Selecting super-precision bearings

A shaft system consists of more than just bearings. Associated components like the shaft and housings are integral parts of the overall system. The lubricant and sealing elements also play a crucial role. To maximize bearing performance, the correct amount of an appropriate lubricant must be present to reduce friction in the bearing and protect it from corrosion. Sealing elements are important because they keep the lubricant in and contaminants out of the bearing. This is particularly important since cleanliness has a profound effect on bearing service life. Therefore, SKF manufactures and sells a wide range of industrial seals and lubrication systems.

There are a number of factors that go into the bearing selection process:

- available space
- loads (magnitude and direction)
- precision and stiffness
- speeds
- operating temperature
- vibration levels
- contamination levels
- lubrication type and method

Once a suitable bearing has been selected, there are several other factors that need to be considered:

- suitable form and design of other components in the arrangement
- appropriate fits and bearing internal clearance or preload
- locking devices
- adequate seals
- mounting and dismounting methods

When designing an application, every decision affects the performance, reliability and economy of the shaft system.

As the leading bearing supplier, SKF manufactures a wide assortment of super-precision bearing types, series, designs, variants and sizes. The most common of them are introduced under *Bearing types and designs*.

Under *Principles of bearing selection and application*, the designer of a bearing system can find the necessary basic information, presented in the order in which it is generally required. Obviously, it is impossible to include all the information needed to cover every conceivable application. For this reason, in many places, reference is made to the SKF application engineering service. This technical service can perform complex calculations, diagnose and solve bearing performance issues, and help with the bearing selection process. SKF also recommends this service to anyone working to improve the performance of their application.

The information provided under *Principles of bearing selection and application* is general and applies to most super-precision bearings. Information specific to one bearing type is provided in the relevant product chapter.

It should be noted that many of the values listed in the product tables are rounded.

Bearing types and designs

SKF's comprehensive assortment of super-precision bearings is designed for machine tool spindles and other applications that require a high level of running accuracy at high to extremely high speeds. Each bearing type incorporates unique features to make it suitable for specific operating conditions. For details about the different bearing types, refer to the relevant product chapter.

Angular contact ball bearings (→ page 21)

high-capacity (D design) (**1**)
high-speed (E design) (**2**)
high-speed (B design) (**3**)
all designs in different variants:

- for single mounting or matched bearing sets
- for universal matching or universally matchable sets
- bearings with steel balls or hybrid bearings
- open or with seals (**3**)

Cylindrical roller bearings (→ page 21)

single row (N design)

- basic design (**4**)
- high-speed designs (**5**)
- hybrid bearings

double row (NN design) (**6**)

- bearings with steel rollers
- hybrid bearings

double row (NNU design) (**7**)

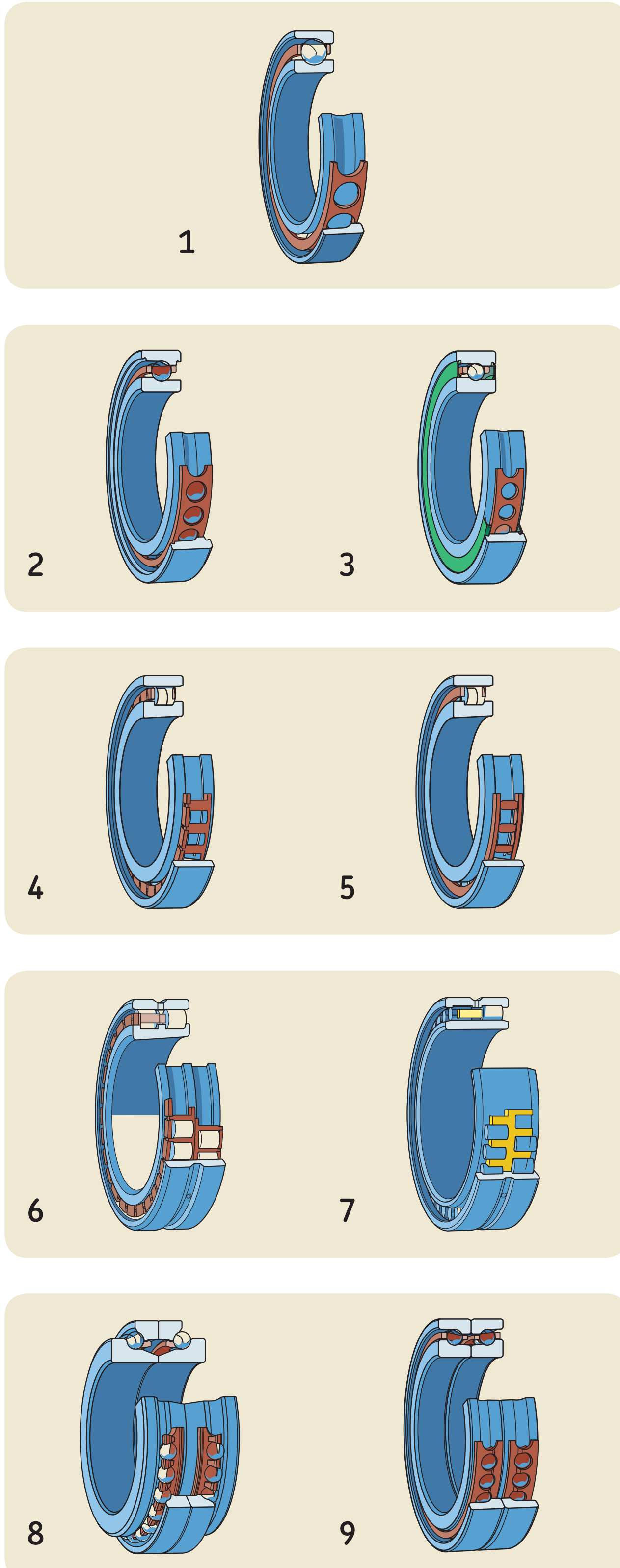
Double direction angular contact thrust ball bearings (→ page 21)

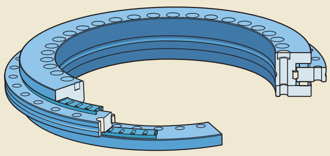
basic design (BTW series) (**8**)

- bearings with steel balls
- hybrid bearings

high-speed design (BTM series) (**9**)

- bearings with steel balls
- hybrid bearings





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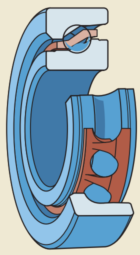

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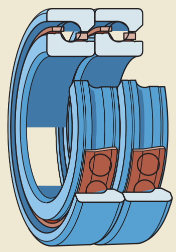

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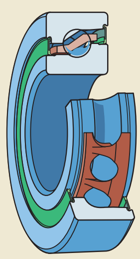

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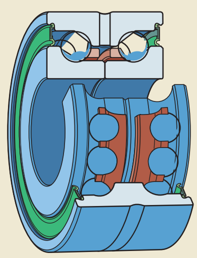

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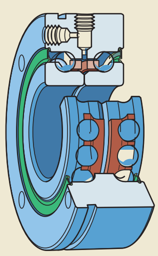

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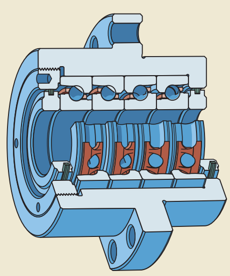

16

Axial-radial cylindrical roller bearings **(→ page 22)**

basic design (NRT series) (**10**)

Angular contact thrust ball bearings for screw drives **(→ page 22)**

single direction (BSA and BSD series) (**11**), universally matchable for mounting as sets (**12**)

- bearings with seals (**13**)

double direction with seals (BEAS series) (**14**)

- for bolt mounting (BEAM series) (**15**)

cartridge units with a flanged housing (FBSA series) (**16**)

Cages

The super-precision bearings shown in this catalogue all contain a cage. For some special applications, however, bearings without a cage (full complement) may be offered. The primary purposes of a cage are to:

- Separate the rolling elements to reduce the frictional moment and frictional heat in the bearing.
- Keep the rolling elements evenly spaced to optimize load distribution and enable quiet and uniform operation.
- Guide the rolling elements in the unloaded zone, to improve the rolling conditions and to help avoid damaging sliding movements.
- Retain the rolling elements of separable bearings when one bearing ring is removed during mounting or dismounting.

Cages are mechanically stressed by frictional, strain and inertial forces. They can also be degraded by high temperatures and chemicals like certain lubricants, lubricant additives or by-products of their ageing, organic solvents or coolants. Therefore, both the design and material of a cage have a significant influence on the suitability of a rolling bearing for a particular application. As a result, SKF has developed a variety of cages, made of different materials, for different bearing types and operating conditions.

