate estimates of bearing life

Analysis of internal stress factors of the rolling element

- Contact pressure and internal load distribution

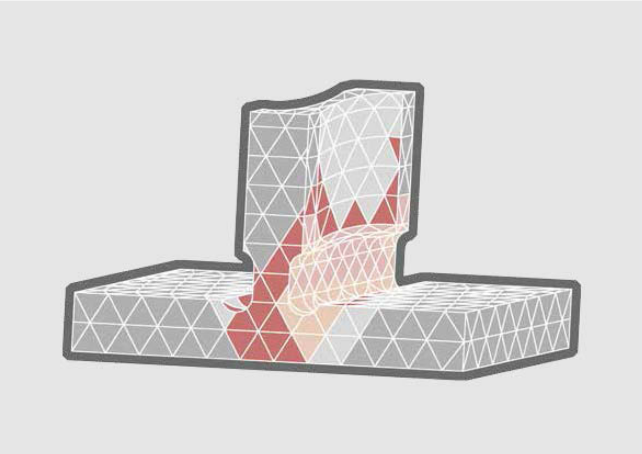
Estimating reliability and operational safety

Wear parameter

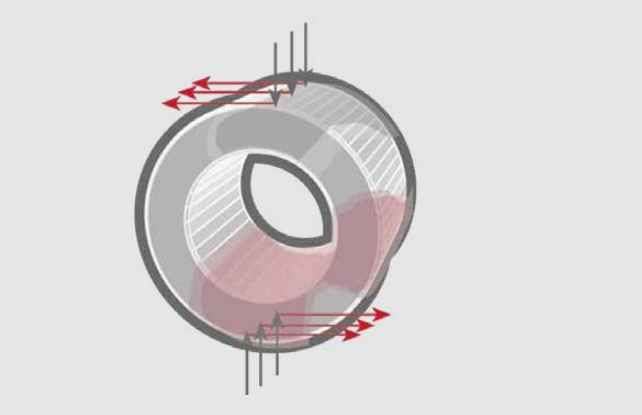
- PV-Value (resulting from contact potential and peripheral velocity; this value gives evidence of potential states of friction and wear)

Even more tools – developed on the basis of experience and skills

Another example of calculation methods employed by NSK is FEM Analysis. Finite Element analysis examines the distribution of stress factors within the bearing and its components and thus provides optimum support for non-standard applications. Frequency analysis, on the otherhand, examines noise generation of the rolling bearing within the application of which performance and operating characteristics of the bearing system can be understood. Adding to these bespoke calculation capabilities are a host of bearing calculation programmes for speeding up more routine analyses.



Optimised cage design: On the basis of the FEM-Analysis, component parts with stresslevels beyond allowable levels can be examined. Such areas can be re-designed enabling stress levels within the bearing to be reduced and thus improve bearing performance.



Planet gears are thin-walled machine parts exposed to high stress. On evaluating planet gear deformation, internal geometry aspects of the bearings were analysed and adjusted for uniform and balanced distribution of load. Thus improved bearing life was achieved.

