Principles of bearing selection and application

Bearing life and load ratings

In industrial applications, bearing size is usually determined by its load carrying capacity relative to the load, required life and required reliability of the application. For machine tool applications, bearing size is almost always determined by other factors such as system rigidity, fixed dimensions of the spindle as well as the speed and feed parameters of the application.

For super-precision bearing arrangements, determining the actual load is particularly complex as it involves many influencing factors. *SKF Spindle Simulator* is a sophisticated computer program to analyse statically indeterminate spindle bearing systems. It supports the analysis of spindles and contains detailed models of super-precision bearings. For additional information, contact the SKF application engineering service or visit *SKF Engineering Consultancy Services* at skf.com.

Dynamic bearing loads and life

The general information about bearing life calculation and basic load ratings provided under *Selecting bearing size* in the SKF catalogue *Rolling bearings*, or at skf.com, is also valid for super-precision bearings. It should be noted that all life calculations based on ISO 281 are valid for normal speeds. For applications where the speed factor A ≥ 500 000 mm/min, contact the SKF application engineering service.

$$A = n\, d_m$$

where

A = speed factor [mm/min]

d_m = bearing mean diameter [mm] = 0,5 (d + D)

n = rotational speed [r/min]

Rated bearing life can be calculated for fatigue conditions based on statistical assumptions. For detailed information, refer to *Basic rating life* in the SKF catalogue *Rolling bearings*, or visit skf.com.

Basic dynamic load rating

The basic dynamic load rating C is used for life calculations involving dynamically stressed bearings, i.e. bearings that rotate under load. It expresses the bearing load that will result in an ISO 281 basic rating life L_{10} of 1 000 000 revolutions. It is assumed that the load is constant in magnitude and direction and is radial for radial bearings and axial, acting centrically, for thrust bearings.

Values for the basic dynamic load rating C are listed in the product tables.

Equivalent dynamic bearing load

To calculate the basic rating life for a bearing using basic dynamic load ratings, it is necessary to convert the actual dynamic loads into an equivalent dynamic bearing load. The equivalent dynamic bearing load P is defined as a hypothetical load, constant in magnitude and direction, that acts radially on radial bearings and axially and centrically on thrust bearings. This hypothetical load, when applied, would have the same influence on bearing life as the actual loads to which the bearing is subjected.

Information and data required for calculating the equivalent dynamic bearing load is provided in each product chapter.

Basic rating life

The basic rating life of a bearing in accordance with ISO 281 is

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

If the speed is constant, it is often preferable to calculate the life expressed in operating hours using

$$L_{10h} = \frac{10^6}{60\ n} L_{10}$$

where

L_{10} = basic rating life (at 90% reliability) [million revolutions]
L_{10h} = basic rating life (at 90% reliability) [operating hours]
C = basic dynamic load rating [kN]
P = equivalent dynamic bearing load [kN]
n = rotational speed [r/min]
p = exponent of the life equation
= 3 for ball bearings
= 10/3 for roller bearings

Rating life for hybrid bearings

When calculating the rating life for hybrid bearings, the same life values can be used as for bearings with steel rolling elements. The ceramic rolling elements in hybrid bearings are much harder and stiffer than steel rolling elements. Although this increased level of hardness and stiffness creates a higher degree of contact stress between the ceramic rolling elements and the steel raceway, field experience and laboratory tests show that the same rating lives can be used for both bearing types.

Extensive experience and testing show that in typical machine tool applications, the service life of a hybrid bearing is significantly longer than the service life of a bearing with steel rolling elements. The extended service life of hybrid bearings is due to the hardness, low density and surface finish of the rolling elements. Low density minimizes internal loading from centrifugal and inertial forces while increased hardness makes the rolling elements less susceptible to wear. Their surface finish enables the bearing to optimize the effects of the lubricant.

Requisite minimum load

In bearings that operate at high speeds or are subjected to rapid accelerations or rapid changes in the direction of load, the inertial forces of the rolling elements and the friction in the lubricant can have a detrimental effect on the rolling conditions in the bearing arrangement and may cause damaging sliding movements to occur between the rolling elements and raceways. To provide satisfactory operation, rolling bearings must always be subjected to a given minimum load. A general “rule of thumb” indicates that minimum loads of 0,01 C should be imposed on ball bearings and 0,02 C on roller bearings.

Calculating life with variable operating conditions

In some applications, the operating conditions, such as the magnitude and direction of loads, speeds, temperatures and lubrication conditions are continually changing. In these types of applications, bearing life cannot be calculated without first reducing the load spectrum or duty cycle of the application to a limited number of simplified load cases.

In case of continuously changing loads, each different load level can be accumulated and the load spectrum reduced to a histogram of constant load blocks (→ **diagram 3**). Each block should characterize a given percentage or time-fraction during operation. Note that heavy and normal loads consume bearing life at a faster rate than light loads. Therefore, it is important to have shock and peak loads well represented in the load diagram, even if the occurrence of these loads is relatively rare and limited to a few revolutions.

Within each duty interval, the bearing load and operating conditions can be averaged to some constant value. The number of operating hours or revolutions expected from each duty interval showing the life fraction required by that particular load condition should also be included. Therefore, if N_1 equals the number of revolutions required under the load condition P_1, and N is the expected number of revolutions for the completion of all variable loading cycles, then the cycle fraction $U_1 = N_1/N$ is used by the load condition P_1, which has a calculated life of $L_{10\,1}$. Under variable operating conditions, bearing life can be rated using

$$L_{10} = \frac{1}{\dfrac{U_1}{L_{10\,1}} + \dfrac{U_2}{L_{10\,2}} + \dfrac{U_3}{L_{10\,3}} + \ldots}$$

where

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

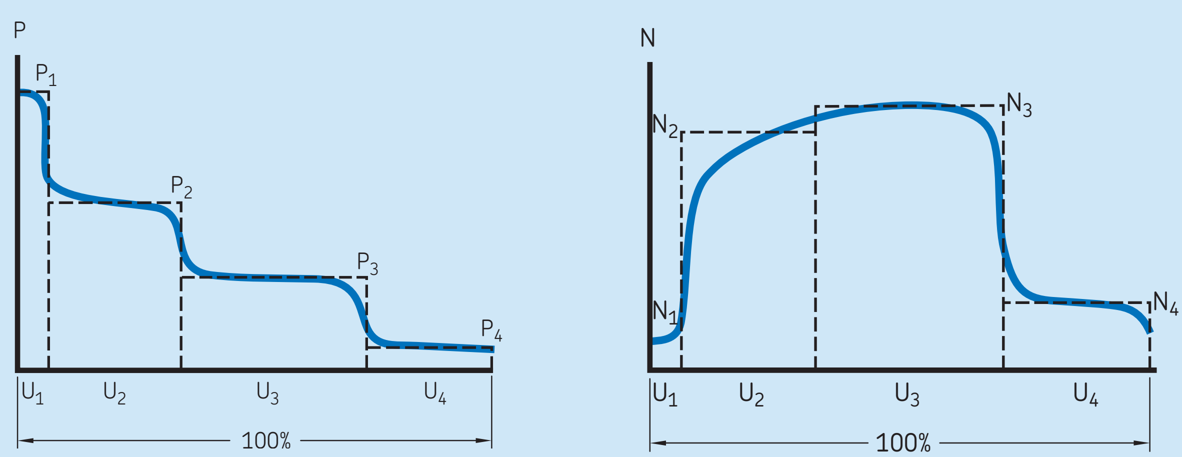
$L_{10\,1}, L_{10\,2}, \ldots$ = basic rating lives (at 90% reliability) under constant conditions 1, 2, ... [million revolutions]

$U_1, U_2, \ldots$ = life cycle fraction under the conditions 1, 2, ...
Note: $U_1 + U_2 + \ldots + U_n = 1$

The use of this calculation method depends very much on the availability of representative load diagrams for the application. Note that this type of load history can also be derived from a similar type of application.

Diagram 3

Histogram of constant load blocks



Permissible static loads

Very heavy loads or shock loads can permanently deform the raceways or rolling elements. In the case of super-precision bearing arrangements, permanent deformation must not occur. To make sure that static loads do not lead to permanent deformation, the basic static load rating of the bearing and equivalent static bearing load can be compared to determine if a bearing is at risk of permanent deformation. For very heavily loaded super-precision angular contact ball bearings, the contact ellipse truncation should be checked to avoid edge stress, which also could lead to permanent deformation. For additional information, contact the SKF application engineering service.

Basic static load rating

The basic static load rating C_0 as defined in ISO 76 corresponds to a calculated contact stress at the centre of the most heavily loaded rolling element / raceway contact. This stress produces a total permanent deformation of the rolling element and raceway, which is approximately 0,0001 of the rolling element diameter. The loads are purely radial for radial bearings and axial, centrically acting, for thrust bearings.

Values for basic static load rating C_0 are listed in the product tables.

Equivalent static bearing load

To compare actual loads with the basic static load rating, the actual loads must be converted into an equivalent load. The equivalent static bearing load P_0 is defined as that hypothetical load (radial for radial bearings and axial for thrust bearings) which, if applied, would cause the same maximum rolling element load in the bearing as the actual loads to which the bearing is subjected.

Information and data required for calculating the equivalent static bearing load are provided in each product chapter.

Required basic static load rating

The required basic static load rating C_0, to protect the bearing from permanent deformation, can be determined from

$$C_0 \geq s_0 \, P_0$$

where

C_0 = basic static load rating [kN]
P_0 = equivalent static bearing load [kN]
s_0 = static safety factor
Guidelines for minimum values:
- 2 for super-precision angular contact ball bearings with steel balls (including thrust ball bearings)
- 3 for super-precision cylindrical roller bearings with steel rollers
- 4 for super precision axial-radial cylindrical roller bearings

For hybrid bearings, the static safety factor should be increased by 10%.

For angular contact thrust ball bearings for screw drives, safety factors down to $s_0 = 1$ can be used.

Friction

Friction in a bearing can be described as the total resistance to rotation. Contributing factors include, but are not limited to:

- elastic deformation of the rolling elements and raceways under load
- speeds
- lubricant and lubrication method
- sliding friction between the rolling elements and cage, flanges and guide rings, and between the seals and their counterfaces

Each of these contributes to the frictional heat generated by the bearing. The bearing operating temperature is attained when frictional heat and heat dissipated by the application are in balance.

For detailed information about friction in super-precision bearings, contact the SKF application engineering service.

Effects of clearance and preload on friction

High operating temperatures or high speeds can reduce the internal clearance or increase the preload in a bearing. Either of these changes can increase friction. This is particularly important for super-precision bearing arrangements because they are typically preloaded and are extremely sensitive to changes in preload.

For applications that are sensitive to changes in clearance or preload, contact the SKF engineering application service.

Effects of grease fill on friction

During initial start-up, or after relubrication, the frictional moment of a grease lubricated bearing can be exceptionally high during the first few hours or days of operation. This high initial frictional moment, which can be seen as a temperature spike, is caused by the uneven distribution of grease within the bearing free space.

After a running-in period, the frictional moment and bearing operating temperature are typically similar to the values for oil lubricated bearings. Bearings filled with an excessive amount of grease may have higher frictional values.

Frictional behaviour of hybrid bearings

The lower density of silicon nitride rolling elements, compared with steel, reduces internal centrifugal forces. This, combined with their low coefficient of friction, significantly reduces bearing temperatures at high speeds. Cooler running extends the service life of both the bearing and the lubricant.

Speeds

The maximum speed at which a rolling bearing can operate is largely determined by its permissible operating temperature. The operating temperature of a bearing depends on the frictional heat generated by the bearing, any externally applied heat, and the amount of heat that can be transferred away from the bearing.

Super-precision bearings that generate low levels of friction are, therefore, best suited for high-speed applications due to their corresponding low operating temperatures. When compared to similarly-sized roller bearings, ball bearings have a lower load carrying capacity but their smaller rolling contact area enables them to operate at much higher speeds. However, hybrid bearings provide additional benefits for all bearing types. **Diagram 4** compares the temperature rise in grease lubricated spindles for different bearing types. The curves for the bearings can be considered representative for the whole bearing series.

Guideline values for attainable speeds per bearing series, are provided in **diagram 5** (→ **page 38**) for oil-air lubrication and in **diagram 6** (→ **page 38**) for grease lubrication. Both diagrams are based on the speed factor A. For details about the bearing series, refer to the designation system of:

- angular contact ball bearings (→ **page 38**)
- cylindrical roller bearings (→ **page 38**)
- double direction angular contact thrust ball bearings (→ **page 38**)
- angular contact thrust ball bearings for screw drives (→ **page 38**)

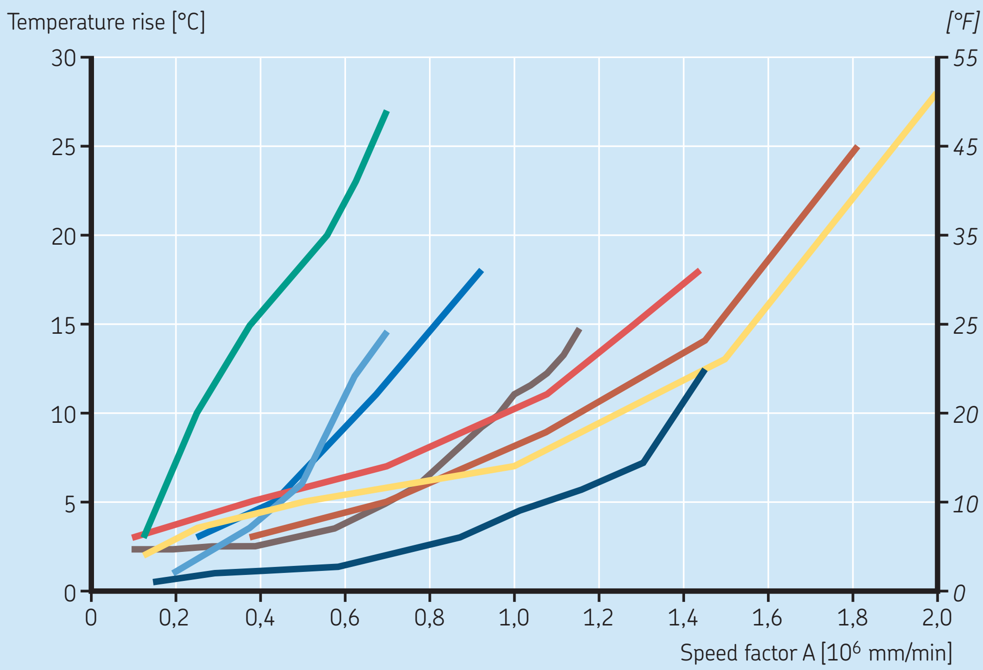
Generally, bearings with a lower cross-sectional height can attain higher speeds because of the smaller value for mean diameter d_m.

Permissible speeds

The permissible speed of a bearing depends on the frictional heat generated by the bearing,

Diagram 4

Temperature rise in grease lubricated spindle bearings



Angular contact ball bearing
7008 CE/HC (high-speed, hybrid, spring preloaded)

Angular contact ball bearings, back-to-back
S71912 ACB/HCDBA (sealed, high-speed, hybrid)
7205 CD/DBA (high-capacity)
71912 CD/DBA (high-capacity, long spacers)
7005 CD/HCDBA (high-capacity, hybrid)

Cylindrical roller bearing
NN 3014 KTN

Angular contact thrust ball bearings
BTW 100
BTM 100 B

any externally applied heat and the amount of heat that can be transferred away from the bearing. In applications where heat dissipation is not adequate, either because of design considerations or high ambient temperatures, additional cooling methods might be needed in order to keep bearing temperatures within a permissible range.

Cooling can be accomplished through different lubrication methods. In oil jet and circulating oil systems, for example, the oil is filtered and, if required, cooled before being returned to the bearing.