In each product chapter, information about standard cages and possible alternatives is provided. Standard cages are those considered most suitable for the majority of applications. If a bearing with a non-standard cage is required, check availability prior to ordering.

Basic selection criteria

Bearing selection is paramount when dealing with machine tool spindles and other applications that require a high degree of running accuracy at high speeds. The SKF super-precision bearing assortment comprises different bearing types, each with features designed to meet specific application requirements.

Since several factors have to be considered and weighed when selecting a super-precision bearing, no general rules can be given. The following factors are the most important to be considered when selecting a super-precision bearing:

- precision (→ **page 23**)
- rigidity (→ **page 23**)
- available space (→ **page 23**)
- speeds (→ **page 23**)
- loads (→ **page 23**)
- axial displacement (→ **page 23**)
- sealing solutions (→ **page 23**)

The total cost of a shaft system and inventory considerations can also influence bearing selection.

Some of the most important criteria to consider when designing a bearing arrangement are covered in depth in separate sections of this catalogue. Detailed information on the individual bearing types, including their characteristics and the available designs, is provided in each product chapter.

Where demands on precision and productivity are exceptionally high, it may be necessary to contact the SKF application engineering service. For highly demanding applications, SKF offers special solutions such as:

- hybrid bearings (→ **page 23**)
- bearings made of NitroMax steel (→ **page 23**)
- coated bearings

Precision

When dealing with rolling bearings, precision is described by tolerance classes for running accuracy and dimensional accuracy. **Table 1** shows a comparison of the tolerance classes used by SKF and different standards organisations.

Most SKF super-precision bearings are manufactured to P4A, P4C or SP tolerance classes. Standard and optional tolerance classes for SKF super-precision bearings are listed in **table 2**.

Each product chapter provides information about the tolerance classes to which the bearings are manufactured.

Table 1

Comparison of the tolerance classes

SKF tolerance class	Standard tolerance classes in accordance with different standards — Running accuracy			Dimensional accuracy		
	ISO[1]	ANSI/ABMA[2]	DIN[3]	ISO[1]	ANSI/ABMA[2]	DIN[3]
P4A	2[4]	ABEC 9[4]	P2[4]	4	ABEC 7	P4
P4	4	ABEC 7	P4	4	ABEC 7	P4
P5	5	ABEC 5	P5	5	ABEC 5	P5
P2	2	ABEC 9	P2	2	ABEC 9	P2
PA9A	2	ABEC 9	P2	2	ABEC 9	P2
P4C	4	ABEC 7	P4	4	ABEC 7	P4
SP	4	ABEC 7	P4	5	ABEC 5	P5
UP[5]	2	ABEC 9	P2	4	ABEC 7	P4

1) ISO 492 or ISO 199
2) ANSI/ABMA Std. 20
3) DIN 620-2 or DIN 620-3
4) d > 120 mm → ISO 4 or better, ABEC 7 or better, DIN P4 or better
5) Depending on bearing size, accuracy might be even better.

Table 2

Standard and optional tolerance classes for SKF super-precision bearings

Bearing type	Standard tolerance class	Optional tolerance class
Angular contact ball bearings	P4A or P4[1]	PA9A or P2[1]
Cylindrical roller bearings	SP	UP
Double direction angular contact thrust ball bearings in the BTW series	SP	UP
Double direction angular contact thrust ball bearings in the BTM series	P4C	–
Angular contact thrust ball bearings for screw drives	P4A	–
Axial-radial cylindrical roller bearings[2]	–	–

1) Only for 718 D series
2) Radial run-out equal to or better than P4, axial run-out close to P4. Reduced axial and radial run-out on request.

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Running accuracy

The running accuracy of a shaft system depends on the accuracy of all the components within the system. Running accuracy of a bearing is mainly affected by the accuracy of the form and position of the raceways on the bearing rings.

When selecting the appropriate tolerance class for a particular bearing, the maximum radial or axial run-out (depending on the bearing type) of the inner ring is usually the determining factor for most applications.

Diagram 1 compares relative values of the maximum radial run-out of the inner ring for different tolerance classes.

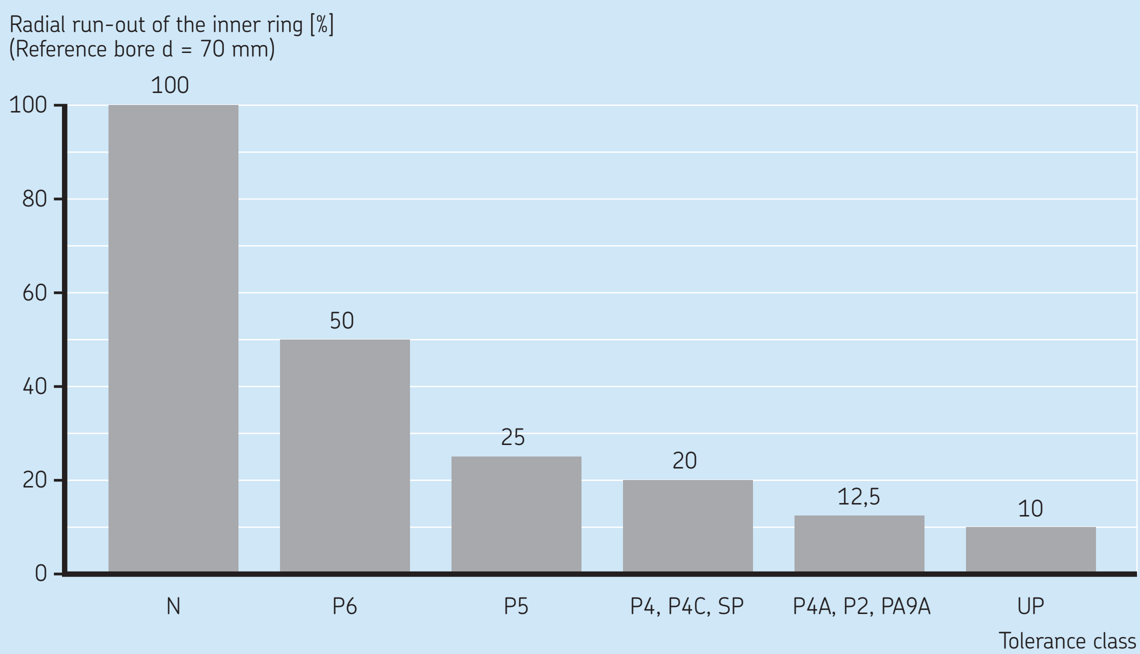
Dimensional accuracy

The accuracy of the boundary dimensions of both a bearing and its mating components is very important to achieve the appropriate fit. The fits between the bearing inner ring and shaft or outer ring and housing influence the internal clearance or preload of the mounted bearing.

Cylindrical roller bearings with a tapered bore have slightly larger permissible dimensional deviations than other types of super-precision bearings. That is because the clearance or preload is determined during mounting, by driving the inner ring up on its tapered seat.

Diagram 1

Relative radial run-out limits for different tolerance classes



Rigidity

In machine tool applications, the rigidity of the spindle is extremely important as the magnitude of elastic deformation under load heavily influences the productivity and accuracy of the tool. Although bearing stiffness contributes to system rigidity, there are other influencing factors including tool overhang as well as the number and position of the bearings.

Factors that determine bearing stiffness include:

- **The rolling element type**
  Roller bearings are stiffer than ball bearings. Ceramic rolling elements are stiffer than those made of steel.

- **The number and size of the rolling elements**
  A larger number of smaller diameter rolling elements increases the degree of stiffness.

- **The contact angle**
  A contact angle close to the load angle results in a higher degree of stiffness.

- **The internal design**
  A close osculation results in a higher degree of stiffness for angular contact ball bearings.

In applications requiring a high degree of radial rigidity, cylindrical roller bearings are typically the best option. However, angular contact ball bearings with a minimal contact angle can also be used.

In applications where a high degree of axial rigidity is required, angular contact thrust ball bearings with a large contact angle are preferred. Rigidity can be increased by preload, but this can limit the permissible speed.

For additional information about system rigidity and bearing stiffness, refer to *System rigidity* (→ **page 26**).

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Available space

High-precision applications generally call for bearings with a low cross-sectional height due to limited space and high requirements for rigidity and running accuracy. Bearings with a low cross-sectional height are able to accommodate relatively large-diameter shafts to provide the necessary rigidity within a relatively small bearing envelope.