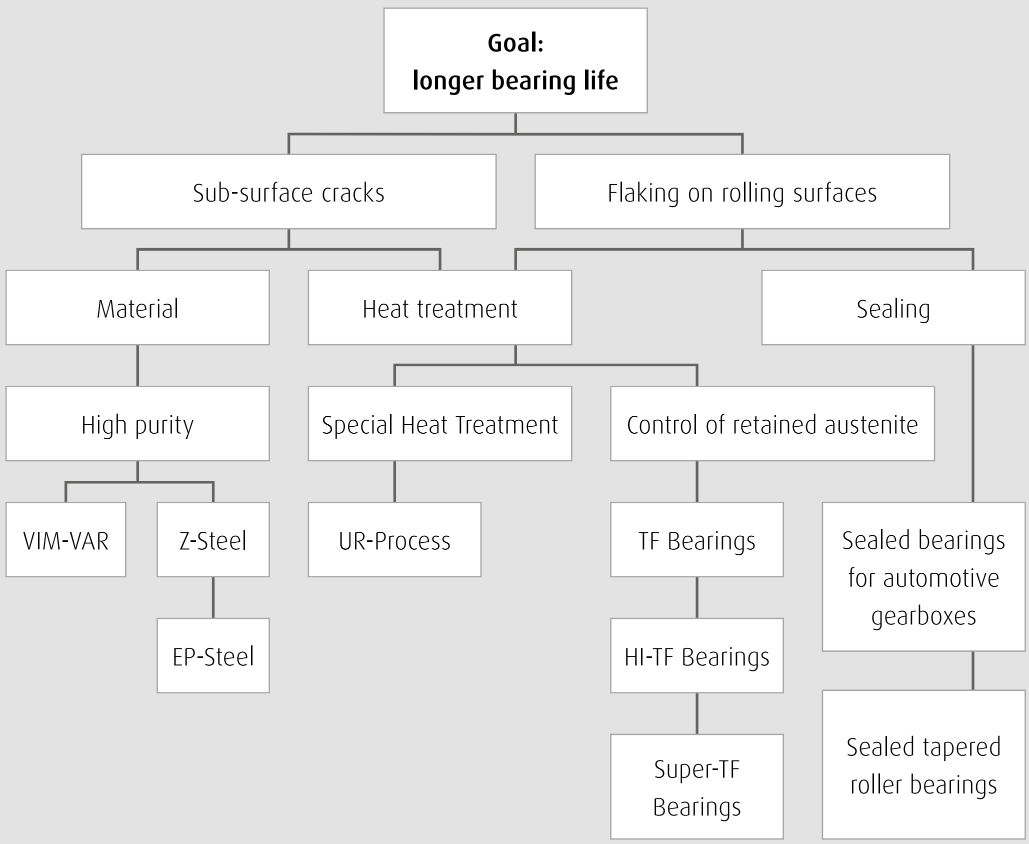
Material for Roller Bearings

NSK – Absolutely tough

NSK is first when it comes to developing rolling bearings which can cope with high stress factors and severe operating conditions. NSK rolling bearings stand for high reliability, long life and high resistance to wear and seizure.

High investments, in particular for basic materials technology research, ensure that our demanding goals are achieved. Investing in new methods has paid dividends as many recent achievements reveal: NSK has developed a ground-breaking material that sets new benchmarks, in particular when it comes to operating conditions in contaminated environment or if high stress factors are encountered. The new materials can be employed for a wide range of bearing types.

Methods for achieving longer bearing life



Cause and effect

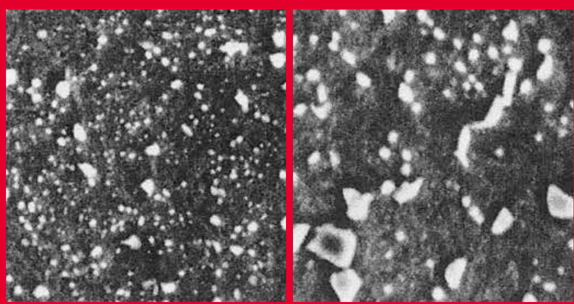
All rolling bearings have a limited fatigue life, which shows when fine cracks develop beneath the surface resulting in flaking on the contact areas of the rolling element and rolling surface. The life is highly dependent on the degree of purity of the steel used for the rolling bearings. Failure before the end of the calculated bearing life; however, is more frequently caused by flaking formation directly at the contact surfaces, which is due to stress at the rolling surfaces. Contamination of the lubrication caused by metallic particles, sand particles, or improper handling during assembly or maintenance is often the reason for premature failure of the rolling bearing. To combat these causes of failure NSK has developed a new material: Super-TF for rolling bearings operating under high stress conditions. A new material that undergoes a new heat treatment method.