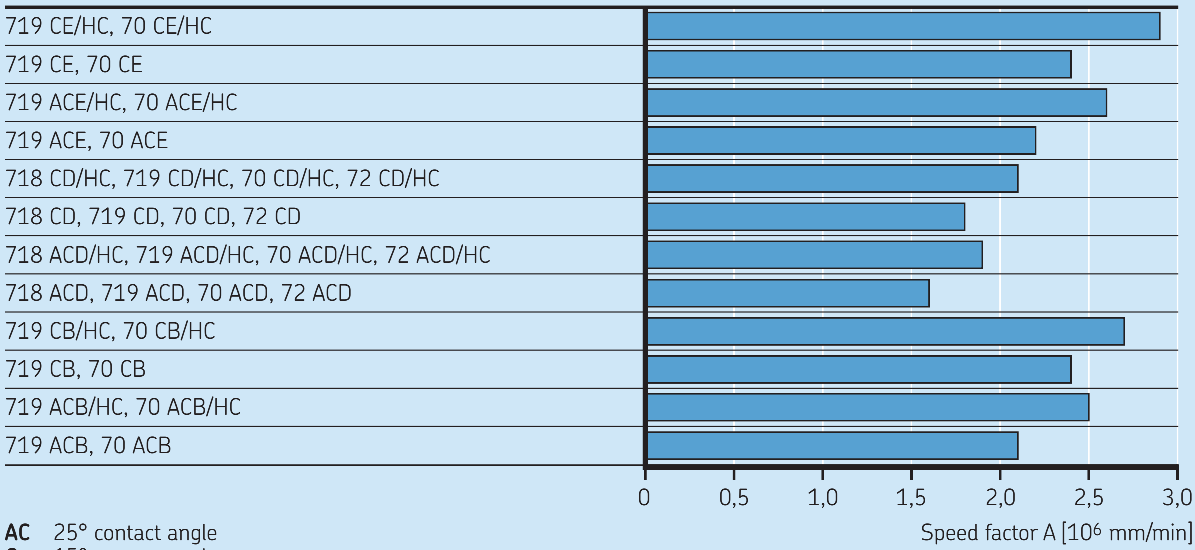
The product tables list attainable speeds, but not speed limits, because the permissible speed is influenced by factors other than the bearing.

Principles of bearing selection and application

Diagram 5

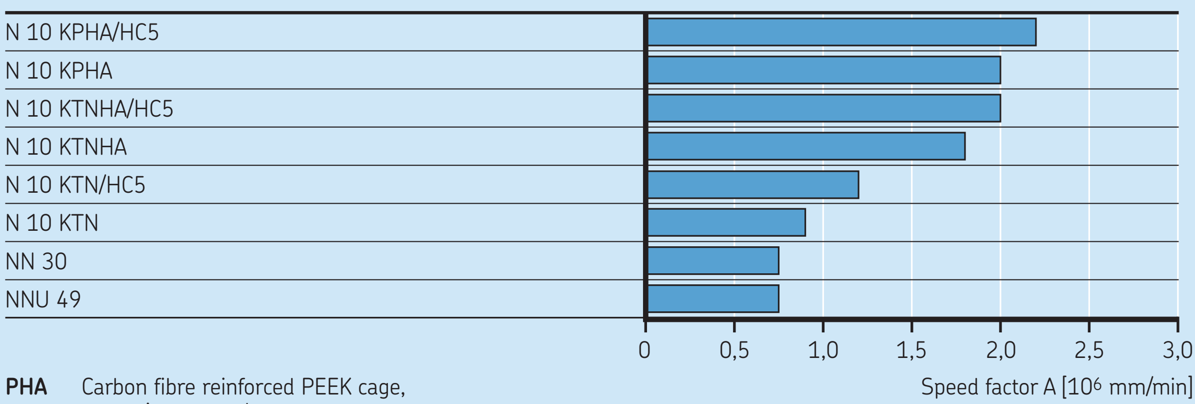
Guideline values for attainable speeds – oil-air lubrication

Angular contact ball bearings
Bearing series



AC 25° contact angle
C 15° contact angle
B High-speed B design
E High-speed E design
D High-capacity D design
HC Ceramic balls

Cylindrical roller bearings
Bearing series

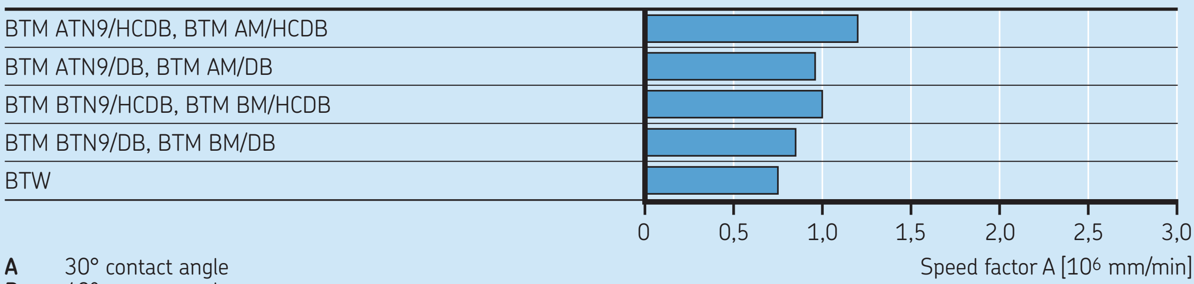


PHA Carbon fibre reinforced PEEK cage, outer ring centred
TN PA66 cage, roller centred
TNHA Glass fibre reinforced PEEK cage, outer ring centred
HC5 Ceramic rollers

cont. diagram 5

Guideline values for attainable speeds – oil-air lubrication

Double direction angular contact thrust ball bearings
Bearing series



A 30° contact angle
B 40° contact angle
M Machined brass cage, ball centred
TN9 Glass fibre reinforced PA66 cage, ball centred
HC Ceramic balls
DB Back-to-back arrangement

Angular contact thrust ball bearings for screw drives
Bearing series

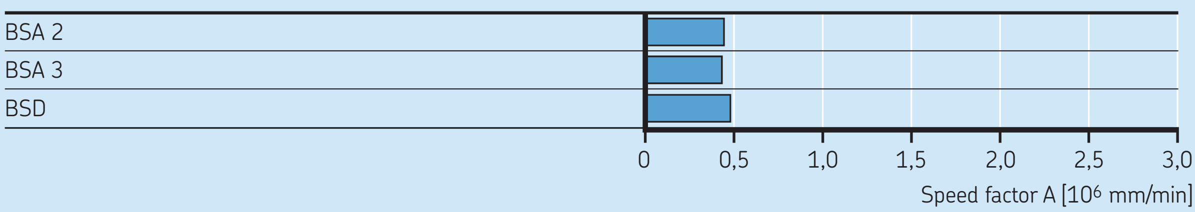
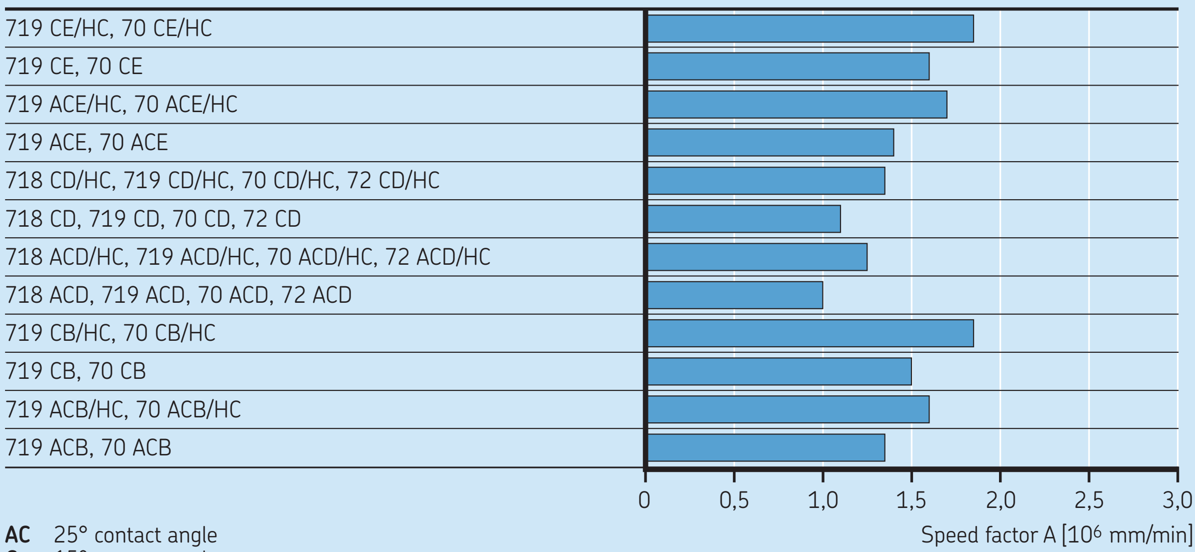


Diagram 6

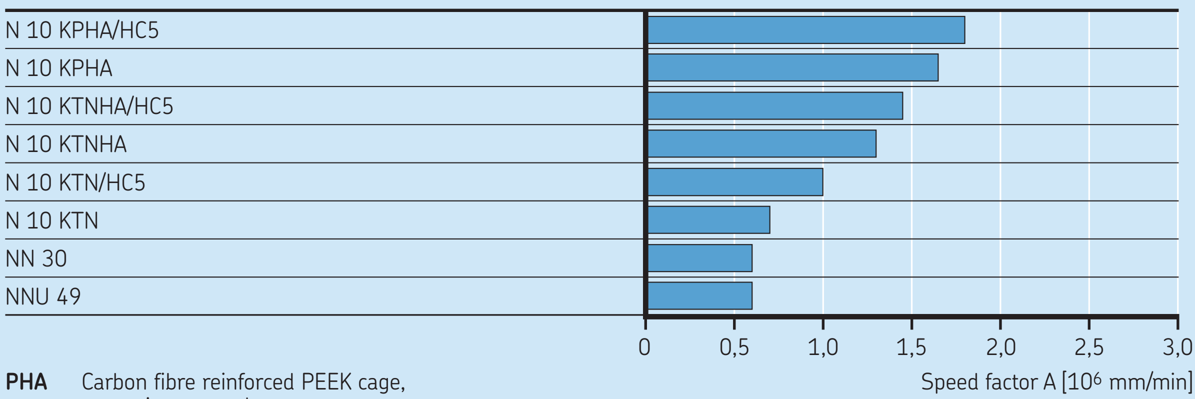
Guideline values for attainable speeds – grease lubrication

Angular contact ball bearings
Bearing series



AC 25° contact angle
C 15° contact angle
B High-speed B design
E High-speed E design
D High-capacity D design
HC Ceramic balls

Cylindrical roller bearings
Bearing series

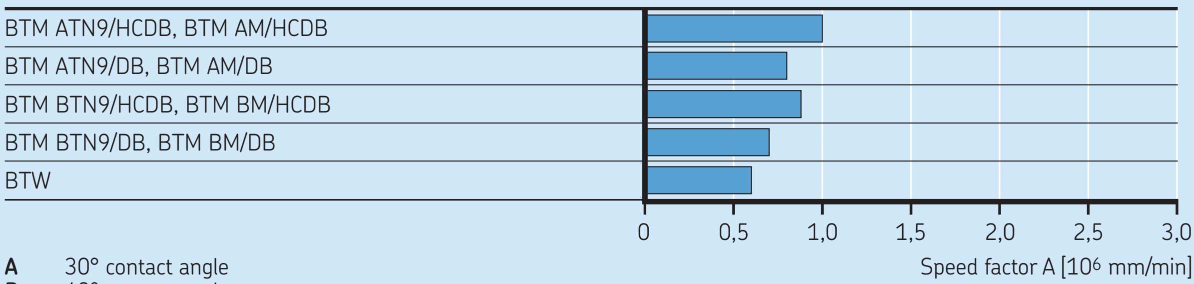


PHA Carbon fibre reinforced PEEK cage, outer ring centred
TN PA66 cage, roller centred
TNHA Glass fibre reinforced PEEK cage, outer ring centred
HC5 Ceramic rollers

cont. diagram 6

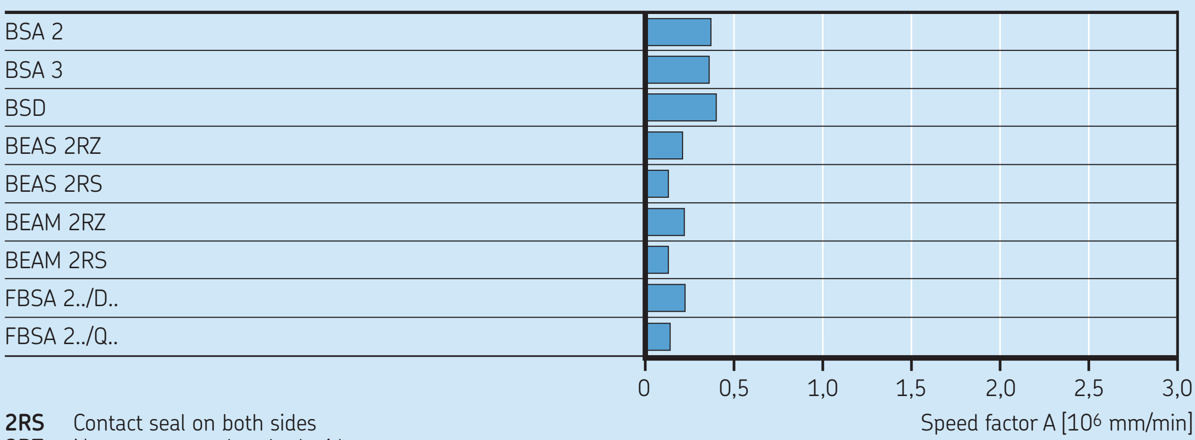
Guideline values for attainable speeds – grease lubrication

Double direction angular contact thrust ball bearings
Bearing series



A 30° contact angle
B 40° contact angle
M Machined brass cage, ball centred
TN9 Glass fibre reinforced PA66 cage, ball centred
HC Ceramic balls
DB Back-to-back arrangement

Angular contact thrust ball bearings for screw drives
Bearing series



2RS Contact seal on both sides
2RZ Non-contact seal on both sides
/D Unit with two bearings
/Q Unit with four bearings

Attainable speeds

The attainable speeds listed in the product tables are guideline values and are valid under the following conditions:

- shaft seat and housing bore machined to the recommended diameter and geometric tolerances (→ *Recommended shaft and housing fits*, **page 44**)
- light loads (P ≤ 0,05 C)
- good heat dissipation away from the bearings
- suitable lubricant and lubrication method
- light spring preload for angular contact ball bearings

The values listed in the product tables for grease lubrication can be attained using an appropriate fill of a suitable, high-quality, soft consistency grease.

The values listed in the product tables for oil-air lubrication can be adapted to apply to other oil lubrication methods. The following reduction factors should be applied:

- 0,3 to 0,4 for oil bath lubrication
- 0,95 for oil mist lubrication

Speeds in excess of the attainable speeds listed in the product tables can be achieved when an oil jet circulating oil system with an oil cooler is used.

For additional information, contact the SKF application engineering service.