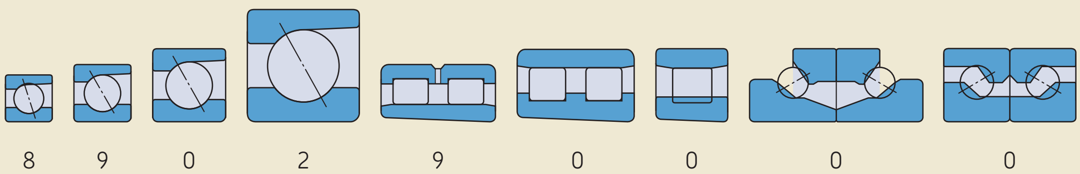
Angular contact ball bearings, cylindrical roller bearings and angular contact thrust ball bearings commonly used in machine tool applications are almost exclusively bearings in the ISO 9 and 0 diameter series (→ **fig. 1**).

Angular contact ball bearings in the 2 diameter series are rarely used in new designs, but are still common in existing applications. When a compact cross section is a key requirement, angular contact ball bearings in the 8 diameter series are the preferred solution.

By selecting bearings in the 9 or 0 diameter series, it is possible to achieve an optimal bearing arrangement regarding rigidity and load carrying capacity for a particular application within the same radial space.

Angular contact thrust ball bearings for screw drives have larger cross-sectional heights. Diameter series 2 and 3 are common for these bearings. The available space is typically not a major concern, but load carrying capacity is extremely important.

Fig. 1



Speeds

The attainable speeds for super-precision bearings are primarily dependent on bearing type, design and material, type and magnitude of load as well as lubricant and lubrication method. For the permissible speed, operating temperature is an additional limit.

Super-precision bearing arrangements in high-speed applications require bearings that generate the least amount of friction and frictional heat. Super-precision angular contact ball bearings and cylindrical roller bearings are best suited for these applications. For extremely high speeds, hybrid bearings (bearings with ceramic rolling elements) may be necessary.

When compared to other super-precision bearing types, angular contact ball bearings enable the highest speeds. **Diagram 2** compares the relative speed capability of SKF angular contact ball bearings in the different series. For details about the bearing series, refer to *Designation system* on **page 28**.

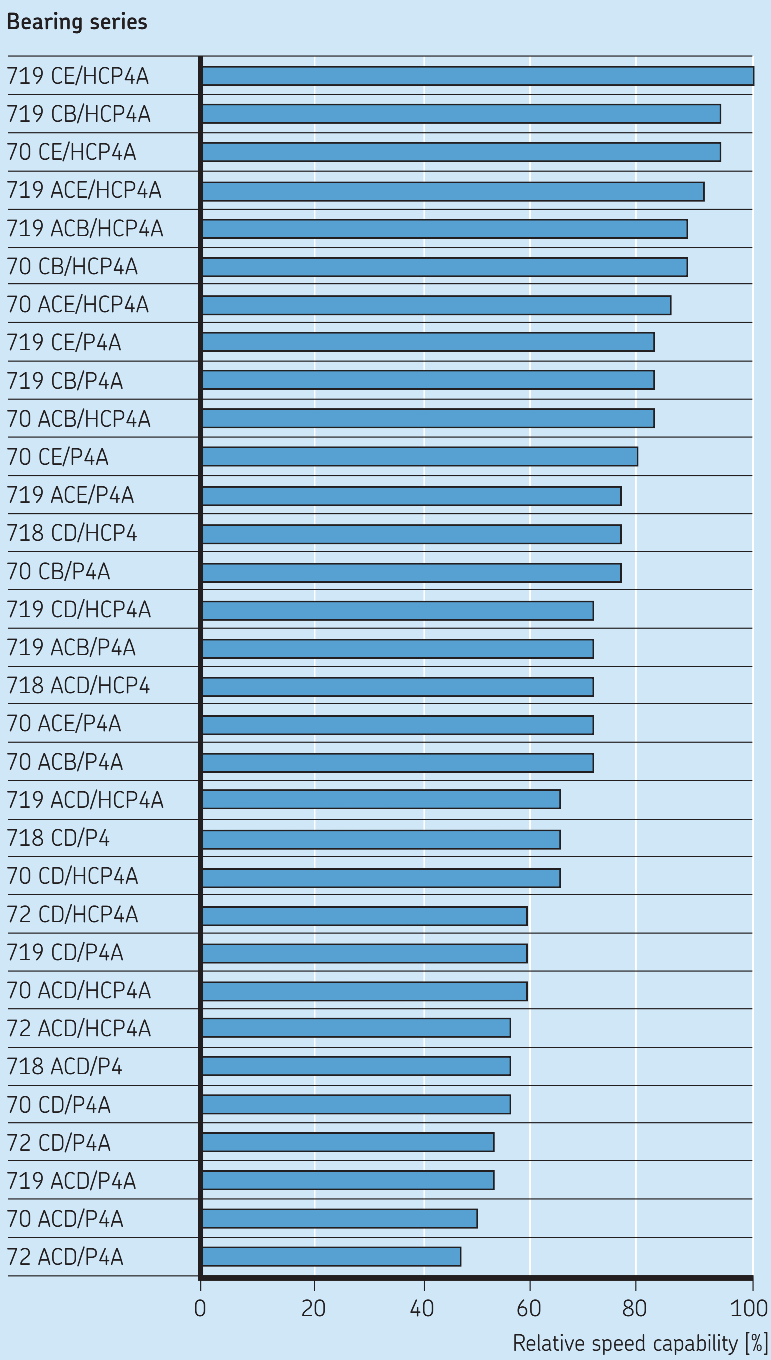
Thrust bearings cannot accommodate speeds as high as radial bearings.

It is a general rule that a certain loss of rigidity must be tolerated to attain higher speeds.

For additional information about attainable speeds, refer to *Speeds* (→ **page 28**).

Diagram 2

Relative speed capability of angular contact ball bearings



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

Loads

When selecting SKF super-precision bearings for high-speed applications, calculated rating life (and therefore basic load rating) is typically not a limiting factor. Other criteria such as stiffness, size of the required bore in a hollow shaft, machining speed and accuracy are normally the decisive factors.

When selecting the bearing type, the magnitude and direction of the load play an important role.

Radial loads

Super-precision cylindrical roller bearings can accommodate heavier radial loads than same-size ball bearings. They are incapable of supporting axial loads but can accommodate a limited amount of axial displacement between their inner and outer rings because there are no flanges on either the inner or outer ring, depending on the specific design.

Axial loads

Double direction angular contact thrust ball bearings in the BTW and BTM series are designed to support axial loads only, acting in either direction. Sets of angular contact ball bearings are also a viable solution, particularly in high-speed applications.

For large size bearing arrangements or those subjected to very heavy axial loads, special single direction thrust ball bearings or cylindrical roller thrust bearings are recommended. For detailed information about these special bearings, contact the SKF application engineering service.

To be sure that an axial bearing is only subjected to axial loads, the housing washer should be mounted with radial clearance.

Combined loads

A combined load consists of a radial and axial load acting simultaneously (→ **fig. 2**). A very effective way to accommodate combined loads is by using bearing types that can accommodate both radial and axial loads.

Super-precision bearings with these characteristics include:

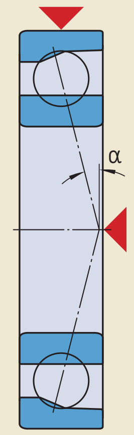
- angular contact ball bearings in the 718, 719, 70 and 72 series
- single direction angular contact thrust ball bearings for screw drives in the BSA and BSD series
- double direction angular contact thrust ball bearings for screw drives in the BEAS and BEAM series
- axial-radial cylindrical roller bearings in the NRT series

The ability of a bearing to accommodate an axial or radial load is determined by the contact angle α (→ **fig. 2**). A bearing with a 0° contact angle can accommodate pure radial loads only. As the contact angle increases, the axial load carrying capacity increases proportionately. When the contact angle reaches 90°, the bearing becomes a full thrust bearing, capable of accommodating only axial loads. Speed capability, however, is inversely proportional to the contact angle, meaning that as the contact angle increases, speed capability decreases.

Axial-radial cylindrical roller bearings accommodate the axial and radial components of a combined load with separate rows of rollers perpendicular to each other.

In applications where there are combined loads with a very heavy axial load component, the radial and axial loads can be supported by separate bearings.

Fig. 2



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Axial displacement

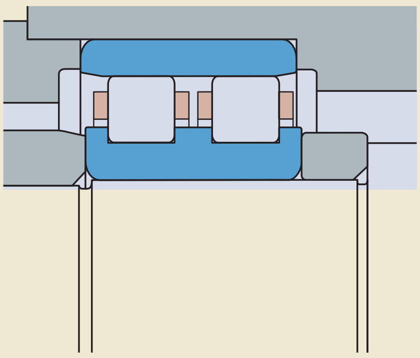
In most applications where thermal expansion and contraction of the shaft must be accommodated without inducing an axial load on the bearings, a locating/non-locating bearing system is typically used.