Simply tough: Super-TF

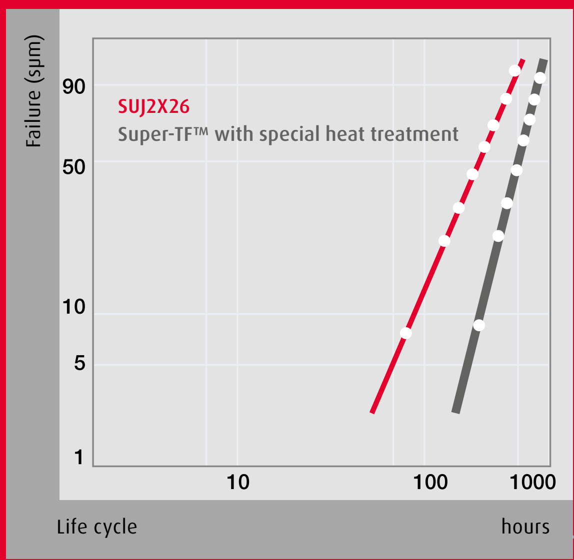
The development process was aimed at improving the properties of the previous TF-material. For this purpose NSK developed a material composition and heat treatment process that ensures even distribution of the carbide particles within the bearing steel while at the same time minimising the size of the particles. In addition, NSK has employed a new method to bond even finer particles of carbides and nitrides in steel – a method that has been patented in Japan and overseas. Rolling bearings made from Super-TF Material not only have a longer bearing life under contaminated lubrication conditions – about ten times above that of standard material – but their resistance against flaking, wear and thermal stress factors is also superior to the previous TF-material. An impressing price-performance ratio for the client.

Main fields of application

Super-TF technology can be applied in a wide range of bearing types, for example, cylindrical roller bearings, tapered roller bearings, spherical roller bearings, deep groove ball bearings as well as angular contact ball bearings.



Distribution and size of carbide and carbonitride particles in Super-TF material (left) compared to distributionand size in a standard material (magnified by 4.000).



Longer bearing life due to Super-TF material

So everything runs smoothly

About 40 % of damage that rolling bearings suffer prior to the end of estimated bearing life is caused by improper lubrication. Damage becomes obvious in the form of wear, insufficient and uneven lubrication, flaking, seizure, fatigue damage or overheating of the bearings. All are caused by deficient lubrication – too much lubrication is also one of the causes – and all could be avoided if more attention were paid to the individual application demands for lubrication. Optimum separation of the contact surfaces by a lubrication film is not the only function of a lubricant in rolling bearings. Reducing friction, preventing contamination, protection against corrosion and aiding heat transfer, are all important features.

Calculation of required oil quantity

$$Q_{10} = \frac{0.19 \cdot 10^{-5}}{T_2 - T_1} \; d \cdot \mu \cdot n \cdot F(N)$$

- **Q** Oil supply (litre/min)
- **T_1** Oil temperature at inlet (in °C)
- **T_2** Oil temperature at outnlet (in °C)
- **d** Bearing bore diameter (in mm)
- **μ** Dynamic friction coefficient (see table below)
- **n** Speed (rpm)
- **F** Radial load on bearing (in N)

Bearing type	Friction coefficient for different bearing types μ
Spherical roller bearing	0.0028
Thrust spherical roller bearing	0.0028
Tapered roller bearing	0.0022
Angular contact ball bearing	0.0015
Radial deep groove ball bearing	0.0013
Cylindrical roller bearing	0.0010

Separating the contact surfaces

To ensure that the contact surfaces are permanently separated, a straight forward method for specifying the conditions of the lubrication necessary. Based on the theory of elasto-hydrodynamic lubrication, the ratio of actual to required oil viscosity during operation needs to exceed a factor 1. According to ISO 281 nominal bearing life expressly refers to this minimum value. The required viscosity is driven by the operating speed and the rolling element pitch circle diameter.

Oil or grease

Commonly rolling bearings are usually lubricated with the same oil as is employed for the gears. A key advantage of oil lubrication is the numerous possibilities to ensure permanent lubrication of all contact points. In this context, selective supply and discharge of oil constitutes another advantage. In addition, oil is an effective medium to transfer heat from the contact points and replacing the lubricant is usually straight forward. Grease lubrication on the other hand, contributes to application sealing and can offer maintenance free lubrication.