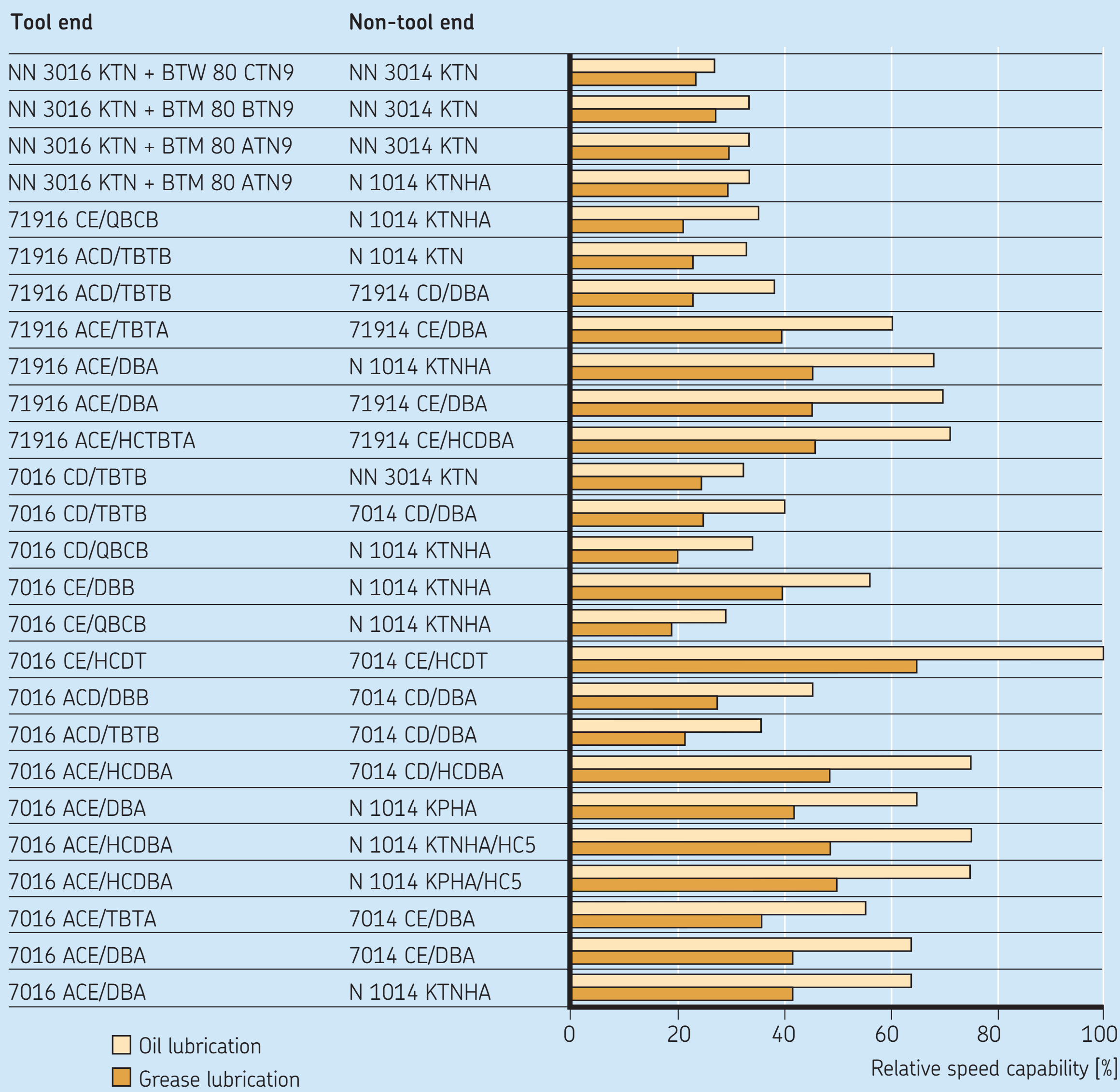
Attainable speeds for typical spindle bearing systems

A typical spindle bearing system, which can contain various bearing types, comprises a bearing arrangement on the tool end and another arrangement on the non-tool end. The arrangement on the tool end is usually the critical one. It typically uses larger bearings, forcing a higher speed factor A. **Diagram 7** provides a comparison of possible bearing systems and their relative speed capability. The comparison is based on bearings with an 80 mm bore on the tool end and 70 mm bore on the non-tool end. For details about the bearing series, refer to the designation system of:

- angular contact ball bearings (→ **page 44**)
- cylindrical roller bearings (→ **page 44**)
- double direction angular contact thrust ball bearings (→ **page 44**)

Diagram 7

Relative speed capability of typical spindle bearing systems



Angular contact ball bearings
AC 25° contact angle
C 15° contact angle
E High-speed E design
D High-capacity D design
HC Ceramic balls
DB Two bearings, back-to-back <>
DT Two bearings, tandem <<
TBT Three bearings, back-to-back and tandem <>>
QBC Four bearings, tandem back-to-back <<>>,
A Light preload
B Moderate preload

Cylindrical roller bearings
PHA Carbon fibre reinforced PEEK cage, outer ring centred
K Tapered bore
TN PA66 cage, roller centred
TNHA Glass fibre reinforced PEEK cage, outer ring centred
HC5 Ceramic rollers

Double direction angular contact thrust ball bearings
A 30° contact angle
B 40° contact angle
C 60° contact angle
TN9 Glass fibre reinforced PA66 cage, ball centred

Bearing specifics

SKF super-precision bearings are manufactured to several general specifications. Those specifications concerning dimensions, tolerances, preload or clearance and materials are described in the following. Additional information is provided in each product chapter.

Boundary dimensions

Boundary dimensions of SKF super-precision bearings follow the ISO 15 general plan for radial rolling bearings, or, in certain circumstances, conform to boundary dimensions accepted by industry.

ISO 15 general plan

The ISO 15 general plan for boundary dimensions of radial bearings contains a progressive series of standardized outside diameters for every standard bore diameter, arranged in a diameter series. Within each diameter series, different width series have also been established.

Dimension series are formed by combining the number for the width series with the number for the diameter series.

For super-precision bearings, only a limited number of dimension series are used (→ **table 3**).

Specific information about compliance to dimension standards is provided in each product chapter.

Chamfer dimensions

Minimum values for the chamfer dimensions (→ **fig. 6**) in the radial direction (r_1, r_3) and the axial direction (r_2, r_4) are listed in the product tables. These values are in accordance with the general plans of ISO 15, ISO 12043 and ISO 12044.

The appropriate maximum chamfer dimensions are in accordance with ISO 582 and are listed under *Chamfer dimension limits*.

Table 3

Diameter and width series for SKF super-precision bearings

ISO 15 dimension series Diameter series	 Width series	SKF bearing series	Bearing type
8	1	718	Angular contact ball bearing
9	1	719	Angular contact ball bearing
	4	NNU 49	Double row cylindrical roller bearing
0	1	70	Angular contact ball bearing
	1 3	N 10 NN 30	Single row cylindrical roller bearing Double row cylindrical roller bearing
	– –	BTW BTM	Double direction angular contact thrust ball bearing Double direction angular contact thrust ball bearing
2	0 0	72 BSA 2	Angular contact ball bearing Angular contact thrust ball bearing for screw drives
3	0	BSA 3	Angular contact thrust ball bearing for screw drives

Tolerances

SKF super-precision bearings are manufactured to tolerance classes similar to internationally standardized tolerance classes. Standards for rolling bearing tolerances are:

- ISO 492 for radial rolling bearings
- ISO 199 for thrust rolling bearings

For available bearing types and tolerance classes, refer to *Precision* (→ **page 47**). Actual tolerance values are listed under *Tolerances* in each product chapter.

Tolerance symbols

The tolerance symbols and their definitions are provided in **table 4** (→ **page 47**).

Chamfer dimension limits

The maximum chamfer limits (→ **fig. 7**) for the relevant minimum chamfer dimensions (→ **product tables**) are listed in **table 5** (→ **page 47**). The values are in accordance with ISO 582.

Double direction angular contact thrust ball bearings in the BTM and BTW series and single direction angular contact thrust ball bearings for screw drives in the BSA series have the same maximum chamfer dimensions as radial bearings.

Fig. 6

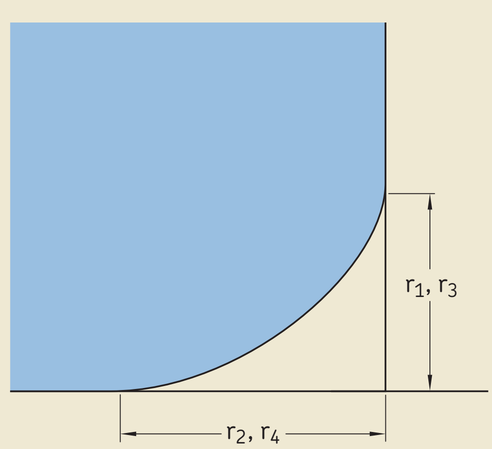


Fig. 7

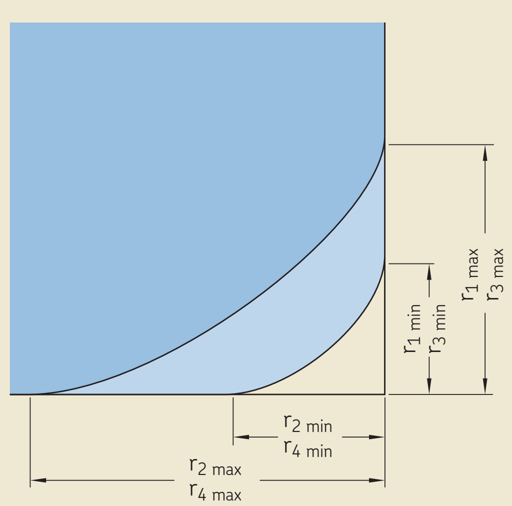


Table 4

Tolerance symbols

Tolerance symbol	Definition
	Bore diameter
d	Nominal bore diameter
d_1	Nominal diameter at the theoretical large end of a tapered bore
d_s	Single bore diameter
d_{mp}	**1** Mean bore diameter; arithmetical mean of the largest and smallest single bore diameters in one plane **2** Mean diameter at the small end of a tapered bore; arithmetical mean of the largest and smallest single diameters
Δ_{ds}	Deviation of a single bore diameter from the nominal ($\Delta_{ds} = d_s - d$)
Δ_{dmp}	Deviation of the mean bore diameter from the nominal ($\Delta_{dmp} = d_{mp} - d$)
Δ_{d1mp}	Deviation of the mean bore diameter at the theoretical large end of a tapered bore from the nominal ($\Delta_{d1mp} = d_{1mp} - d_1$)
V_{dp}	Bore diameter variation; difference between the largest and smallest single bore diameters in one plane
V_{dmp}	Mean bore diameter variation; difference between the largest and smallest mean bore diameters
	Outside diameter
D	Nominal outside diameter
D_s	Single outside diameter
D_{mp}	Mean outside diameter; arithmetical mean of the largest and smallest single outside diameters in one plane
Δ_{Ds}	Deviation of a single outside diameter from the nominal ($\Delta_{Ds} = D_s - D$)
Δ_{Dmp}	Deviation of the mean outside diameter from the nominal ($\Delta_{Dmp} = D_{mp} - D$)
V_{Dp}	Outside diameter variation; difference between the largest and smallest single outside diameters in one plane
V_{Dmp}	Mean outside diameter variation; difference between the largest and smallest mean outside diameters
	Chamfer limits
r_s	Single chamfer dimension
$r_{s\,min}$	Smallest single chamfer dimension of r_s, r_1, r_2, r_3, r_4 ...
r_1, r_3	Radial direction chamfer dimensions
r_2, r_4	Axial direction chamfer dimensions

cont. table 4

Tolerance symbols

Tolerance symbol	Definition
	Width or height
B, C	Nominal width of an inner ring and outer ring, respectively
B_s, C_s	Single width of an inner ring and outer ring, respectively
B_{1s}, C_{1s}	Single width of an inner ring and outer ring, respectively, of a bearing specifically manufactured for paired mounting[1)]
Δ_{Bs}, Δ_{Cs}	Deviation of a single inner ring width or single outer ring width from the nominal ($\Delta_{Bs} = B_s - B$; $\Delta_{Cs} = C_s - C$)
Δ_{B1s}, Δ_{C1s}	Deviation of a single inner ring width or single outer ring width, of a bearing specifically manufactured for paired mounting[1)], from the nominal ($\Delta_{B1s} = B_{1s} - B_1$; $\Delta_{C1s} = C_{1s} - C_1$)
V_{Bs}, V_{Cs}	Ring width variation; difference between the largest and smallest single widths of an inner ring and outer ring, respectively
T	Nominal height H of a thrust bearing
2C	Total nominal height of outer ring of a thrust bearing
T_s	Single height
Δ_{Ts}	Deviation of the height of a single direction thrust bearing from the nominal
Δ_{T2s}	Deviation of the height of a double direction thrust bearing from the nominal
H_s	Single bearing height
H_{1s}	Single cross section height
Δ_{Hs}	Deviation of a single bearing height
Δ_{H1s}	Deviation of a single cross section height
	Running accuracy
K_{ia}, K_{ea}	Radial run-out of an inner ring and outer ring, respectively, of an assembled bearing
S_d	Side face run-out with reference to the bore (of an inner ring)
S_D	Outside inclination variation; variation in inclination of the outside cylindrical surface to the outer ring side face
S_{ia}, S_{ea}	Axial run-out of an inner ring and outer ring, respectively, of an assembled bearing
S_i	Thickness variation, measured from the middle of the raceway to the back (seat) face of the shaft washer (axial run-out)
S_e	Thickness variation, measured from the middle of the raceway to the back (seat) face of the housing washer (axial run-out)

[1)] Does not apply to universally matchable angular contact ball bearings.

Table 5

Maximum chamfer limits

Minimum single chamfer dimension	Nominal bearing bore diameter		Maximum chamfer dimensions	
			Radial bearings	
$r_{s\,min}$	d over	incl.	$r_{1,3}$ max.	$r_{2,4}$ max.
mm	mm		mm	
0,15	–	–	0,3	0,6
0,2	–	–	0,5	0,8
0,3	–	40	0,6	1
	40	–	0,8	1
0,6	–	40	1	2
	40	–	1,3	2
1	–	50	1,5	3
	50	–	1,9	3
1,1	–	120	2	3,5
	120	–	2,5	4
1,5	–	120	2,3	4
	120	–	3	5
2	–	80	3	4,5
	80	220	3,5	5
	220	–	3,5	6
2,1	–	280	4	6,5
	280	–	4,5	7
2,5	–	100	3,8	6
	100	280	4,5	6
	280	–	5	7
3	–	280	5	8
	280	–	5,5	8
4	–	–	6,5	9
5	–	–	8	10
6	–	–	10	13
7,5	–	–	12,5	17

Preload and internal clearance

Angular contact ball and thrust ball bearings

SKF super-precision universally matchable angular contact ball bearings, sets of angular contact ball bearings and angular contact thrust ball bearings are manufactured so that a predetermined amount of preload results when assembled immediately adjacent to each other. The preload values listed in the relevant product chapter represent the axial force required to press together the rings or washers of new unmounted bearings.

When mounted, and further when in operation, the preload will change. The main reasons are:

- An interference fit in the housing contracts the outer ring raceway while an interference fit on the shaft expands the inner ring raceway.
- Pressing the inner rings or shaft washers of bearings or bearing sets against each other causes deformation of the rings or washers. Especially when mounted on a solid shaft, the bore diameter cannot decrease and the lateral expansion increases preload.
- Differences in thermal expansion of the bearing rings or washers, and mating components typically increase preload in operation.

For details about the preload in unmounted bearings and ways to estimate the preload in operation, refer to the relevant product chapter.

Cylindrical roller bearings

SKF super-precision cylindrical roller bearings are manufactured with radial internal clearance. Radial internal clearance is defined as the total distance through which one bearing ring can be moved relative to the other in the radial direction.

It is necessary to distinguish between initial internal clearance in the bearing prior to mounting and operating internal clearance, which applies to a bearing in operation that has reached a stable temperature.

In almost all applications, the initial clearance in a bearing is greater than its operating clearance. The difference can be attributed to interference fits on the shaft and/or in the housing, combined with thermal expansion of the bearing and mating components. In some cases, these factors can reduce clearance enough to create radial preload in the bearing.

For details about the internal clearance in new bearings prior to mounting and recommendations about clearance or preload in operation, refer to *Radial internal clearance* (→ **page 51**).