The bearing in the locating position must be able to locate the shaft axially in both directions. In machine tool applications, a set of angular contact ball bearings or a pair of angular contact thrust ball bearings can be used.

Non-locating bearings must accommodate thermal expansion and contraction of the shaft. Cylindrical roller bearings are well suited for this because they accommodate shaft movements relative to the housing, within the bearing (→ **fig. 3**). This enables the bearing to be mounted with an interference fit on both the inner and outer rings.

If paired angular contact ball bearings are used in the non-locating position, either the inner or outer ring of both bearings must have a loose fit so that they can slide on the shaft or in the housing. A loose fit, however, has a negative effect on system rigidity.

Fig. 3



Sealing solutions

To keep lubricant in and contaminants out of the bearing, SKF can supply some super-precision bearings with integral seals:

- non-contact seals (→ **fig. 4**)
- contact seals (→ **fig. 5**)

Sealed bearings can provide cost-effective and space-saving solutions for many applications. Sealed bearings include:

- angular contact ball bearings with non-contact seals
- single direction angular contact thrust ball bearings for screw drives with non-contact seals
- double direction angular contact thrust ball bearings for screw drives with contact or non-contact seals

Bearings sealed on both sides are typically lubricated for the life of the bearing and should not be washed. They are filled with the appropriate amount of high-quality grease under clean conditions. They cannot be relubricated except for certain bearings for screw drives which are equipped with relubrication features.

Fig. 4

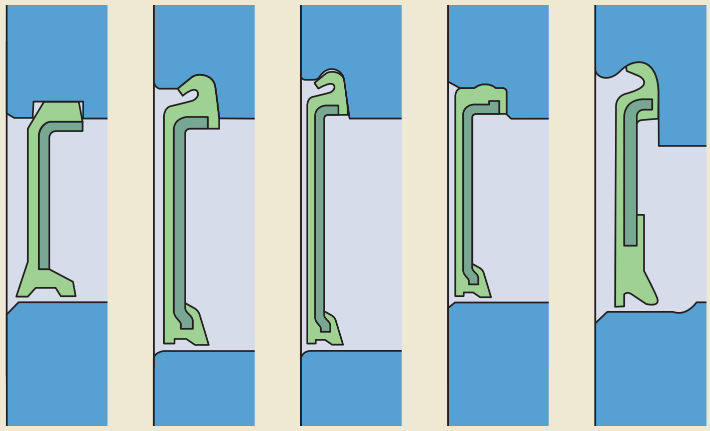
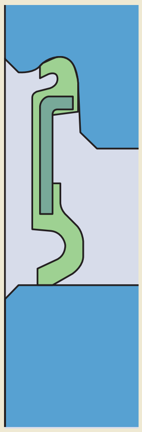


Fig. 5



Design considerations

The majority of super-precision bearings are used in machine tool spindles. Most of the information required when designing a bearing arrangement for maximum bearing performance can be found in the following sections.

Bearing arrangements

A bearing system, which is typically used to support a rotating shaft, generally requires two bearing arrangements. Depending on the requirements, such as stiffness or load directions, a bearing arrangement consists of one or more (matched) bearings.

Bearing arrangements for heavy loads

Lathe spindles are typically used to cut metals at relatively slow speeds. Depth of cut and feed rates are usually pushed to the limit depending on the required surface finish. In a lathe, power is normally transmitted to the spindle by a pulley or gears, resulting in heavy radial loads at the non-tool end. On the tool end of the spindle, where there are heavy combined loads, a high degree of rigidity and high load carrying capacity are important operational requirements.

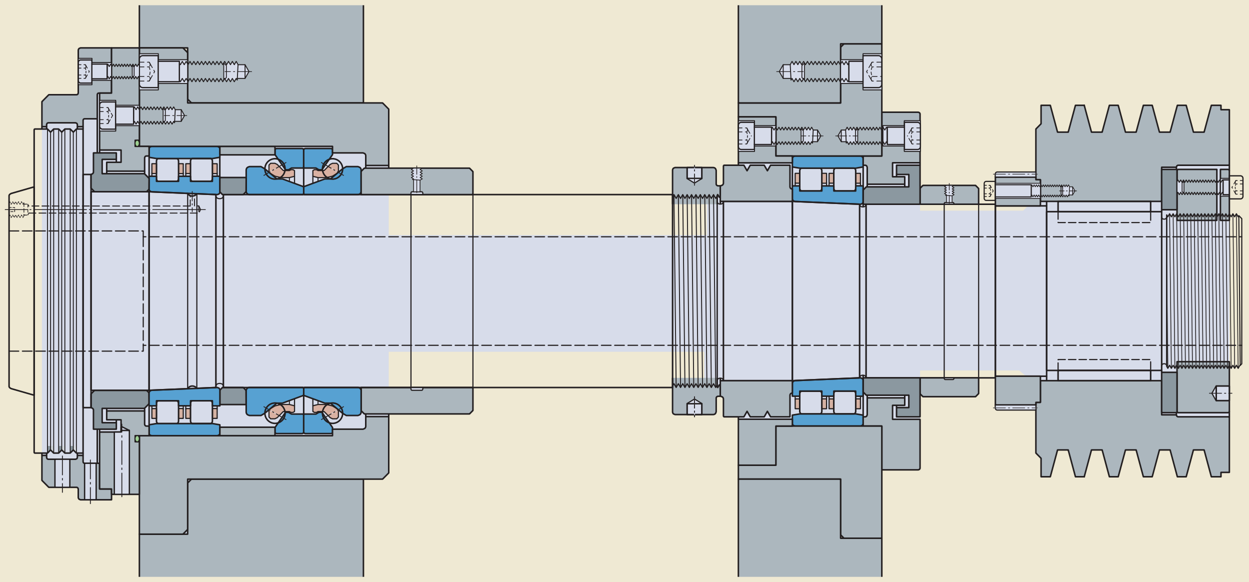
In a lathe spindle, it is common to have a double row cylindrical roller bearing in combination with a double direction angular contact thrust ball bearing at the tool end and a double row cylindrical roller bearing at the non-tool end (→ **fig. 10**).

The outside diameter of the thrust bearing housing washer is manufactured to a special tolerance. This tolerance enables the bearing to be radially free when mounted in a housing of appropriate bore diameter tolerance for the adjacent double row cylindrical roller bearing. This clearance is sufficient to relieve the thrust bearing from carrying significant radial load. This bearing arrangement provides a long calculated life and a high degree of rigidity and stability, both essential to the manufacture of good quality workpieces.

A good rule of thumb is to have the distance between the tool end and non-tool end bearing centres in the range 3 to 3,5 times the bore diameter of the bearing(s) at the tool end. This rule is particularly important when heavy loads are involved. For additional information, refer to *System rigidity* (→ **page 57**).

Fig. 10

Belt-driven CNC lathe spindle for large diameter bar stock



Additional arrangements for CNC lathes and conventional milling machines (→ **figs. 11** and **12**) and live centres (→ **fig. 13**) are provided.