Lubrication for the purpose of heat reduction

Rolling bearings which operate at high speed run the risk of excessive heat generation due to the friction of the bearing and churning of the lubricant. This may result in unacceptable temperature rise of the gearbox components. Heat transfer is thus essential for preventing overheating of the bearing. Various methods are available for this purpose, but one procedure has proven to be particularly effective with respect to large machines employing large rolling bearings, e.g. pressing machines, paper machines, steel processing machines: heat transfer is effected by means of higher lubricant volume supplied under pressure. The actual operating conditions of the gear serve as a basis for calculating the lubrication quantity required for sufficient heat transfer.

Damage caused by lubrication problems

Damage symptom	Cause	Reason
Noise	Insufficient lubrication	In places of component contact a lubrication film is not formed. Lubrication film is insufficient to totally separate components
	Inappropriate lubrication	Application film too thin due to insufficient viscosity of oil or grease base oil. When grease is employed, the structure of the thickener may have an unfavourable effect (grease component particles cause noise generation)
	Contamination	Foreign particles disrupt lubrication film causing noise generation
Cage wear	Insufficient lubrication	In places of component contact, a lubrication film is not formed. Lubrication film is insufficient to totally separate components
	Inappropriate lubrication	Insufficient viscosity of oil or grease base oil; lubricant does not contain additives for protection against wear
Wear of rolling elements, rolling surfaces, rib surfaces	Insufficient lubrication	In places of component contact lubrication film is not formed. Lubrication film is insufficient to totally separate components. Fretting corrosion from oscillating relative movement
	Inappropriate lubrication	Insufficient viscosity of oil or grease base oil. Lubricant does not contain additives for protection against wear or EP-Additive (for high load)
	Contamination	Particulate or liquid contaminants with corrosive or abrasive effects
Fatigue spalling	Insufficient lubrication	In places of component contact a insufficient lubrication film to support high contact stresses. For protection against wear
	Inappropriate lubrication	Insufficient viscosity of oil or grease base oil. Lubricant pressure-viscosity characteristics insufficient
	Contamination	Ingress of hard particles resulting in indentations and thus high surface stress. Corrosion damaging contact surfaces
High temperature rise of bearing, seizure (overheating)	Insufficient lubrication	In places of component contact a lubrication film is not formed. Lubrication film is insufficient to totally separate components
	Inappropriate lubrication	High friction and temperature rise due to sporadic component contact
	Contamination	High lubrication friction with average and high speed, in particular on sudden lubrication supply
Degraded lubricant (discoloured, solidified, reduced lubrication performance)	Insufficient lubrication	Operating temperature exceeds temperature permissible for lubricant (causing breakdown and residue)
	Inappropriate lubrication	Re-lubrication intervals or lubricant change period too long

Monitoring through lubrication

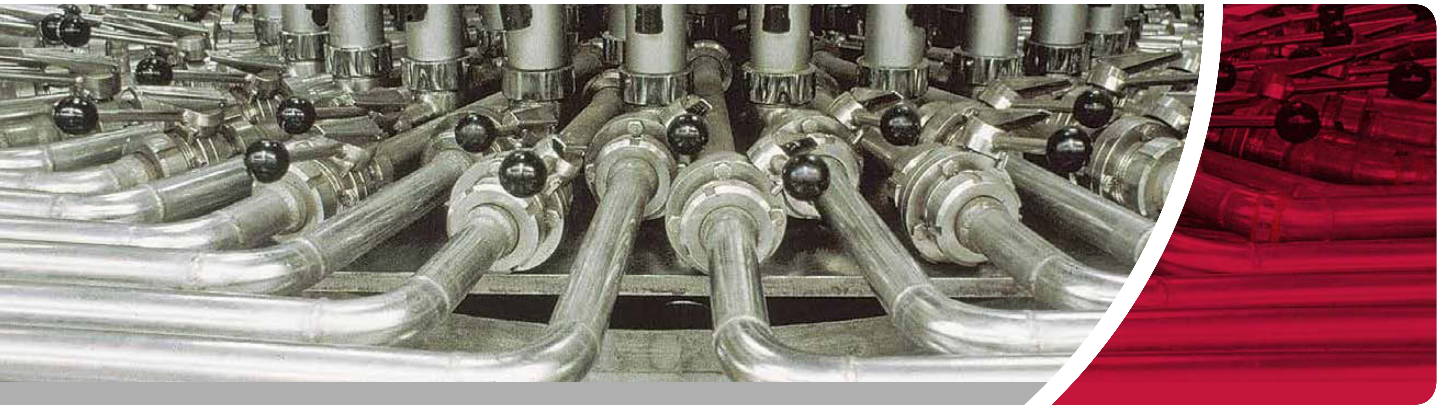
Monitored Parameters	Method	Detectable or avoidable damage type
Lubrication	Analysis (water content, contamination, content, pH, saponification number)	Fatigue wear, wear, corrosion, inappropriate lubrication
Lubrication system	Oil pressure, oil condition, oil flow and oil temperature	Bearing runs hot, wear