Materials

The materials from which bearing components are made, determine, to a large extent, the performance and reliability of the bearing. For the bearing rings and rolling elements, typical considerations include hardness, fatigue resistance in the rolling contact area, under clean or contaminated lubrication conditions, and the dimensional stability of the bearing components. For the cage, considerations include friction, strain, temperatures, inertial forces, and in some cases, the chemical action of certain lubricants, lubricant additives, solvents, coolants and refrigerants.

Seals integrated in rolling bearings can also have a considerable impact on the performance and reliability of the bearings. Their materials must be able to withstand oxidation (ageing), wear and chemical attack over a wide temperature range.

SKF has the competence and facilities to provide a variety of materials, processes and coatings. Therefore, SKF application engineers can assist in selecting the bearing, cage and seal materials that best meet the needs of a particular application.

Materials for bearing rings and rolling elements

Standard bearing steel

The steel used for standard SKF super-precision bearings is an extremely clean, through-hardened carbon chromium steel (100Cr6), containing approximately 1% carbon and 1,5% chromium, in accordance with ISO 683-17. The composition of this bearing steel provides an optimum balance between manufacturing and application performance. This steel normally undergoes a martensitic or bainitic heat treatment to obtain a hardness between 58 and 65 HRC.

SKF super-precision bearings are heat stabilized up to 150 °C (*300 °F*). But other factors like cage material, seal material or lubricant might limit the permissible operating temperature.

For information about material properties, refer to **table 6** (→ **page 51**).

NitroMax steel (high-nitrogen stainless steel)

NitroMax is a new generation of ultra clean, high nitrogen stainless steel. When compared to standard carbon chromium bearing steel (100Cr6), NitroMax steel provides the following:

- enhanced fatigue/wear resistance under poor lubrication conditions ($\kappa < 1$)
- higher degree of fracture toughness
- superior corrosion resistance

Each of these characteristics is beneficial when speed is higher than A = 1 to $1{,}15 \times 10^6$ mm/min.

Enhanced fatigue/wear resistance enables the bearings to operate longer under all lubrication conditions and particularly those of thin-film operation that result from kinematic lubricant starvation at very high speeds.

Increased fracture toughness reduces the risk of inner ring fracture due to increased tensile hoop stresses caused by centrifugal forces when operating at very high speeds.

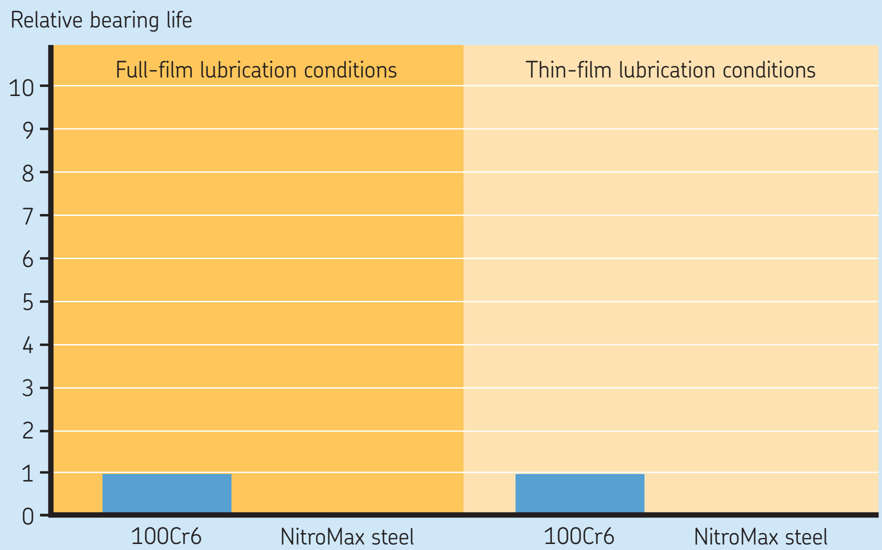
Compared with bearings made of carbon chromium steel, this ultra-clean, high nitrogen content steel can significantly extend bearing service life when operating under full-film lubrication conditions ($\kappa \geq 1$). Under thin-film lubrication conditions, this life extending effect is even more significant (→ **diagram 8**).

NitroMax steel is superior not only to conventional carbon chromium bearing steels but also to other high-nitrogen stainless steels. To illustrate why this is the case, it is necessary to understand the way that nitrogen influences the microstructure of the steel and how this is optimized during heat treatment.

When carbon chromium steel is heat treated, the process produces large, brittle chromium and chromium-molybdenum carbides that deplete the surrounding steel matrix of chromium and molybdenum, thereby reducing its corrosion pitting resistance. On the other hand, when NitroMax steel is hardened

Diagram 8

Relative life of hybrid bearings with NitroMax steel rings



$$\text{Relative bearing life} = \frac{L_{10}\ \text{test life for hybrid bearings with NitroMax steel rings}}{L_{10}\ \text{reference life for hybrid bearings with 100Cr6 rings}}$$

Test conditions:
κ = 2,72 for full-film lubrication conditions
κ = 0,1 for thin-film lubrication conditions

and tempered, small, fine chromium nitrides are formed (→ **fig. 8**). This occurs because when the nitrogen partly replaces the carbon in the steel alloy, a much higher content of chromium is dissolved in the steel matrix. The resulting, smaller chromium-depleted zones around the nitrides make NitroMax steel much more corrosion resistant (→ **fig. 9**).

The enhanced fatigue strength of NitroMax steel is associated with its coherent microstructure and fine distribution of chromium nitride precipitates with few, if any, undissolved secondary carbides in the microstructure. The fineness of the NitroMax structure compares favourably to the standard bearing steel 100Cr6, which helps in explaining the superior performance of the NitroMax steel structure. High impact toughness, dimensional stability, and hardness (> 58 HRC) result from the final quenching and tempering stages of heat treatment.

Another benefit of NitroMax steel is that it has a lower coefficient of thermal expansion than 100Cr6. This benefit, when paired with the extremely low coefficient of thermal expansion of ceramic rolling elements, used as standard in SKF bearings with NitroMax steel rings, enables bearings combining the two materials to be less sensitive to temperature differences between the inner and outer rings. The level of preload therefore remains much more stable even over the extremes of operating conditions, resulting in reduced frictional losses, lower operating temperatures and extended grease service life.

Fig. 8

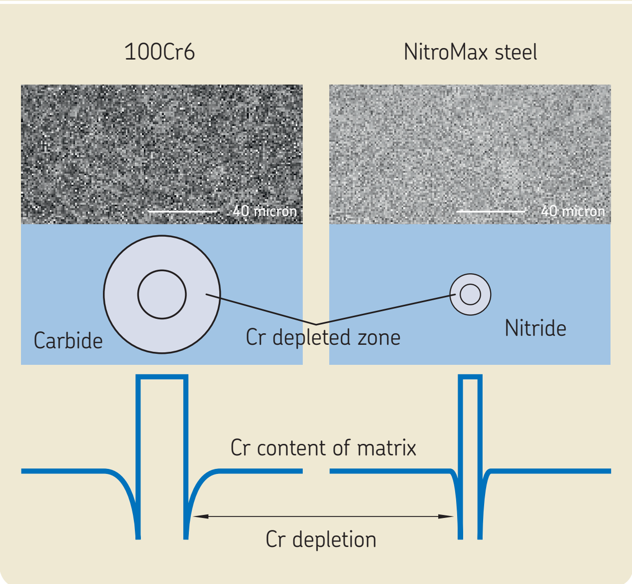
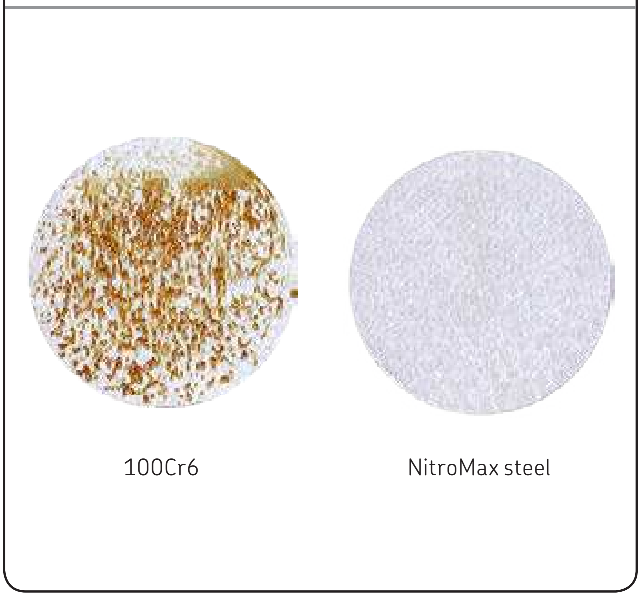


Fig. 9



Ceramics

The ceramic material used for rolling elements in SKF super-precision bearings is a bearing grade silicon nitride in accordance with ISO 26602. It consists of fine elongated grains of beta-silicon nitride in a glassy phase matrix. It provides a combination of favourable properties especially for high-speed bearings:

- high hardness
- high modulus of elasticity
- low density
- low coefficient of thermal expansion
- high electrical resistivity
- low dielectric constant
- no response to magnetic fields

For information about material properties, refer to **table 6**.

Bearings with steel rings and ceramic rolling elements are called hybrid bearings.

Table 6

Comparison of the material properties of bearing grade silicon nitride and bearing steel 100Cr6

Material properties	Bearing grade silicon nitride	Bearing steel
Mechanical properties		
Density [g/cm^3]	3,2	7,9
Hardness	1 600 HV10	700 HV10
Modulus of elasticity [kN/mm^2]	310	210
Thermal expansion [10^{-6}/K]	3	12
Electrical properties (at 1 MHz)		
Electrical resistivity [Ωm]	10^{12} (Insulator)	$0,4 \times 10^{-6}$ (Conductor)
Dielectric strength [kV/mm]	15	–
Relative dielectric constant	8	–

SKF

Cage materials

Phenolic resin

Cotton fabric reinforced phenolic resin is a lightweight material. Cages made of this material can withstand heavy inertial forces and operating temperatures up to 120 °C *(250 °F)*. The material tends to absorb oil, assisting the lubrication of the cage / rolling element contact and providing a safety margin for run down, should there be an interruption of lubricant supply.

Cotton fabric reinforced phenolic resin is the standard cage material for super-precision angular contact ball bearings.

Polyamide 66

Polyamide 66 (PA66), with or without glass fibre reinforcement, is characterized by a favourable combination of strength and elasticity. Due to its excellent sliding properties on lubricated steel surfaces and the superior finish of the contact surfaces, PA66 cages reduce friction, frictional heat and wear. PA66 can be used at operating temperatures up to 120 °C *(250 °F)*. However, some synthetic oils and greases with a synthetic oil base and lubricants containing EP additives, when used at high temperatures, can have a detrimental effect on PA66 cages. For information about the suitability of cages, refer to *Cages* and *Cage materials* in the SKF catalogue *Rolling bearings*, or visit skf.com.

PA66 is the standard cage material for many super-precision cylindrical roller bearings and angular contact thrust ball bearings.

Polyetheretherketone

Glass or carbon fibre reinforced polyetheretherketone (PEEK) is popular for demanding applications where there are either high speeds or high temperatures or a need for chemical resistance. The maximum temperature for high-speed use is limited to 150 °C *(300 °F)* as this is the softening temperature of the polymer. The material does not show signs of ageing by temperature or oil additives up to 200 °C *(390 °F)*.

PEEK is the standard cage material for some super-precision angular contact ball and for high-speed design cylindrical roller bearings.

Brass

Brass is unaffected by most common bearing lubricants, including synthetic oils and greases, and can be cleaned using normal organic solvents. Brass cages can be used at operating temperatures up to 250 °C *(480 °F)*.

Machined brass cages are used in a number of super-precision double row cylindrical roller bearings and double direction angular contact thrust ball bearings and are standard for large super-precision angular contact ball bearings ($d \geq 300$ mm).

Other cage materials

In addition to the materials described above, SKF super-precision bearings for special applications can be fitted with cages made of other engineered polymers, light alloys or silver-plated steel. For information about alternative cage materials, contact the SKF application engineering service.

Seal materials

Seals integrated in SKF super-precision bearings are typically made of sheet steel reinforced elastomers.

Acrylonitrile-butadiene rubber

Acrylonitrile-butadiene rubber (NBR) is the "universal" seal material. This copolymer, manufactured from acrylonitrile and butadiene, has good resistance to the following media:

- most mineral oils and greases with a mineral oil base
- normal fuels, such as petrol, diesel and light heating oils
- animal and vegetable oils and fats
- hot water

The permissible operating temperature range is –40 to +100 °C *(–40 to +210 °F)*. The seal lip can tolerate dry running within this temperature range for short periods. Temperatures up to 120 °C *(250 °F)* can be tolerated for brief periods. At higher temperatures, the material hardens.

Fluoro rubber

Fluoro rubbers (FKM) are characterized by their high thermal and chemical resistance. Their resistance to ageing and ozone is very good and their gas permeability is very low. They have exceptionally good wear characteristics even under harsh environmental conditions. The permissible operating temperature range is –30 to +230 °C *(–20 to +445 °F)*. The seal lip can tolerate dry running within this temperature range for short periods.

FKM is resistant to oils and hydraulic fluids, fuels and lubricants, mineral acids and aliphatic as well as aromatic hydrocarbons which would cause seals made of other materials to fail. FKM should not be used in the presence of esters, ethers, ketones, certain amines and hot anhydrous hydrofluorides.

Seals made of FKM exposed to an open flame or temperatures above 300 °C *(570 °F)* are a health and environmental hazard! They remain dangerous even after they have cooled. Read and follow the safety precautions (→ **WARNING**).

WARNING: HAZARDOUS FUMES

Safety precautions for fluoro rubber

Fluoro rubber (FKM) is very stable and harmless up to normal operating temperatures of 200 °C *(390 °F)*. However, if exposed to temperatures above 300 °C *(570 °F)*, such as fire or the open flame of a cutting torch, FKM seals give off hazardous fumes. These fumes can be harmful if inhaled, as well as if they contact the eyes. In addition, once the seals have been heated to such temperatures, they are dangerous to handle even after they have cooled. Therefore, they should never come in contact with the skin.

If it is necessary to handle bearings with seals that have been subjected to high temperatures, such as when dismounting the bearing, the following safety precautions should be observed:

- Always wear protective goggles, gloves and appropriate breathing apparatus.
- Place all of the remains of the seals in an airtight plastic container marked with a symbol for "material will etch".
- Follow the safety precautions in the material safety data sheet (MSDS).

If there is contact with the seals, wash hands with soap and plenty of water and, if contact has been made with the eyes, flush the eyes with plenty of water and consult a doctor immediately. If the fumes have been inhaled, consult a doctor immediately.

The user is responsible for the correct use of the product during its service life and its proper disposal. SKF takes no responsibility for the improper handling of FKM seals, or for any injury resulting from their use.

Lubrication

Selecting a suitable lubricant and lubrication method for a super-precision bearing arrangement depends primarily on the operating conditions such as the required speed or permissible operating temperature. However, other factors like vibration, loads and the lubrication of adjacent components, such as gears, can also influence the selection process.

To generate an adequate hydrodynamic film between the rolling elements and raceways, only a very small amount of lubricant is required. Therefore, using grease as a lubricant for spindle bearing arrangements is becoming increasingly popular. With a properly designed grease lubrication system, the hydrodynamic frictional losses are low and operating temperatures can be kept to a minimum. However, where speeds are very high, grease service life may be too short and oil lubrication may be required. Typically, oil lubrication is accomplished with an oil-air system or an oil circulation system which can also provide the added benefit of cooling.

Grease lubrication

Grease lubricated bearing arrangements are suitable for a wide range of speeds. Lubricating super-precision bearings with suitable quantities of good quality grease permits relatively high speed operation without an excessive rise in temperature.