Fig. 11

Belt-driven CNC lathe spindle

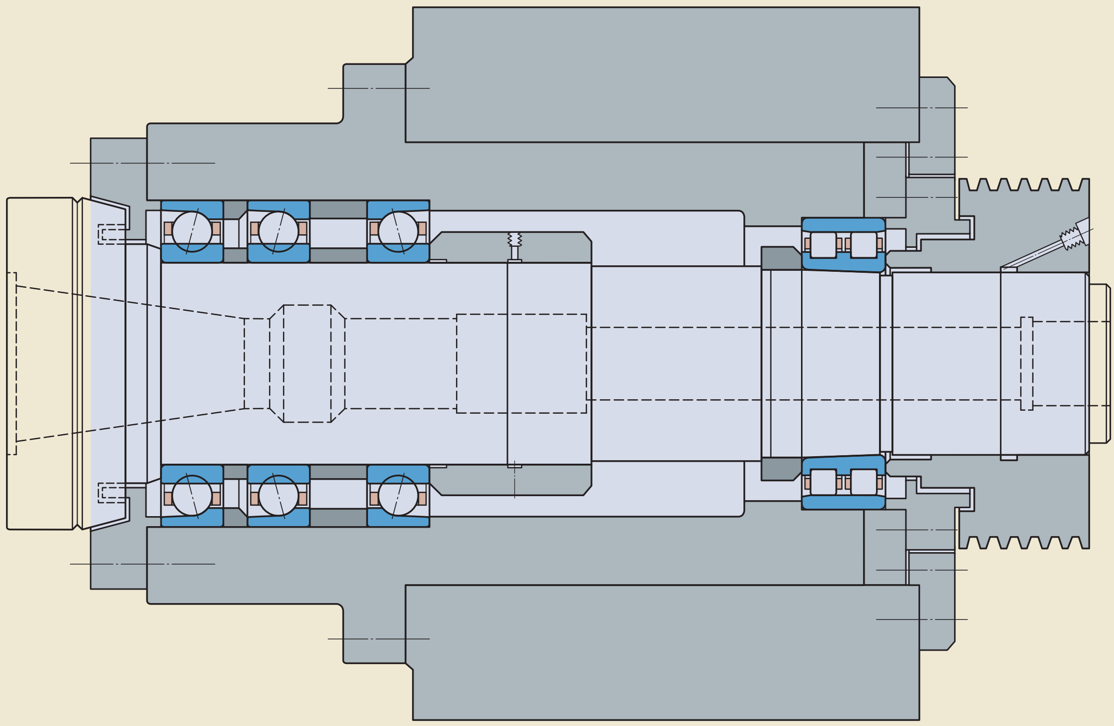


Fig. 12

Conventional milling machine spindle

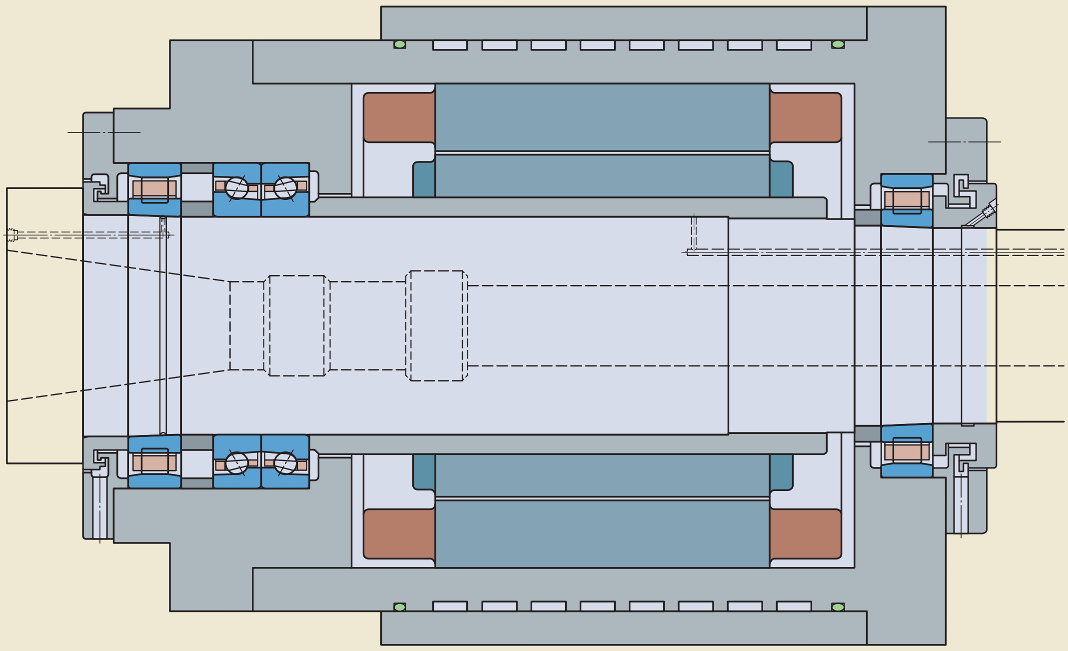
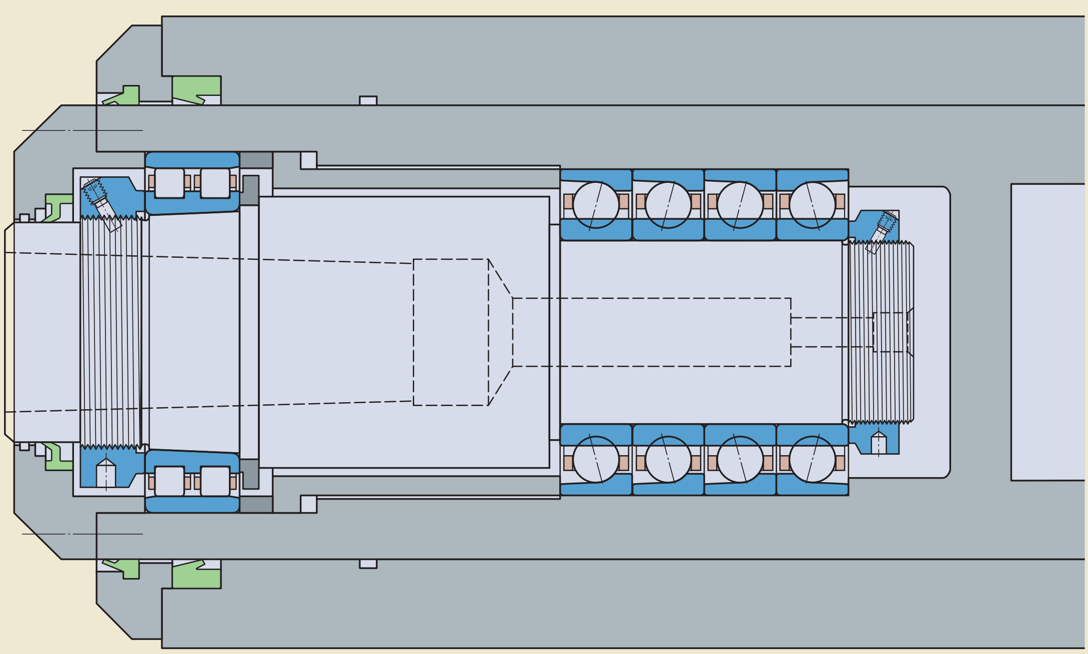


Fig. 13

Live centre spindle



For applications where available space is limited, super-precision angular contact ball bearings in the 718 or 719 series may be more suitable (→ **figs. 14** and **15**).