Proper dimensioning

If the inner ring of a rolling bearing element is fitted to the shaft, without using other fixing methods, there is often the risk of slippage between the inner ring and the shaft. This slippage, commonly referred to as creep, may cause particles to separate from the surfaces resulting in wear, which in turn, causes considerable damage to the shaft. Particles from metallic abrasion can enter into the inside of the bearing and damage the rolling surfaces. In addition, metallic abrasion can cause excessive temperature rise and vibration. It is important to prevent creep by providing a sufficient and permanent location for the safe attachment of the ring – either on the shaft or in the housing. However, an interference fit is not always required for rings where the load does not move with respect to it. Depending on the field of application a clearance fit may be employed for either the inner or outer ring. For example, if the bearing needs to move in the axial direction for the purpose of assembly, disassembly or to accommodate thermal expansion. In this case lubrication or other suitable procedures need to be considered to avoid damage at the contact points caused by creeping.

Fits of Radial Bearings with Housings

Load Conditions			Examples	Tolerances for Housing Bores	Axial Displacement of Outer Ring	Remarks
Solid Housings	**Rotating Outer Ring Load**	Heavy Loads on Bearing in Thin-Walled Housing of Heavy Shock Loads	Automotive Wheel Hubs (Roller Bearings) Crane Travelling Wheels	P7	Impossible	–
		Normal or Heavy Loads	Automotive Wheel Hubs (Ball Bearings) Vibrating Screens	N7		
		Light or Variable Loads	Conveyor Rollers Rope Sheaves Tension Pulleys	M7		
Solid or Split Housings	**Direction of Load Indeter-minate**	Heavy Shock Loads	Traction Motors	M7	Impossible	–
		Normal or Heavy Loads	Pumps Crankshaft Main Bearings Medium and Large Motors	K7	Impossible	If axial displacement of the outer ring is not required
		Normal or Light Loads		JS7 (J7)	Possible	Axial displacement of outer ring is necessary
	Rotating Inner Ring Load	Loads of All Kinds	General Bearing Applications, Railway Axleboxes	H7	Easily possible	–
		Normal or Light Loads	Plummer Blocks	H8		



Procedures for perfect fit selection

To calculate the proper fit for the bearing, it is important to consider the bearing load. At the load application point the inner ring of the bearing undergoes radial compression while opposite to this point the ring expands. This effectively reduces the component interference. The method shown in **Equation method 1** may be employed for calculating fit reduction. In practice, the actual interference level selected should always exceed the result from Equation 1. Calculation on the basis of Equation 1 is sufficient for comparatively low loads, expected in most areas of application. If higher loads are expected, however, **Equation method 2** should serve as basis for calculation.

Equation Method 1

$$\Delta d_F = 0.08 \sqrt{\frac{d}{B} F} \cdot 10^{-3}\ (N)$$

- **Δd_F** Required Interference fit
- **d** Bore diameter (mm)
- **B** Width of inner ring (mm)
- **F** Radial load (N)

Equation Method 2

$$\Delta d_F \geq 0.02 \frac{F_1}{B} \cdot 10^{-3}\ (N)$$

- **Δd_F** Required Interference fit
- **B** Width of inner ring (mm)
- **F** Radial load (N)