The use of grease also means that the design of a bearing arrangement can be relatively simple because grease is more easily retained in a bearing arrangement than oil, particularly where shafts are inclined or vertical. Grease can also contribute to sealing the arrangement against solid and liquid contaminants as well as moisture.

Selecting grease

In most spindle applications with super-precision bearings, grease with a mineral base oil and lithium thickener is suitable. These greases adhere well to the bearing surfaces and can be used in applications where temperatures range from –30 to +110 °C (*–20 to +230 °F*). For applications with high speeds and high temperatures or where long service life is required, grease with a synthetic base oil e.g. SKF diester oil based grease LGLT 2 has been proven to be effective.

For angular contact thrust ball bearings for screw drives, grease with an ester or mineral base oil and calcium complex thickener can be used under most operating conditions.

Alternative greases may be required under any of the following conditions:

- operating temperatures < 10 °C (*50 °F*) or > 100 °C (*210 °F*)
- bearing speed is very high or very low
- static operation, infrequent rotation or oscillation
- bearings are subjected to vibration
- bearings are subjected to heavy loads or shock loads
- water resistance is important
- screw drive bearings at low speeds, under heavy loads or exposed to vibration should be lubricated with a lithium soap grease with a mineral base oil and EP additives like SKF LGEP 2

An appropriate grease selection process comprises four steps.

1. Select the consistency grade

Greases are divided into various consistency grades in accordance with the National Lubricating Grease Institute (NLGI). Greases with a high consistency, i.e. stiff greases, are assigned high NLGI grades, while those with low consistency, i.e. soft greases, are assigned low NLGI grades. In rolling bearing applications, three consistency grades are recommended:

- The most common greases, used in normal bearing applications, have an NLGI grade of 2.
- Low consistency rolling bearing greases, classified as NLGI 1 greases, are preferred for low ambient temperatures and oscillating applications.
- NLGI 3 greases are recommended for large bearings, vertical shaft arrangements, high ambient temperatures or the presence of vibration.

2. Determine the required base oil viscosity

For detailed information about calculating the required base oil viscosity, refer to *Lubrication conditions – the viscosity ratio κ* in the SKF catalogue *Rolling bearings* or at skf.com. The graphs in this catalogue are based on the elasto-hydrodynamic theory of lubrication (EHL) with full-film conditions.

It has been found, however, that when using greases containing very low or very high viscosity base oils, a thinner oil film than that predicted by EHL theories results. Therefore, when using the graphs to determine the required base oil viscosity for grease lubricated super-precision bearings, corrections may be necessary. From practical experience, determine the required viscosity ν at reference temperature 40 °C *(150 °F)* and then adjust as follows:

- $\nu \leq 20$ mm²/s → multiply the viscosity by a factor of 1 to 2
  In this low range, the viscosity of the oil is too thin to form a sufficiently thick oil film.
- 20 mm²/s $< \nu \leq 250$ mm²/s → no correction factor is used
- $\nu > 250$ mm²/s → contact the SKF application engineering service

Calculations can also be made using the SKF program, Viscosity, available online at skf.com/bearingcalculator.

High viscosity greases increase friction and heat generated by the bearing but may be necessary, for example, for ball screw support bearings in low-speed applications or in applications where there is a risk of false brinelling.

3. Verify the presence of EP additives

Grease with EP additives may be appropriate if super-precision bearings are subjected to any of the following conditions:

- very heavy loads (P > 0,15 C)
- shock loads
- low speeds
- periods of static loading
- frequent starts and stops during a work cycle

Lubricants with EP additives should only be used when necessary and always within their operating temperature range. Some EP additives are not compatible with bearing materials particularly at higher temperatures. For additional information, contact the SKF application engineering service.

4. Check additional requirements

In some applications, operating conditions may put additional requirements on the grease, requiring it to have unique characteristics. The following recommendations are provided as guidelines:

- For superior resistance to water wash-out, consider grease with a calcium thickener over a lithium thickener.
- For good rust protection, select an appropriate additive.
- If there are high vibration levels, choose grease with a high mechanical stability.

To select the appropriate grease for a specific bearing type and application, the grease selection program, SKF LubeSelect, available online at skf.com/lubrication, can be used.

Initial grease fill

Super-precision bearings operating at high speeds should have less than 30% of the free space in the bearings filled with grease.

Open angular contact thrust ball bearings for screw drives should be lubricated with a grease quantity that fills ~ 25 to 35% of the free space in the bearing.

Freshly greased bearings should be operated at low speeds during the running-in period (→ *Running-in of grease lubricated bearings*, **page 101**). This enables excess grease to be displaced and the remainder to be evenly distributed within the bearing. If this running-in phase is neglected, there is a risk that temperature peaks can lead to premature bearing failure.

The initial grease fill depends on the bearing type, series and size as well as the speed factor A.

$A = n\, d_m$

where
A = speed factor [mm/min]
d_m = bearing mean diameter [mm]
= 0,5 (d + D)
n = rotational speed [r/min]

The initial grease fill for open bearings can be estimated using

$G = K\, G_{ref}$

where
G = initial grease fill [cm^3]
G_{ref} = reference grease quantity [cm^3]
– for angular contact ball bearings → **table 22**, **page 101**
– for cylindrical roller bearings → **table 23**, **page 101**
– for double direction angular contact thrust ball bearings → **table 24**, **page 101**
– for single direction angular contact thrust ball bearings for screw drives → **table 25**, **page 101**
K = a calculation factor dependent on the bearing type and the speed factor A (→ **diagram 14**, **page 101**)

Sealed bearings are filled with a high grade, low viscosity grease that fills ~ 15% of the free space in the bearing. They are considered to be relubrication-free under normal operating conditions. The grease is characterized by:

- high-speed capability
- excellent resistance to ageing
- very good rust inhibiting properties

The technical specifications of the grease are listed in **table 26**, **page 101**.

Table 22

Reference grease quantity for angular contact ball bearings

Bore diameter d	Size	Reference grease quantity G_{ref} for bearings in the series 718 CD 718 ACD	719 CD 719 ACD	719 CE 719 ACE	719 CB 719 ACB	70 CD 70 ACD	70 CE 70 ACE	70 CB 70 ACB	72 CD 72 ACD
mm	–	cm^3							
6	**6**	–	–	–	–	0,09	0,09	–	–
7	**7**	–	–	–	–	0,12	0,11	–	0,16
8	**8**	–	–	0,09	–	0,15	0,17	–	0,23
9	**9**	–	–	0,09	–	0,18	0,19	–	0,26
10	**00**	0,06	0,12	0,1	–	0,24	0,28	–	0,36
12	**01**	0,07	0,12	0,1	–	0,27	0,31	–	0,51
15	**02**	0,08	0,21	0,2	–	0,39	0,5	–	0,73
17	**03**	0,09	0,24	0,2	–	0,54	0,68	–	1
20	**04**	0,18	0,45	0,5	–	0,9	1,1	–	1,5
25	**05**	0,21	0,54	0,6	–	1	1,3	–	1,9
30	**06**	0,24	0,63	0,6	0,72	1,6	1,7	1,4	2,8
35	**07**	0,28	0,93	0,8	0,96	2	2,4	1,8	3,9
40	**08**	0,31	1,4	1,4	1,4	2,4	2,8	2,2	4,7
45	**09**	0,36	1,6	1,5	1,8	3,3	3,4	2,9	5,9
50	**10**	0,5	1,7	1,7	1,9	3,6	4,1	3,1	6,7
55	**11**	0,88	2,5	2,3	2,6	5,1	5	4,7	8,6
60	**12**	1,2	2,7	2,5	2,8	5,4	5,3	5	10
65	**13**	1,3	2,9	2,6	3	5,7	6,2	5,5	12
70	**14**	1,4	4,5	4,3	4,5	8,1	8,2	7,3	14
75	**15**	1,5	5,1	4,5	4,8	8,4	8,6	7,7	15
80	**16**	1,6	5,1	4,8	5,3	11	12	10	18
85	**17**	2,7	7,2	7	6,5	12	12	11	22
90	**18**	2,9	7,5	7	7,4	15	14	14	28
95	**19**	3,1	7,8	7,3	7,5	16	17	15	34
100	**20**	3,2	11	10	10	16	17	15	41
105	**21**	4	11	–	–	20	–	–	48
110	**22**	5,1	11	11	11	26	23	22	54
120	**24**	5,5	15	15	14	27	28	24	69
130	**26**	9,3	20	–	–	42	–	–	72
140	**28**	9,9	22	–	–	45	–	–	84
150	**30**	13	33	–	–	54	–	–	–
160	**32**	14	33	–	–	66	–	–	–
170	**34**	–	36	–	–	84	–	–	–
180	**36**	–	54	–	–	111	–	–	–
190	**38**	–	57	–	–	114	–	–	–
200	**40**	–	81	–	–	153	–	–	–
220	**44**	–	84	–	–	201	–	–	–
240	**48**	–	93	–	–	216	–	–	–
260	**52**	–	150	–	–	324	–	–	–
280	**56**	–	159	–	–	–	–	–	–
300	**60**	–	265	–	–	–	–	–	–
320	**64**	–	282	–	–	–	–	–	–
340	**68**	–	294	–	–	–	–	–	–
360	**72**	–	313	–	–	–	–	–	–

Values refer to 30% filling grade.

Table 23

Reference grease quantity for cylindrical roller bearings

Bore diameter	Size	Reference grease quantity G_{ref} for bearings in the series				
d		N 10 TN	N 10 TNHA	N 10 PHA	NN 30[1]	NNU 49[1]
mm	–	cm³				
25	**05**	–	–	–	0,9	–
30	**06**	–	–	–	1	–
35	**07**	–	–	–	1,9	–
40	**08**	2,3	2,5	3,1	1,8	–
45	**09**	2,9	3,2	4,1	2,4	–
50	**10**	3,2	3,5	4,4	2,7	–
55	**11**	4,4	4,9	6,1	3,6	–
60	**12**	4,7	5,2	6,5	3,8	–
65	**13**	5	5,5	6,9	4,1	–
70	**14**	6,7	7,2	9,2	5,9	–
75	**15**	7,1	7,7	9,6	6,3	–
80	**16**	9	9,8	13	8,3	–
85	**17**	9,2	10	–	8,4	–
90	**18**	12	14	–	11	–
95	**19**	13	14	–	12	–
100	**20**	13	14	–	12	13
105	**21**	18	18	–	17	15
110	**22**	21	21	–	20	17
120	**24**	22	34	–	23	27
130	**26**	–	–	–	34	31
140	**28**	–	–	–	52	45
150	**30**	–	–	–	63	57
160	**32**	–	–	–	78	63
170	**34**	–	–	–	105	72
180	**36**	–	–	–	138	81
190	**38**	–	–	–	144	85
200	**40**	–	–	–	191	117
220	**44**	–	–	–	260	150
240	**48**	–	–	–	288	171
260	**52**	–	–	–	392	366
280	**56**	–	–	–	420	384

Values refer to 30% filling grade.
[1] For bearings in the NN 30 and NNU 49 series with d > 280 mm, contact the SKF application engineering service.

Table 24

Reference grease quantity for double direction angular contact thrust ball bearings

Bore diameter d	Size	Reference grease quantity G_{ref} for bearings in the series BTW	BTM
mm	–	cm^3	
35	**07**	1,9	–
40	**08**	2,5	–
45	**09**	3,1	–
50	**10**	3,3	–
55	**11**	4,8	–
60	**12**	5,2	7,8
65	**13**	5,6	8,4
70	**14**	7,4	11
75	**15**	7,8	11,8
80	**16**	11	16
85	**17**	11	16,8
90	**18**	14	22
95	**19**	15	22
100	**20**	16	22
105	**21**	–	–
110	**22**	27	38
120	**24**	28	40
130	**26**	40	58
140	**28**	45	62
150	**30**	56	80
160	**32**	67	94
170	**34**	90	126
180	**36**	117	160
190	**38**	122	–
200	**40**	157	–

Values refer to 30% filling grade.

Table 25

Reference grease quantity for single direction angular contact thrust ball bearings for screw drives

Designation	Reference grease quantity G_{ref}
–	cm^3
BSA 201 C	0,4
BSA 202 C	0,5
BSA 203 C	0,7
BSA 204 C	1,2
BSA 205 C	1,5
BSA 206 C	2,2
BSA 207 C	3
BSA 208 C	3,7
BSA 209 C	4,5
BSA 210 C	5,2
BSA 212 C	8,5
BSA 215 C	11,1
BSA 305 C	2,4
BSA 306 C	2,1
BSA 307 C	4,2
BSA 308 C	6,4
BSD 2047 C	1,4
BSD 2562 C	2
BSD 3062 C	2
BSD 3572 C	2,5
BSD 4072 C	2,5
BSD 4090 C	5,2
BSD 45100 C	5,9
BSD 4575 C	2,7
BSD 50100 C	6,5
BSD 55100 C	6,5
BSD 55120 C	7,5
BSD 60120 C	7,5

Values refer to 35% filling grade.

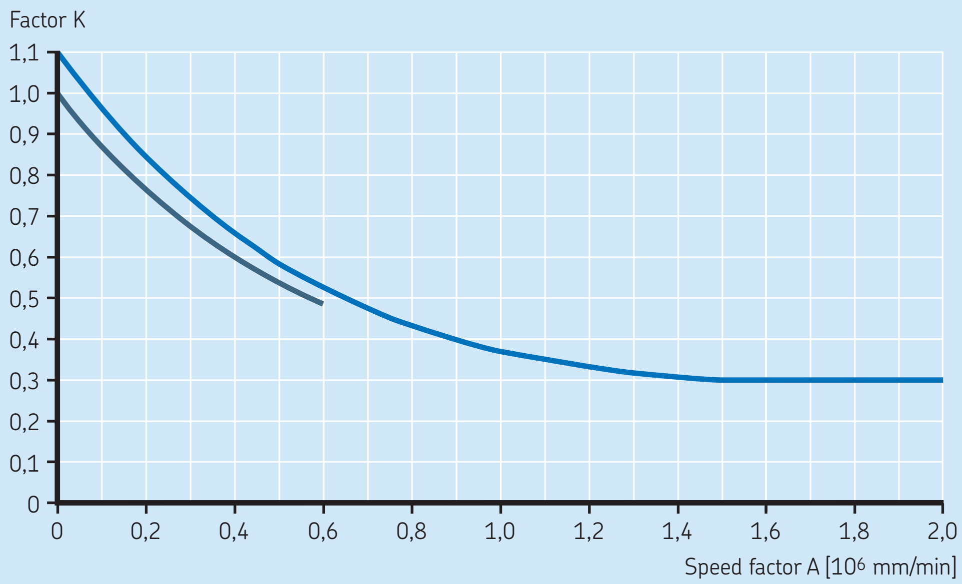
Table 26

Technical specifications of the grease in sealed bearings

Properties	Grease specification
Thickener	Special lithium soap
Base oil type	Ester/PAO
NLGI consistency class	2
Temperature range	
[°C]	–40 to +120
[°F]	*–40 to +250*
Kinematic viscosity [mm^2/s]	
at 40 °C *(105 °F)*	25
at 100 °C *(210 °F)*	6

Diagram 14

Factor K for initial grease fill estimation



Angular contact ball bearings, cylindrical roller bearings, double direction angular contact thrust ball bearings

Angular contact thrust ball bearings for screw drives

Speed factor limits depend on the bearing type and series.

Applying grease

When greasing bearings, the grease should be distributed evenly in the free space between the rolling elements and bearing rings. The bearings should be turned by hand until all internal surfaces are covered.

Small angular contact thrust ball bearings for screw drives often require very small quantities of grease. When a very small grease quantity has to be applied, the bearing should be immersed in a grease solution (3 to 5% grease in a solvent) first. After the solvent has drained and evaporated, grease can be applied. Immersing the bearing in a grease solution ensures that all surfaces are covered with a thin layer of the lubricant.