Fig. 14

Multispindle drilling head

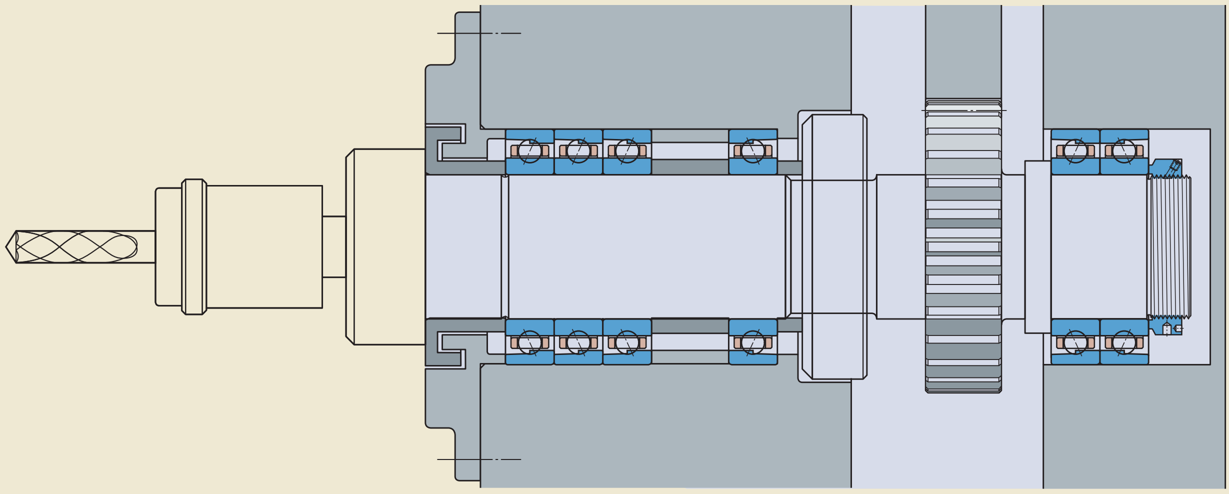


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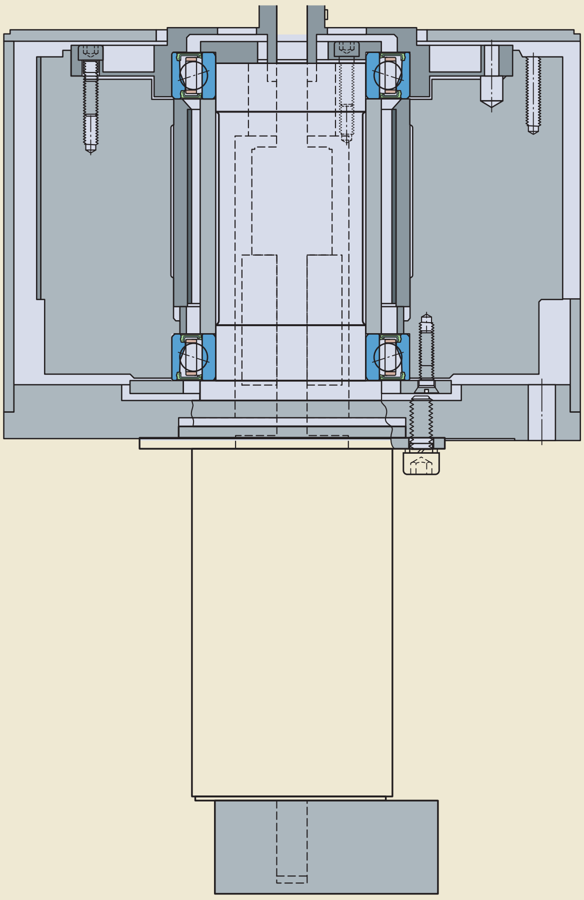
Fig. 15

Unit for detecting defects on silicon wafer chips



Bearing arrangements for greater rigidity and higher speeds

When higher speeds are required, as is the case for high-speed machining centres (A > 1 200 000 mm/min), there is typically a compromise between rigidity and load carrying capacity. In these applications, the spindle is usually driven directly by a motor (motorized spindles or electro-spindles), or through a coupling. Therefore, there are no radial loads on the non-tool end as is the case with a belt driven spindle. Consequently, single row angular contact ball bearings mounted in sets and single row cylindrical roller bearings are frequently used (→ **fig. 16**). In this bearing system, the tool end bearing set is axially located, while the cylindrical roller bearing on the non-tool end accommodates thermal expansion of the spindle shaft relative to the housing within the bearing.

Other arrangement examples for spindles in high-speed machining centres and milling machines are shown in **figs. 17** and **18**.

If enhanced performance is required, SKF recommends using hybrid bearings equipped with rolling elements made of bearing grade silicon nitride (Si_3N_4).

Fig. 16

Electro-spindle in a horizontal machining centre

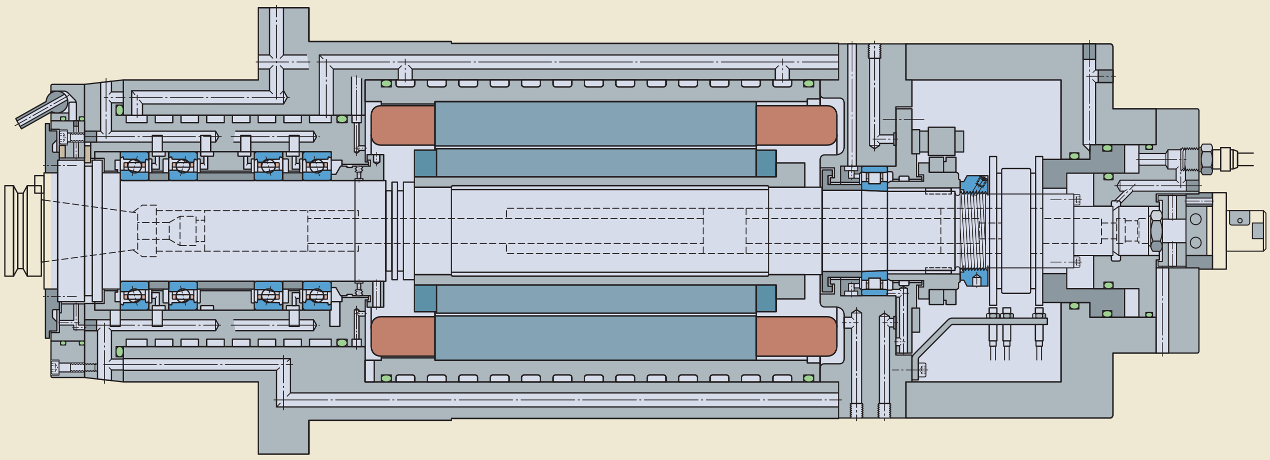


Fig. 17

Spindle in a horizontal machining centre

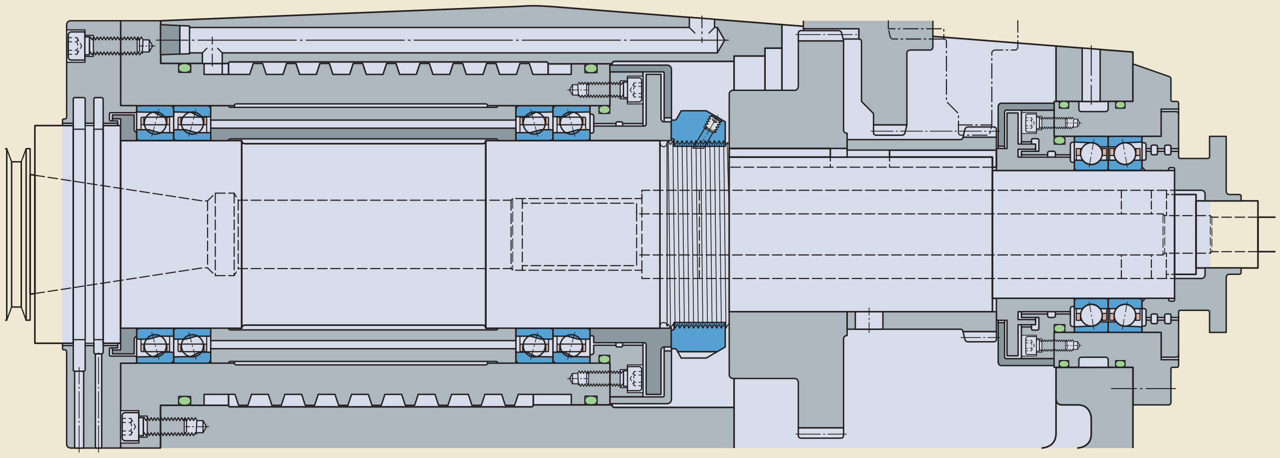
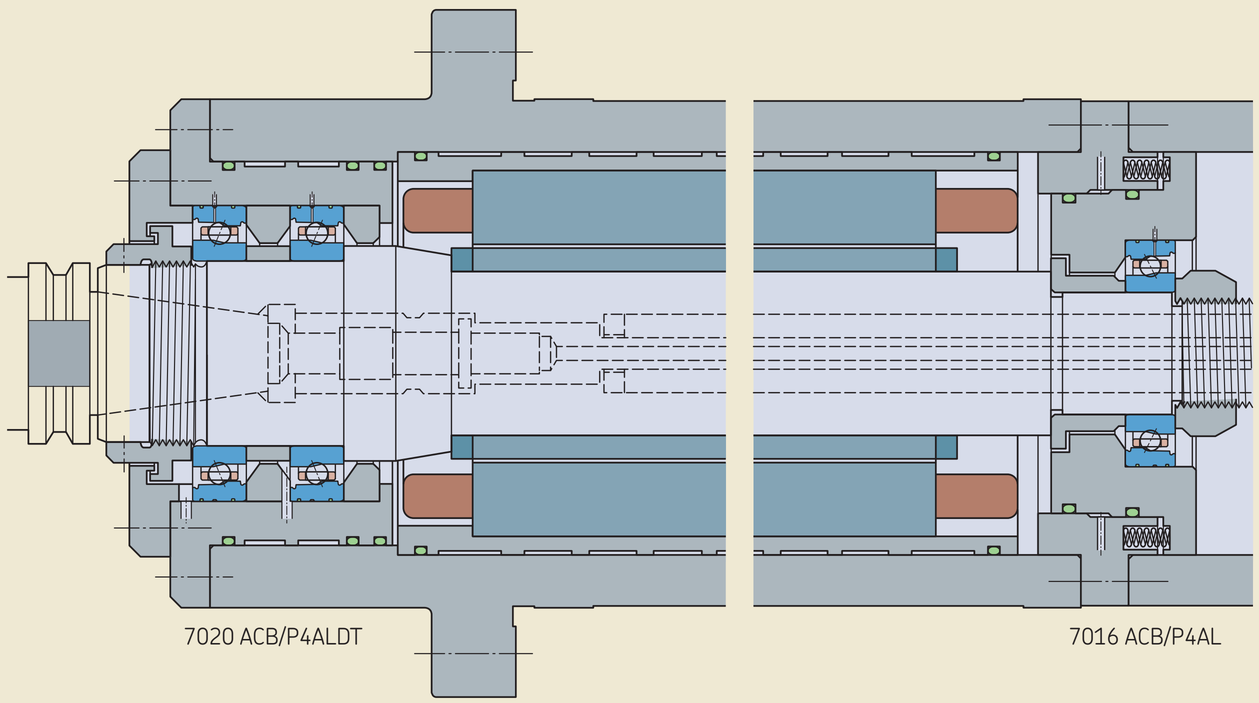