<table>
<tr><th colspan="3">Load Conditions</th><th>Examples</th><th>Tolerances for Housing Bores</th><th>Axial Displacement of Outer Ring</th><th>Remarks</th></tr>
<tr><td>Solid or Split Housings</td><td rowspan="3">Rotating Inner Ring Load</td><td>High Temperature Rise of Inner Ring Through Shaft</td><td>Paper Dryers</td><td>G7</td><td>Easily Possible</td><td>-</td></tr>
<tr><td rowspan="6">Solid Housing</td><td rowspan="4">Accurate Running Desirable under Normal or Light Loads</td><td>Grinding Spindle Rear Ball Bearings</td><td>JS6 (J6)</td><td rowspan="2">Possible</td><td rowspan="2">-</td></tr>
<tr><td>High Speed Centrifugal Compressor Free Bearings</td><td></td></tr>
<tr><td rowspan="2">Direction of Load Indeter-minate</td><td>Grinding Spindle Front Ball Bearings</td><td rowspan="2">K6</td><td rowspan="2">Impossible</td><td rowspan="3">For heavy loads, interference fit tigh-ter than K is used. When high accuracy is required, very strict tolerances sould be used for fitting</td></tr>
<tr><td>High Speed Centrifugal Compressor Fixed Bearings</td></tr>
<tr><td rowspan="2">Rotating Outer Ring Load</td><td>Accurate Running and High Rigidity Desirable under Variable Loads</td><td>Cylindrical Roller Bearings for Machine Tool Main Spindle</td><td>M6 or N6</td><td>Impossible</td></tr>
<tr><td>Minimum noise is required</td><td>Electrical Home Appliances</td><td>H6</td><td>Easily Possible</td><td>-</td></tr>
</table>

Fits of Radial Bearings with Shafts

Load conditions		Examples
Radial Bearings with cylindrical bores		
Rotating Outer Ring Load	Easy axial displacement of inner ring on shaft desirable	Wheels on stationary axles
	Easy axial displacement of inner ring on shaft unnecessary	Tension pulleys, rope sheaves
Rotating Inner Load or Direction of Load Indeterminate	Light loads or variable Loads ($\leq$ 0.06 Cr[1])	Electrical home appliances, pumps, blowers, transport vehicles, precision machinery, machine tools
	Normal loads (0.06 to 0.13 Cr[1])	General bearing applications, medium and large motors, turbines, pumps, engine main bearings, gears, woodworking machine
	Heavy loads or shock loads (> 0.13 Cr[1])	Railway axleboxes, industrial vehicles, traction motors, construction, equipment, crushers
Axial Loads Only		

Radial Bearings with tapered bores and sleeves	
All Types of Loading	General bearing applicaions, railway axleboxes
	Transmission shafts, woodworking spindles

Notes: [1] Cr represents the basic load rating of the bearing.
This table is applicable only to solid steel shafts.

Shaft Diameter (mm)			Tolerance of shaft	Remarks
Ball bearings	Cylindrical roller bearings, tapered roller bearings	Spherical roller bearings		
All Shaft Diameters			g6	Use g5 and h5 where accuracy is required. In case of large bearings, f6 can be used to allow easy axial movement
			h6	
≤18	–	–	js5	–
18~100	≤40	–	js6 (j6)	
100~200	40~140	–	k6	
–	140~200	–	m6	
≤18	–	–	js5~6 (j5~6)	k6 and m6 can be used for single-row tapered roller bearings and single-row angular contact ball bearings instead of k5 and m5
18~100	≤40	≤40	k5~6	
100~140	40~100	40~65	m5~6	
140~200	100~140	65~100	m6	
200~280	140~200	100~140	n6	
–	200~400	140~280	p6	
–	–	280~500	r6	
–	–	>500	r7	
–	50~140	50~100	n6	More than CN bearing internal clearance is necessary
–	140~200	100~140	p6	
–	>200	140~200	r6	
–	–	200~500	r7	
All Shaft Diameters			**js6 (J6)**	**-**

All Shaft Diameters	h9/IT5	IT5 and IT7 mean that the deviation of the shaft from its true geometric from, e.g. roundnes and cylindricity should be within the tolerances of IT5 and IT7 respectively
	h10/IT7	

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