Grease service life and relubrication intervals

There are several interactive factors influencing grease service life, the effects of which are extremely complex to calculate for any particular application. It is, therefore, standard practice to use estimated grease service life based on empirical data.

The estimated relubrication interval for grease lubricated bearings is based on the estimated grease service life. Various methods can be used, however, SKF recommends the following to assist in making the best estimate for super-precision bearings.

Diagram 15 shows the relubrication interval t_f for super-precision bearings in various executions. The diagram is valid under the following conditions:

- bearing with steel rolling elements
- horizontal shaft
- operating temperature ≤ 70 °C *(160 °F)*
- high-quality grease with a lithium thickener
- relubrication interval at the end of which 90% of the bearings are still reliably lubricated (L_{10} life)

If necessary, the relubrication interval obtained from **diagram 15** should be adjusted by correction factors depending on the bearing type, variant and operating conditions.

The relubrication interval can be estimated using

$$T_{relub} = t_f \, C_1 \, C_2 \dots C_8$$

The curves for angular contact ball and thrust ball bearings are for single bearings only. Values for matched sets should be adjusted according to the arrangement, number of bearings in the set and preload, by multiplying the relubrication interval by factor C_1 (→ **table 27**, **page 106**). When sets comprising more than four bearings are used, contact the SKF application engineering service.

For hybrid bearings, the estimated grease service life can be revised by multiplying the calculated value for a bearing with steel rolling elements by the correction factor C_2 (→ **table 28**, **page 106**).

Depending on the operating conditions, the relubrication interval should be multiplied by each of the relevant correction factors from C_3 to C_8 (→ **table 29**, **page 106**).

Other conditions, not included here, such as the presence of water, cutting fluids and vibration may also affect grease service life.

Machine tool spindles often operate under conditions of varying speed, load and operating temperature. If the speed/load spectrum is known and is sufficiently cyclic, the relubrication interval for each speed/load interval can be estimated as above. A relubrication interval for the total duty cycle can then be calculated from

$$t_{f\,tot} = \frac{100}{\Sigma \, (a_i / t_{fi})}$$

where
$t_{f\,tot}$ = total relubrication interval [hours]
a_i = part of the total cycle time at speed n_i [%]
t_{fi} = relubrication interval at speed n_i [hours]

Diagram 15

Grease relubrication interval guidelines

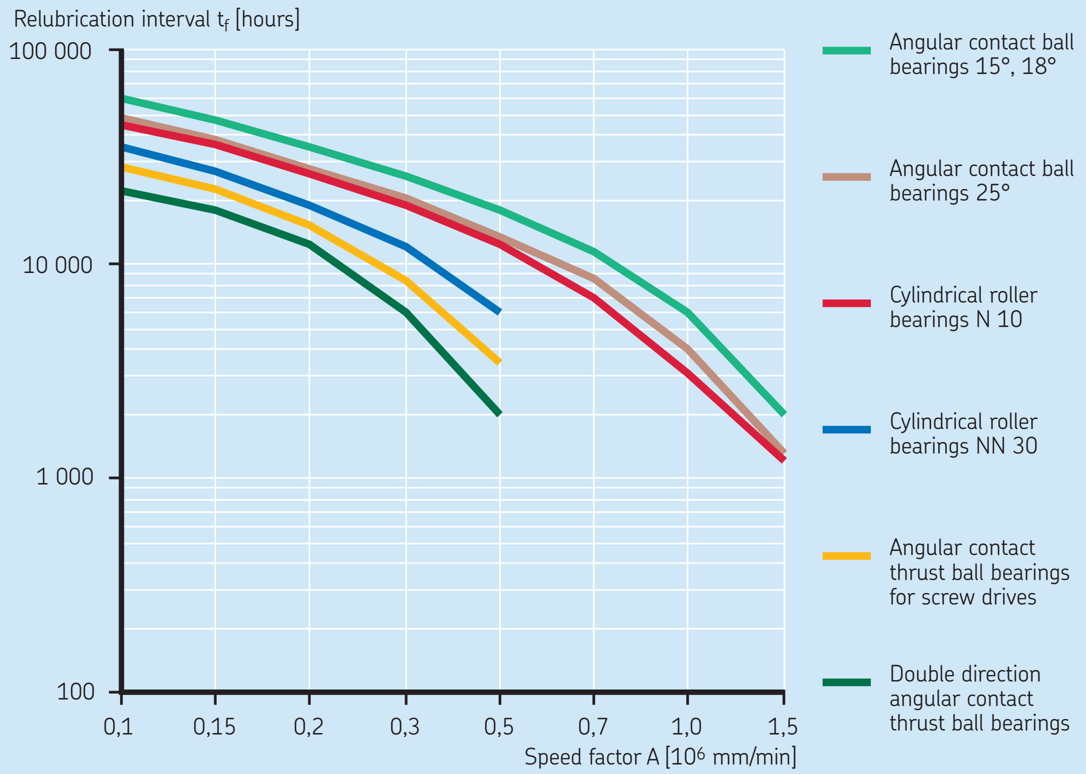


Table 27

Correction factor for bearing sets and different preload classes

Bearing type / Bearing series	Arrangement	Design. suffix	Correction factor C_1 Preload class A	L	B	M	C	F	D
Angular contact ball bearings									
719 D, 70 D, 72 D	Set of 2, back-to-back	DB	0,81	–	0,75	–	0,65	–	0,4
	Set of 2, face-to-face	DF	0,77	–	0,72	–	0,61	–	0,36
	Set of 3, back-to-back and tandem	TBT	0,7	–	0,63	–	0,49	–	0,25
	Set of 3, face-to-face and tandem	TFT	0,63	–	0,56	–	0,42	–	0,17
	Set of 4, tandem back-to-back	QBC	0,64	–	0,6	–	0,53	–	0,32
	Set of 4, tandem face-to-face	QFC	0,62	–	0,58	–	0,48	–	0,27
718 D, 719 E, 70 E	Set of 2, back-to-back	DB	0,8	–	0,65	–	0,4	–	–
	Set of 2, face-to-face	DF	0,77	–	0,61	–	0,36	–	–
	Set of 3, back-to-back and tandem	TBT	0,69	0,72	0,49	0,58	0,25	0,36	–
	Set of 3, face-to-face and tandem	TFT	0,63	0,66	0,42	0,49	0,17	0,24	–
	Set of 4, tandem back-to-back	QBC	0,64	–	0,53	–	0,32	–	–
	Set of 4, tandem face-to-face	QFC	0,62	–	0,48	–	0,27	–	–
719 B, 70 B	Set of 2, back-to-back	DB	0,83	–	0,78	–	0,58	–	–
	Set of 2, face-to-face	DF	0,8	–	0,74	–	0,54	–	–
	Set of 3, back-to-back and tandem	TBT	0,72	–	0,66	–	0,4	–	–
	Set of 3, face-to-face and tandem	TFT	0,64	–	0,56	–	0,3	–	–
	Set of 4, tandem back-to-back	QBC	0,67	–	0,64	–	0,48	–	–
	Set of 4, tandem face-to-face	QFC	0,64	–	0,6	–	0,41	–	–
Double direction angular contact thrust ball bearings									
BTW	–	–	1	–	–	–	–	–	–
BTM	–	–	1	–	0,5	–	–	–	–
Angular contact thrust ball bearings for screw drives									
BSA, BSD	Set of 2	–	0,8	–	0,4	–	–	–	–
	Set of 3	–	0,65	–	0,3	–	–	–	–
	Set of 4	–	0,5	–	0,25	–	–	–	–

Table 28

Correction factor for hybrid bearings

Bearing type	Correction factor C_2 Speed factor A [10^6 mm/min] 0,5	0,7	1	1,5
Angular contact ball bearings	3	3,5	3	2,8
Double direction angular contact thrust ball bearings	3	–	–	–
Cylindrical roller bearings	3	3	3	2,5

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Table 29

Correction factors for operating conditions

Operating condition	Correction factor	
Shaft orientation		
Vertical	C_3	0,5
Horizontal		1
Bearing load		
P < 0,05 C	C_4	1
P < 0,1 C		0,7
P < 0,125 C		0,5
P < 0,2 C		0,3
P < 0,5 C		0,2
P < C		0,1
Reliability		
L_1	C_5	0,37
L_{10}		1
L_{50}		2
Air flow through the bearing		
Low	C_6	1
Moderate		0,3
Strong		0,1
Moisture and dust		
Low	C_7	1
Moderate		0,5
High		0,3
Very high		0,1
Operating temperature		
40 °C *(105 °F)*	C8	2
55 °C *(130 °F)*		2
70 °C *(125 °F)*		1
85 °C *(185 °F)*		0,5
100 °C *(210 °F)*		0,25

Miscibility

When an alternative grease is being considered for an existing application, check the compatibility of the new grease with the current grease relative to the base oil (→ **table 30**) and thickener (→ **table 31**, **page 109**). These tables are based on grease composition and should only be used as guidelines. SKF recommends verifying miscibility with a grease expert and then testing the new grease in the application.

Before applying a new grease type, remove as much of the old grease as possible from the bearing arrangement. If the new grease is incompatible with the existing grease, or if the old grease contains a PTFE thickener or is silicone based, the bearings should be washed thoroughly using an appropriate solvent. Once the new grease is applied, monitor the bearings carefully to be sure that the new grease functions properly.

Table 30

Compatibility of base oil types

	Mineral oil	Ester oil	Polyglycol	Silicone-methyl	Silicone-phenyl	Polyphenylether
Mineral oil	+	+	–	–	+	o
Ester oil	+	+	+	–	+	o
Polyglycol	–	+	+	–	–	–
Silicone-methyl	–	–	–	+	+	–
Silicone-phenyl	+	+	–	+	+	+
Polyphenylether	o	o	–	–	+	+

+ compatible
– incompatible
o individual testing required

Table 31

Compatibility of thickener types

	Lithium soap	Calcium soap	Sodium soap	Lithium complex soap	Calcium complex soap	Sodium complex soap	Barium complex soap	Alumin-ium complex soap	Clay	Poly-urea
Lithium soap	+	o	–	+	–	o	o	–	o	o
Calcium soap	o	+	o	+	–	o	o	–	o	o
Sodium soap	–	o	+	o	o	+	+	–	o	o
Lithium complex soap	+	+	o	+	+	o	o	+	–	–
Calcium complex soap	–	–	o	+	+	o	–	o	o	+
Sodium complex soap	o	o	+	o	o	+	+	–	–	o
Barium complex soap	o	o	+	o	–	+	+	+	o	o
Aluminium complex soap	–	–	–	+	o	–	+	+	–	o
Clay	o	o	o	–	o	–	o	–	+	o
Polyurea	o	o	o	–	+	o	o	o	o	+

+ compatible
– incompatible
o individual testing required

Running-in of grease lubricated bearings

Grease lubricated super-precision bearings initially run with a relatively high frictional moment. If they are run at high speeds without a running-in period, the temperature rise can be considerable. The high frictional moment is due to the churning of excess grease, which takes time to work its way out of the contact zone. For open bearings, this time period can be minimized by applying the required quantity of grease distributed evenly on both sides of the bearing during assembly. Spacers between adjacent bearings can also reduce the running-in period.

The time required to stabilize the operating temperature depends on the following factors:

- the type of grease
- the initial grease fill
- how the grease is applied to the bearings
- the number and arrangement of bearings in a set
- the available space for excess grease to accumulate on either side of the bearing
- the running-in procedure

Super-precision bearings can typically operate with a minimum quantity of lubricant when properly run-in, enabling the lowest frictional moment and operating temperature to be achieved. Grease that collects on each side of the bearing acts as a reservoir, enabling oil to bleed into the raceway to provide effective lubrication for a long time.

Running-in can be done in several ways. Wherever possible and regardless of the procedure chosen, running-in should involve operating the bearing in both a clockwise and counter-clockwise direction.

Standard running-in procedure

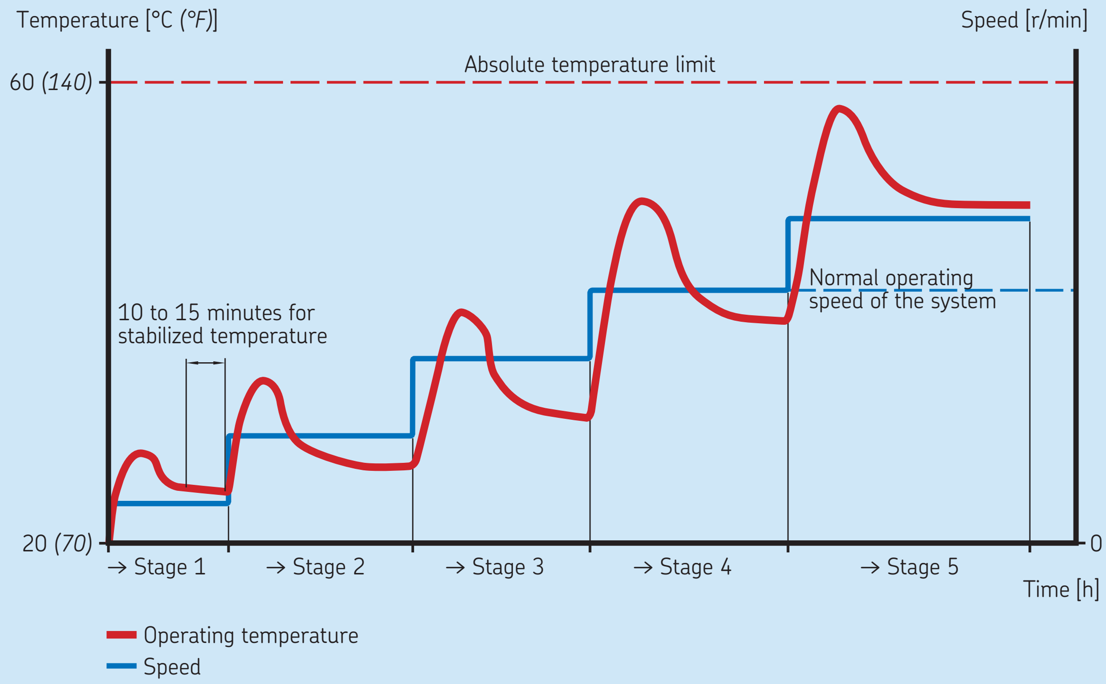
The most common running-in procedure can be summarized as follows:

1 Select a low start-up speed and a relatively small speed increment.
2 Decide on an absolute temperature limit, usually 60 to 65 °C *(140 to 150 °F)*. SKF recommends setting the machine with limit switches that stop the spindle if the temperature rise exceeds the set limit.
3 Start operation at the selected start-up speed.
4 Monitor the temperature rise by taking measurements at the bearing outer ring position, and wait for the temperature to stabilize. If the temperature reaches the limit, stop the spindle and allow the bearing to cool. Repeat the process at the same speed and run the spindle until the temperature stabilizes below the limit.
5 Once the bearing temperature has stabilized, continue to run the spindle for an additional 10 to 15 minutes. Then, increase the speed by one increment and repeat step **4**.
6 Continue increasing the speed incrementally, allowing the temperature to stabilize at each stage, until the spindle reaches one speed interval above the operating speed of the system. This results in a lower temperature rise during normal operation. The bearing is now properly run-in.

This standard running-in procedure is time-consuming. For a medium- to high-speed spindle, each stage can take anywhere from 30 minutes to 2 hours before the temperature stabilizes. The total time for the running-in procedure can be 8 to 10 hours
(→ **diagram 16**, **page 111**).