Fig. 18

Electro-spindle in a high-speed metal cutting machine



Bearing arrangements for maximum speed

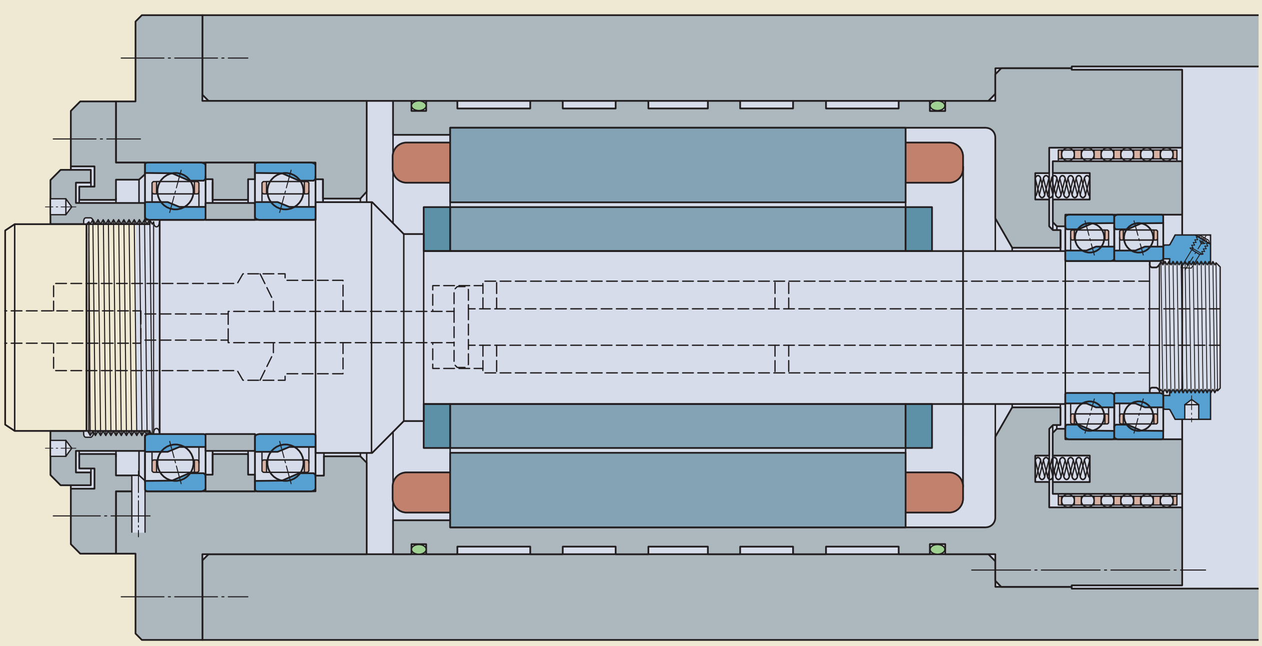
When sets of angular contact ball bearings are mounted with a fixed preload (without springs), that preload tends to increase when in service due to differential thermal expansion. As speeds rise the significance of this effect tends to increase.

To avoid the damaging effects of excessive preload, particularly in exceptionally high speed applications (A > 2 000 000 mm/min), it is quite common to use angular contact ball bearings preloaded by springs (→ **fig. 19**). Springs control preload independent of the effects of relative thermal expansion and minimize the amount of frictional heat generated in the bearings.

An even better solution than springs is to preload angular contact ball bearings with a hydraulic system. A hydraulic system adjusts the amount of preload according to the speed of the spindle to obtain the best combination of rigidity, frictional heat and bearing service life.

Fig. 19

Electro-spindle for an internal grinding machine



System rigidity

System rigidity in machine tool applications is extremely important because deflection under load has a major impact on machining accuracy. Bearing stiffness is only one factor that influences system rigidity. Others include:

- shaft stiffness
- tool overhang
- housing stiffness
- number and position of bearings and the influence of fits

Some general guidelines for designing high-speed precision applications include:

- Select the largest possible shaft diameter.
- Minimize the distance between the tool end bearing position and the spindle nose.
- Keep the distance between the two bearing sets short (→ **fig. 20**). A guideline for the spacing is:

  l ≈ 3 ... 3,5 d

where
l = distance between the first tool end bearing row and the rearmost non-tool end bearing row
d = tool end bearing bore diameter

Diagram 9 provides an overview of the relative stiffness of different bearing systems. For details about the bearing series, refer to *Designation system* in the relevant product chapter. The comparison is based on preloaded bearings with 100 mm bore on the tool end and 90 mm bore on the non-tool end. These guideline values cannot substitute for precise system rigidity calculations. For advanced system analysis, contact the SKF application engineering service.

Fig. 20

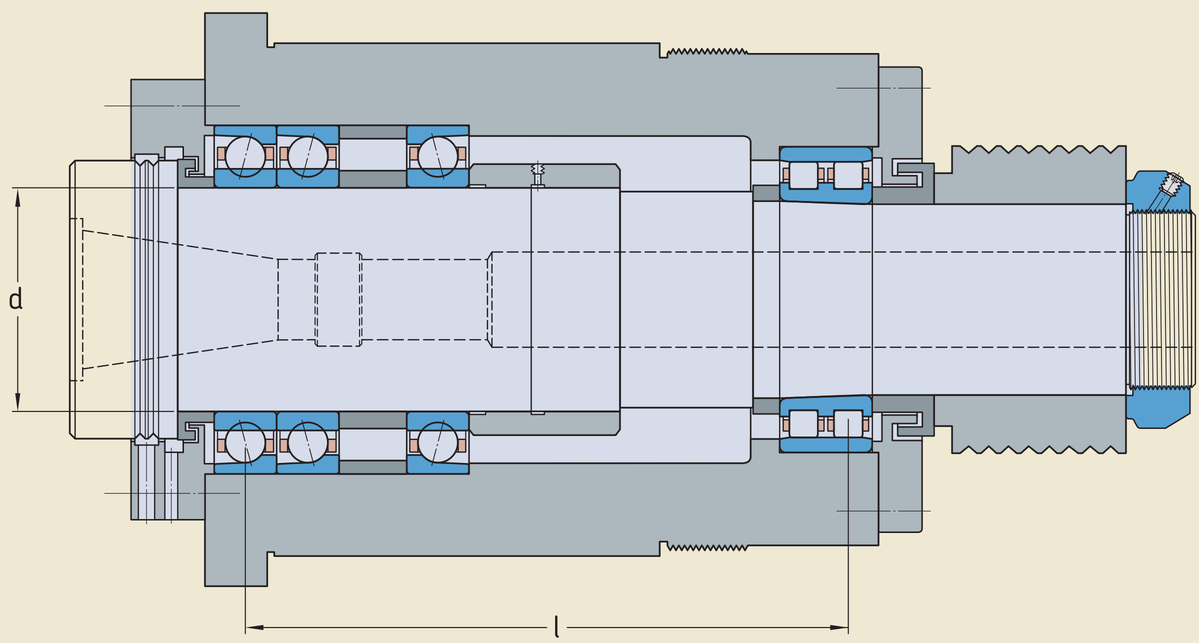
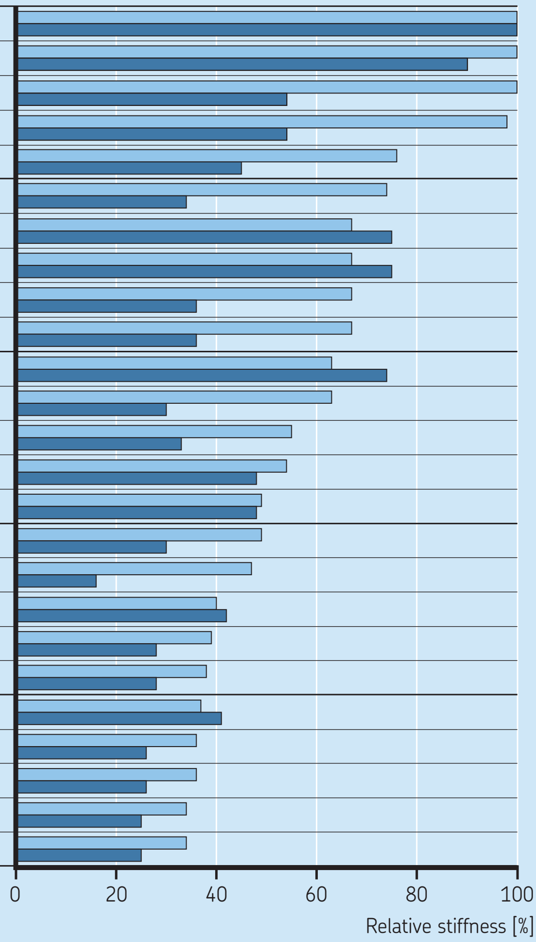