Diagram 16

Graphic representation of a running-in procedure



Short running-in procedure

An alternative to the standard running-in procedure reduces the number of stages and shortens the overall running-in time. The main steps can be summarized as follows:

1. Select a start-up speed approximately 20 to 25% of the attainable speed for grease lubrication (→ **product tables**) and choose a relatively large speed increment.
2. Decide on an absolute temperature limit, usually 60 to 65 °C *(140 to 150 °F)*. It is advisable to set the machine with limit switches that stop the spindle if the temperature rise exceeds the limits set.
3. Start operation at the chosen start-up speed.
4. Monitor the temperature by taking measurements at the bearing outer ring position until the temperature reaches the limit. Care should be taken as the temperature increase may be very rapid.
5. Stop operation and let the outer ring of the bearing cool down by 5 to 10 °C *(10 to 20 °F)*.
6. Start operation at the same speed a second time and monitor the temperature until the limit is reached again.
7. Repeat steps **5** and **6** until the temperature stabilizes for 10 to 15 minutes below the limit. The bearing is run-in at that particular speed.
8. Increase the speed by one increment and repeat steps **4** to **7**.
9. Proceed until the bearing is running at one speed increment above the operating speed of the system. This results in a lower temperature rise during normal operation. The bearing is now properly run-in.

Although each stage may have to be repeated several times, each cycle is just a few minutes long. The total time for this running-in procedure is substantially less than for the standard procedure.

Oil lubrication

Oil lubrication is recommended for many applications, as different supply methods can be adapted to suit different operating conditions and the machine's design. When selecting the most appropriate oil lubrication method for a bearing arrangement, the following application requirements should be considered:

- required quantity and viscosity of the oil
- speed and hydrodynamic frictional losses
- permissible bearing temperature

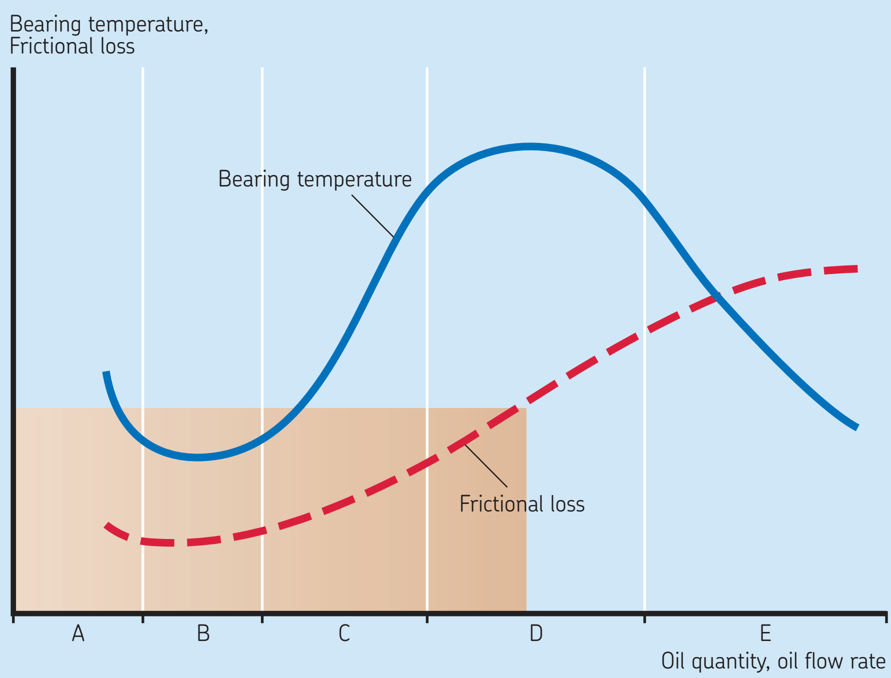
The typical relationship between oil quantity / oil flow rate, frictional losses and bearing temperature is shown in **diagram 17**. The diagram illustrates the conditions in different regions:

- Region A
  The oil quantity is insufficient to create a hydrodynamic film between the rolling elements and raceways. Metal-to-metal contact leads to increased friction, high bearing temperatures, wear and surface fatigue.
- Region B
  A larger quantity of oil is available and a cohesive, load-carrying oil film of sufficient thickness to separate the rolling elements and raceways can be formed. Here, the condition is reached where friction and temperature are at a minimum.
- Region C
  A further increase in oil quantity increases frictional heat due to churning and bearing temperature rises.
- Region D
  The oil flow quantity increases such that equilibrium between frictional heat generation at the bearing and heat removal by the oil flow is achieved. Bearing temperature peaks.
- Region E
  With increasing oil flow, the rate at which heat is removed exceeds the frictional heat generated by the bearing. Bearing temperature decreases.

Maintaining low operating temperatures at extremely high speeds generally requires either an oil-air lubrication system or a circulating oil lubrication system with cooling capabilities. With these systems, the operating conditions shown in regions B (oil-air) or E (circulating oil) can be maintained.

Diagram 17

Bearing temperature and frictional losses as a function of oil quantity



Oil lubrication methods

Oil bath

The simplest method of oil lubrication is the oil bath. The oil, which is picked up by the rotating components of the bearing, is distributed within the bearing and then flows back to a sump in the housing. Typically, the oil level should almost reach the centre of the lowest rolling element when the bearing is stationary. Oil bath lubrication is particularly suitable for low speeds. At high speeds, however, too much oil is supplied to the bearings, increasing friction and causing the operating temperature to rise.

Circulating oil

In general, high-speed operation increases frictional heat, elevates operating temperatures and accelerates ageing of the oil. To reduce operating temperatures and avoid frequent oil changes, the circulating oil lubrication method is generally preferred (→ **fig. 42**). Circulation is usually controlled by a pump. After the oil has passed through the bearing, it generally settles in a tank where it is filtered and cooled before being returned to the bearing. Proper filtering decreases the contamination level and extends bearing service life. In bigger systems with several different bearing sizes, the main volume flow from the pump can be split into several smaller flows. The flow rate in each sub-circuit in the system can be checked by SKF flow monitoring devices.

Guideline values for oil flow rates are listed in **table 32**. For a more accurate analysis, contact the SKF application engineering service.

For information about the SKF CircOil system and SKF flow monitoring devices, refer to the product information available online at skf.com/lubrication.

Fig. 42

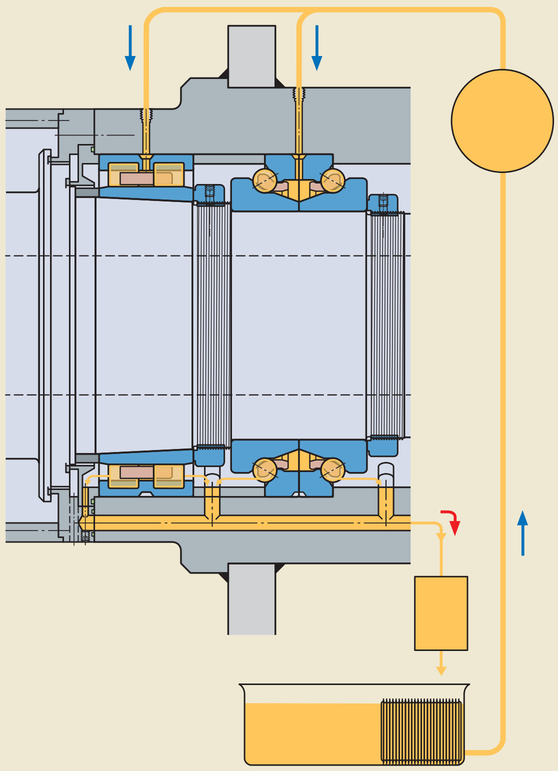


Table 32

Oil flow rate guidelines
(valid for single bearings)

Bore diameter d over	incl.	**Oil flow rate** Q low	high
mm		l/min	
–	50	0,3	1
50	120	0,8	3,6
120	400	1,8	6

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Oil jet

The oil jet lubrication method (→ **fig. 43**) is an extension of circulating oil systems. A jet of oil under high pressure is directed at the side of the bearing. The velocity of the oil jet should be sufficiently high (≥ 15 m/s) to penetrate the turbulence surrounding the rotating bearing. Oil jet lubrication is used for very high speed operation, where a sufficient, but not excessive, amount of oil should be supplied to the bearing without increasing the operating temperature unnecessarily.

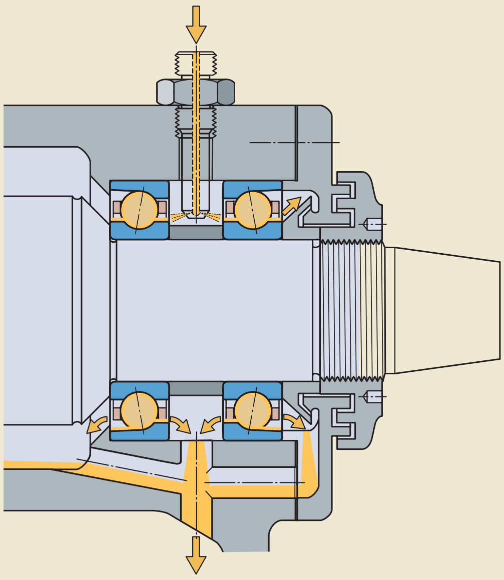
Oil drop

With the oil drop method, an accurately metered quantity of oil is supplied to the bearing at given intervals. The delivered quantity may be relatively small, keeping frictional losses at high speeds to a minimum. However, it is difficult to ascertain whether the oil is able to penetrate the bearing at high speeds and, therefore, individual testing is always recommended. Whenever possible, the oil-air method should be preferred over the oil drop method.

Oil mist

Modern application specific oil mist systems, such as those offered by SKF, matched with a suitable non-toxic and non-carcinogenic oil formulated for minimum stray mist emissions and suitable sealing systems, address environmental and health concerns. These systems, when well maintained, provide a cost-effective, environmentally clean way to continuously and effectively atomise oil and deliver metered minimum required quantities to the bearings. Modern oil mist systems suspend oil droplets 1 to 5 µm in size in dry instrument air. The oil to air ratio, which is typically 1:200 000, creates a very lean but effective mixture that is delivered under 0,005 MPa pressure.

Fig. 43



Oil-air

Oil-air lubrication systems are appropriate for high-precision applications with very high operating speeds and requisite low operating temperatures. For information about the SKF Oil+Air lubrication systems, refer to the product information available online at skf.com/lubrication.

The oil-air method (→ **fig. 44**), also called the oil-spot method, uses compressed air to transport small, accurately metered quantities of oil as small droplets along the inside of feed lines to an injector nozzle, where it is delivered to the bearing (→ **fig. 45**). This minimum quantity lubrication method enables bearings to operate at very high speeds with relatively low operating temperature. The compressed air serves to cool the bearing and also produces an excess pressure in the bearing housing to prevent contaminants from entering. Because the air is only used to transport the oil and is not mixed with it, the oil is retained within the housing. Oil-air systems are considered to be environmentally safe, provided that any residual used oil is disposed of correctly.

For bearings used in sets, each bearing should be supplied by a separate injector. Most designs include special spacers that incorporate the oil nozzles.

Guideline values for the oil quantity to be supplied to an angular contact ball bearing for high-speed operation can be obtained from

$$Q = 1{,}3\ d_m$$

Guideline values for the oil quantity to be supplied to a cylindrical roller bearing or double direction angular contact thrust ball bearing can be obtained from

$$Q = \frac{q\ d\ B}{100}$$

where

Q = oil flow rate [mm^3/h]
B = bearing width [mm]
d = bearing bore diameter [mm]
d_m = bearing mean diameter [mm]
= 0,5 (d + D)
q = factor
= 1 to 2 for cylindrical roller bearings
= 2 to 5 for double direction angular contact thrust ball bearings

Individual testing is, however, always recommended in order to optimize the conditions.

Fig. 44

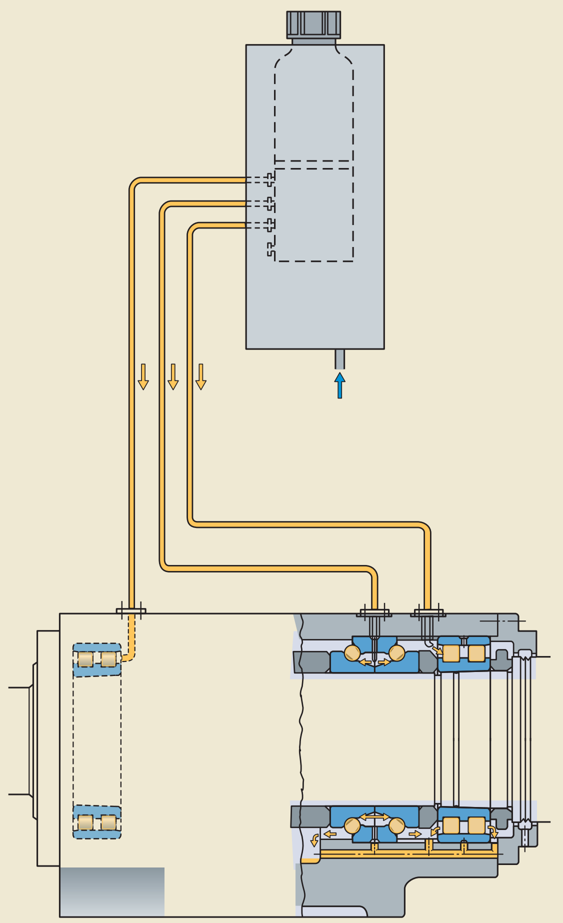
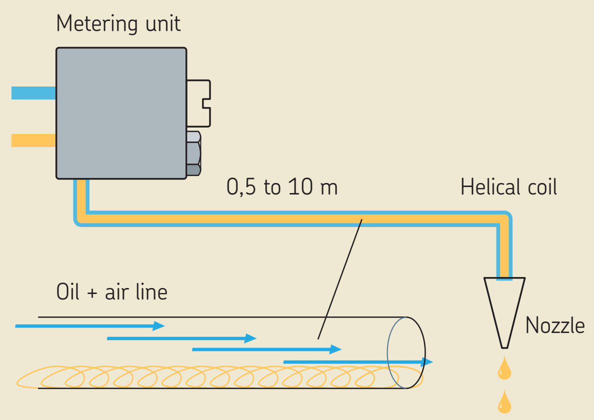


Fig. 45



Different bearing designs show varying sensitivity to oil quantity changes. For example, roller bearings are very sensitive, whereas for ball bearings, the quantity can be changed substantially without any major rise in bearing temperature.

A factor influencing temperature rise and reliability of oil-air lubrication is the lubrication interval, i.e. the time in between two measures from the oil-air lubricator. Generally, the lubrication interval is determined by the oil flow rate generated by each injector and the oil quantity supplied per hour. The interval can vary from one minute to one hour, with the most common interval being 15 to 20 minutes.

Feed lines from the lubricator are 1 to 5 m in length, depending on the lubrication interval. A filter that prevents particles > 5 µm from reaching the bearings should be incorporated. The air pressure should be 0,2 to 0,3 MPa, but should be increased for longer runs to compensate for the pressure drop along the pipe's length.

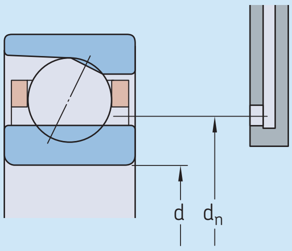
To maintain the lowest possible operating temperature, ducts must be able to drain any excess oil away from the bearing. With horizontal shafts it is relatively easy to arrange drainage ducts on each side of the bearings. For vertical shafts the oil passing the upper bearing(s) should be prevented from reaching the lower bearings, which would otherwise receive too much lubricant. Drainage, together with a sealing device, should be incorporated beneath each bearing. An effective seal should also be located at the spindle nose to prevent lubricant from reaching the work piece.

The oil nozzles should be positioned so that oil can be introduced into the contact area between the rolling elements and raceways without interference by the cage. For the diameter (measured on the bearing) where oil injection should take place, refer to **tables 33** and **34** (→ **pages 117** and **117**). For bearings equipped with alternative cages that are not listed, contact the SKF application engineering service.

The attainable speeds listed in the product tables for oil lubrication refer specifically to oil-air lubrication.

Table 33

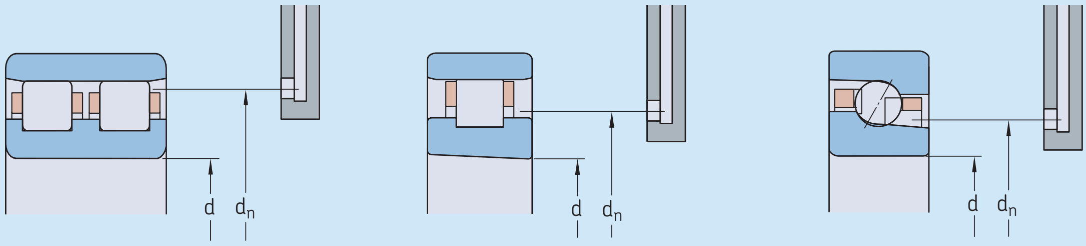
Oil nozzle position for angular contact ball bearings



Bore diameter d	Size	Oil nozzle position d_n for bearings in the series 718 CD 718 ACD	719 CD 719 ACD	719 CE 719 ACE	719 CB 719 ACB	70 CD 70 ACD	70 CE 70 ACE	70 CB 70 ACB	72 CD 72 ACD
mm	–	mm							
6	**6**	–	–	–	–	10,3	10,1	–	–
7	**7**	–	–	–	–	11,7	11,4	–	13,6
8	**8**	–	–	12,2	–	13,6	13,3	–	14,3
9	**9**	–	–	13,3	–	15,1	14,8	–	16,3
10	**00**	13,4	14,8	14,8	–	16	16,5	–	18,3
12	**01**	15,4	16,8	16,8	–	18	18,5	–	20
15	**02**	18,4	20,1	20	–	21,5	21,9	–	23
17	**03**	20,4	22,1	22	–	23,7	24,1	–	25,9
20	**04**	24,5	26,8	26,7	–	28,4	28,1	–	31,1
25	**05**	29,5	31,8	31,8	–	33,4	33,1	–	36,1
30	**06**	34,5	36,8	36,8	36,6	39,3	39,9	40	42,7
35	**07**	39,5	43	43	43	45,3	45,6	46,1	49,7
40	**08**	44,5	48,7	48	49,1	50,8	51,6	51,6	56,2
45	**09**	50	54,2	54,2	54,2	56,2	57,6	57,2	60,6
50	**10**	55,6	58,7	58,4	58,7	61,2	62,3	61,8	65,6
55	**11**	61,3	64,7	64,6	64,8	68,1	69,6	69,2	72,6
60	**12**	66,4	69,7	69,6	69,8	73,1	74,6	74,2	80,1
65	**13**	72,4	74,7	74,5	74,8	78,1	79,3	79	86,6
70	**14**	77,4	81,7	81,5	81,9	85	86,5	86,1	91,6
75	**15**	82,4	86,7	86,5	86,9	90	91,5	91,1	96,6
80	**16**	87,4	91,7	91,5	91,7	96,9	98,5	98	103,4
85	**17**	94,1	98,6	98,6	99,2	101,9	103,5	103	111,5
90	**18**	99,1	103,3	103,5	103,9	108,7	111	110	117,5
95	**19**	104,1	108,6	108,5	109	113,7	115,4	115	124,4
100	**20**	109,1	115,6	115,4	116,1	118,7	120,4	120	131,4
105	**21**	114,6	120,6	–	–	125,6	–	–	138,4
110	**22**	120,9	125,6	125,4	125,7	132,6	135,4	134,6	145,9
120	**24**	130,9	137,6	137,4	138,2	142,6	144,9	144,7	158,2
130	**26**	144	149,5	–	–	156,4	–	–	170,7
140	**28**	153,2	159,5	–	–	166,3	–	–	184,8
150	**30**	165,6	173,5	–	–	178,2	–	–	–
160	**32**	175,6	183,5	–	–	191,4	–	–	–
170	**34**	–	193,5	–	–	205,8	–	–	–
180	**36**	–	207,4	–	–	219,7	–	–	–
190	**38**	–	217,4	–	–	229,7	–	–	–
200	**40**	–	231,4	–	–	243,2	–	–	–
220	**44**	–	251,4	–	–	267,1	–	–	–
240	**48**	–	271,4	–	–	287	–	–	–
260	**52**	–	299,7	–	–	315	–	–	–
280	**56**	–	319,7	–	–	–	–	–	–
300	**60**	–	347	–	–	–	–	–	–
320	**64**	–	367	–	–	–	–	–	–
340	**68**	–	387	–	–	–	–	–	–
360	**72**	–	407	–	–	–	–	–	–

Table 34

Oil nozzle position for cylindrical roller and double direction angular contact thrust ball bearings



Bore diameter d	Size	Oil nozzle position d_n for bearings in the series[1) N 10 NN 30	N 10 PHA	NNU 49	BTM
mm	–	mm			
25	05	40,5	–	–	–
30	06	47,6	–	–	–
35	07	54	–	–	–
40	08	60	52,1	–	–
45	09	66,4	57,9	–	–
50	10	71,4	63	–	–
55	11	79,8	70,1	–	–
60	12	85	75,2	–	73,8
65	13	89,7	80,1	–	78,8
70	14	98,5	87,7	–	86,1
75	15	103,5	92,7	–	91,1
80	16	111,4	99,3	–	97,9
85	17	116,5	–	–	102,9
90	18	125,4	–	–	109,7
95	19	130,3	–	–	114,7
100	20	135,3	–	113,8	119,7
105	21	144,1	–	119	–
110	22	153	–	124	134,1
120	24	162,9	–	136,8	144,1
130	26	179,6	–	147	158,3
140	28	188	–	157	168,3
150	30	201,7	–	169,9	179,9
160	32	214,4	–	179,8	191,6
170	34	230,8	–	189,8	205,4
180	36	248,9	–	203,5	219,9
190	38	258,9	–	213	–
200	40	275,3	–	227	–
220	44	302,4	–	247	–
240	48	322,4	–	267	–
260	52	355,2	–	294,5	–
280	56	375,3	–	313,5	–

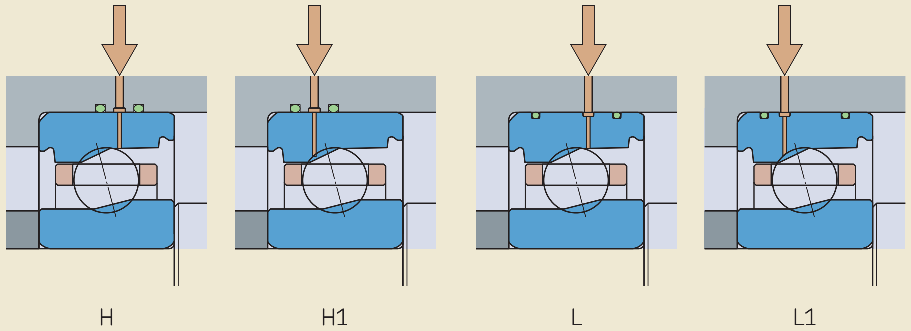
The illustrations show examples only. Position depends on design and series.
[1) For bearings in the N 10 series equipped with an TNHA cage, bearings in the NN 30 and NNU 49 series with d > 280 mm, contact the SKF application engineering service.

Direct oil-air lubrication

For super-precision angular contact ball bearings operating at very high speeds, the injection of small amounts of oil-air directly through the outer ring is beneficial. With this method, lubricant dispersion is prevented, as the lubricant is supplied directly and safely to the ball/raceway contact area. As a result, lubricant consumption is minimized and bearing performance is improved. The different variants (→ **fig. 45**) for direct oil-air lubrication provide different benefits:

- Bearings with an annular groove and O-rings in the outer ring (designation suffix L or L1) prevent lubricant leakage between the bearing and its seat in the housing. For bearings without these features (designation suffix H or H1), SKF recommends machining the housing bore and incorporating O-rings into the bearing arrangement design.
- Bearings with lubrication holes on the thick side of the bearing shoulder (designation suffix H1 or L1) enable the lubricant to be supplied very close to the ball/raceway contact area. The locations of these lubrication holes enable the bearings to achieve maximum speeds.

Fig. 45



Direct minimum quantity lubrication with minimal air consumption

The use of a continuous air flow in an oil-air lubrication system includes some system-related disadvantages like the high cost of compressed air, high noise levels and a complex dosing and control process. The SKF Microdosage system (→ **fig. 46**) virtually eliminates these disadvantages and offers better control and a lower cost of ownership.

Designed for ultra high speed spindles where the speed factor A ≥ 2 000 000 mm/min, this system delivers precisely metered amounts of oil to each bearing based on the machine tool's CAM program. The SKF Microdosage system also automatically re-calibrates when conditions like temperature or oil viscosity change. With this technology, oil consumption can typically be reduced to 0,5 to 5 mm^3/min with a minimal amount of compressed air.

For information about the SKF Microdosage system, refer to the product information available online at skf.com/lubrication.

Lubricating oils

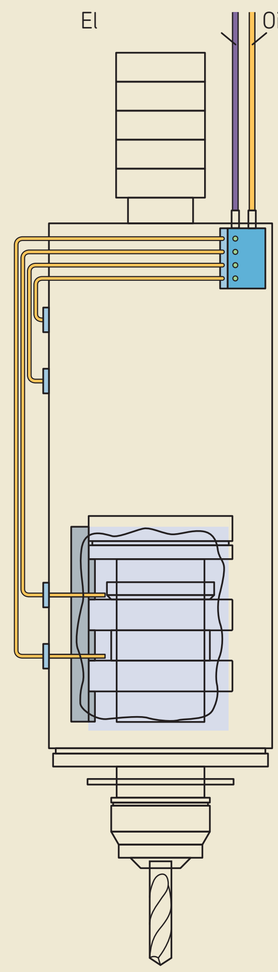
To lubricate super-precision bearings, high-quality lubricating oils without EP additives are generally recommended. The requisite viscosity of the oil can be determined following the recommendations under *Lubrication conditions – the viscosity ratio κ* in the SKF catalogue *Rolling bearings* or at skf.com, and is essentially a function of bearing size, speed and operating temperature.

Calculations can be made using the SKF program, Viscosity, available online at skf.com/bearingcalculator.

With oil-air lubrication systems, many oil types are suitable. Oils with a viscosity of 40 to 100 mm^2/s at 40 °C *(105 °F)* are typically used as are oils with EP additives which are preferable, especially for roller bearings. Oils with a viscosity of 10 to 15 mm^2/s at 40 °C *(105 °F)* are typically used for oil jet lubrication, whereas oil mist lubrication systems typically use oils with a viscosity of 32 mm^2/s at 40 °C *(105 °F)*.

The intervals at which the oil should be changed when using an oil bath, circulating oil or oil jet lubrication system, depend mainly on the operating conditions and the quantity of oil involved. When oil drop, oil mist or oil-air lubrication systems are used, the lubricant is supplied to the bearings only once.

Fig. 46



Oil cleanliness

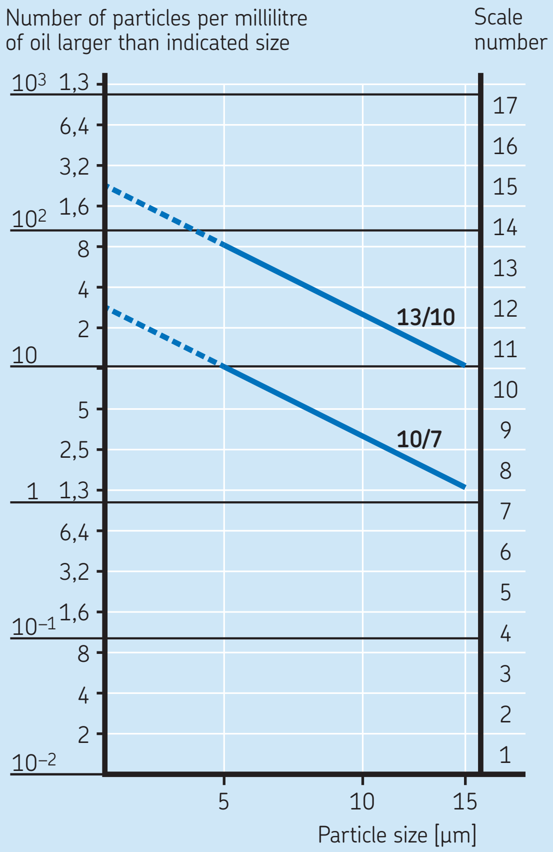
Oil cleanliness, which affects bearing service life and performance, requires an effective sealing system. Even with effective seals, however, the condition of the oil should be monitored on a regular basis. This is particularly true for oil re-circulation systems where the ingress of coolants, cutting oils, and other liquid contaminants can alter the lubricating properties of the oil.

Oil cleanliness requirements can be described by the number of particles per millilitre of oil for different particle sizes. ISO 4406 provides a coding system for the level of solid contaminants. The oil cleanliness requirements for high-precision applications like electro-spindles go beyond this coding. The maximum particle size should not exceed 5 µm. The acceptable contamination levels can be specified as an extrapolation of the contamination codes to ISO 4406 (→ **diagram 18**):

- 10/7, for new spindles
- 13/10, after long use (~ 2 000 hours)

Diagram 18

Acceptable oil contamination levels



Lubricant storage

The conditions under which lubricants are stored can have an adverse effect on their performance. Inventory control can also play an important role. Therefore, SKF recommends a "first in, first out" inventory policy.

Lubricant properties may vary considerably during storage due to exposure to air/oxygen, temperature, light, water, moisture and other contaminants, or oil separation. Therefore, lubricants should be stored in a cool, dry, indoor area and should never be exposed to direct sunlight. The lubricants should be stored in their original containers, which should be kept closed until needed. After use, the containers should be resealed immediately.

The recommended maximum storage time is two years for greases and ten years for lubricating oils; assuming reasonable stock keeping practices and protection from excessive heat and cold.

Grease or oil that has exceeded the recommended shelf life is not necessarily unsuitable for service. However, it is advisable to confirm that the lubricant still meets the product requirements and specifications.

SKF spindle service

Machine tool spindles often require special tools and skills for maintenance and repair. SKF supports customers with a worldwide network of SKF Spindle Service Centres (→ skf.com). The services offered include spindle reconditioning, from bearing replacement to shaft and nose restorations, performance upgrades and analysis. SKF can also provide complete monitoring services as well as preventative maintenance services for machine tool spindles.

Bearing storage

The conditions under which bearings and seals are stored can have an adverse effect on their performance. Inventory control can also play an important role in performance, particularly if seals are involved. Therefore, SKF recommends a "first in, first out" inventory policy.

Storage conditions

To maximize the service life of bearings, SKF recommends the following basic housekeeping practices:

- Store bearings flat, in a vibration-free, dry area with a cool, steady temperature.
- Control and limit the relative humidity of the storage area as follows:
  - 75% at 20 °C *(68 °F)*
  - 60% at 22 °C *(72 °F)*
  - 50% at 25 °C *(77 °F)*
- Keep bearings in their original unopened packages until immediately prior to mounting to prevent the ingress of contaminants and corrosion.
- Bearings that are not stored in their original packaging should be well protected against corrosion and contaminants.

Shelf life of open bearings

SKF bearings are coated with a rust-inhibiting compound and suitably packaged before distribution. For open bearings, the preservative provides protection against corrosion for approximately three years, provided the storage conditions are appropriate.

Shelf life of sealed bearings

The maximum storage interval for sealed SKF bearings is dictated by the lubricant inside the bearings. Lubricant deteriorates over time as a result of ageing, condensation, and separation of the oil and thickener. Therefore, sealed bearings should not be stored for more than three years.


Super-precision bearing
SKF