Diagram 9

Relative stiffness of typical spindle bearing systems

Tool end	Non-tool end
NN 3020 KTN + BTW 100 CTN9	NN 3018 KTN
NN 3020 KTN + BTM 100 BTN9/DBB	NN 3018 KTN
NN 3020 KTN + BTM 100 ATN9/DBB	NN 3018 KTN
NN 3020 KTN + BTM 100 ATN9/DBB	N 1018 KTN
7020 CD/QBCB	N 1018 KTN
71920 CE/QBCB	N 1018 KTNHA
71920 ACD/TBTB	NN 3018 KTN
71920 ACD/TBTB	71918 CD/DBA
7020 CD/TBTB	NN 3018 KTN
7020 CD/TBTB	7018 CD/DBA
7020 ACD/TBTB	7018 CD/DBA
7020 CE/QBCB	N 1018 KTNHA
7020 CE/HCDT	7018 CE/HCDT
7020 ACD/DBB	7018 CD/DBA
71920 ACE/HCTBTA	71918 CE/HCDBA
7020 CD/DT	7018 CE/DT
7020 CE/DBB	N 1018 KTNHA
71920 ACE/TBTA	71918 CE/DBA
7020 ACE/HCDBA	7018 CD/HCDBA
7020 ACE/HCDBA	N 1018 KTNHA/HC5
7020 ACE/TBTA	7018 CE/DBA
71920 ACE/DBA	N 1018 KTNHA
71920 ACE/DBA	71918 CE/DBA
7020 ACE/DBA	7018 CE/DBA
7020 ACE/DBA	N 1018 KTNHA



Angular contact ball bearings
AC 25° contact angle
C 15° contact angle
D High-capacity D design
E High-speed E 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 Extra light or light preload
B Light or moderate preload

Cylindrical roller bearings
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 stiffness

The stiffness of a rolling bearing is characterized by the magnitude of the elastic deformation (deflection) in the bearing under load. It is expressed as the ratio of load to deflection and depends on the bearing type, design and size. The most important parameters are:

- type of rolling elements; roller bearings have a higher degree of stiffness than ball bearintgs because of the contact conditions between the rolling elements and raceways
- rolling element material (→ **diagram 10**)
- number and size of rolling elements
- contact angle (→ **diagram 11**)
- preload class (→ **diagram 12**)

Bearing stiffness can be further enhanced by applying a preload (→ *Bearing preload*, **page 68**). Preloading bearings is standard practice in machine tool applications.

A loose fit on a mating component can have a negative influence on the stiffness of a bearing arrangement. However, a loose housing fit may be necessary for bearing arrangements using angular contact ball bearings in the non-locating position. Typically the non-locating bearing position is on the non-tool end of a spindle shaft and, therefore, the influence on system rigidity for the tool end is limited. If a high degree of stiffness is also desired for the non-tool end, a cylindrical roller bearing with a tapered bore should be used. This arrangement can accommodate axial displacement of the spindle shaft relative to the housing within the bearing and enables an interference fit for both the inner and outer rings.

Diagram 10

Radial stiffness of spring preloaded bearings

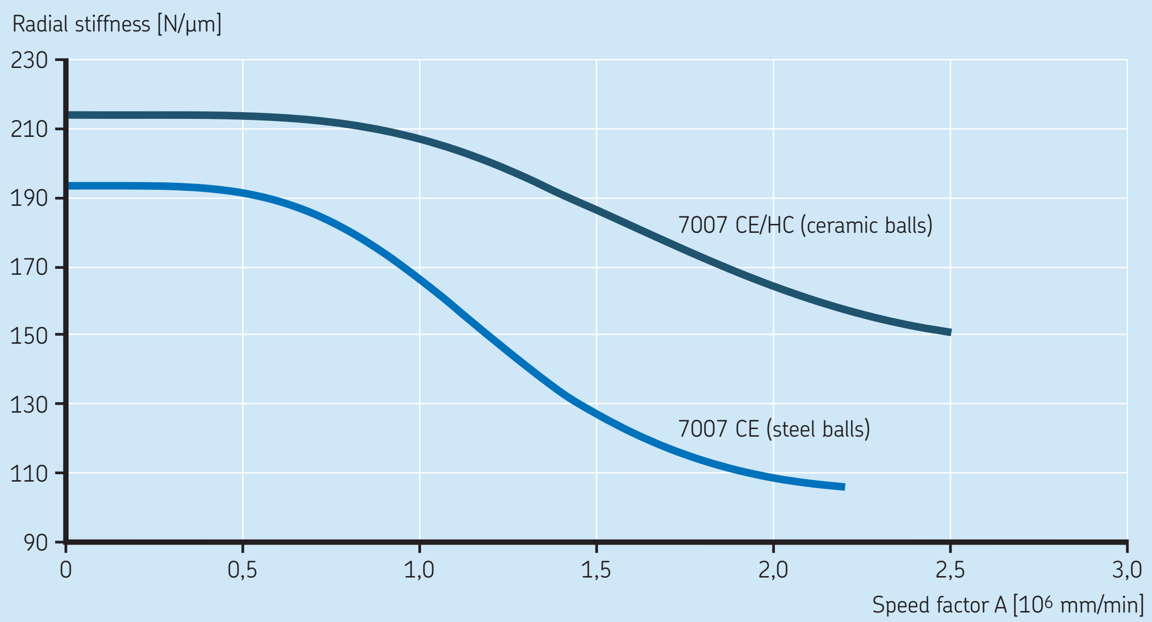


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Diagram 11

Axial displacement of back-to-back bearing sets with different contact angles

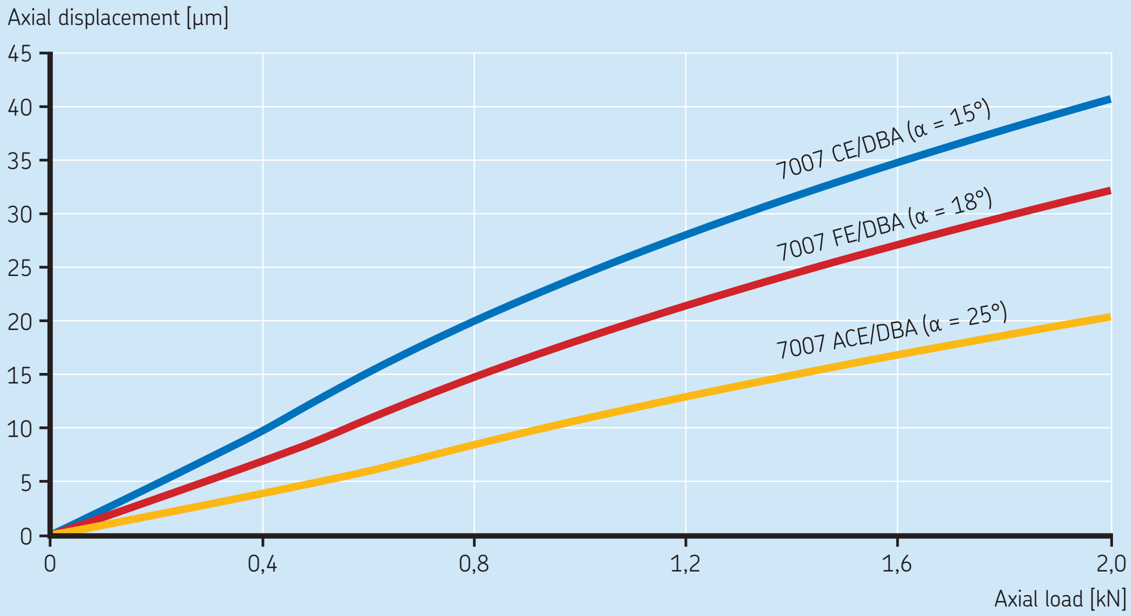
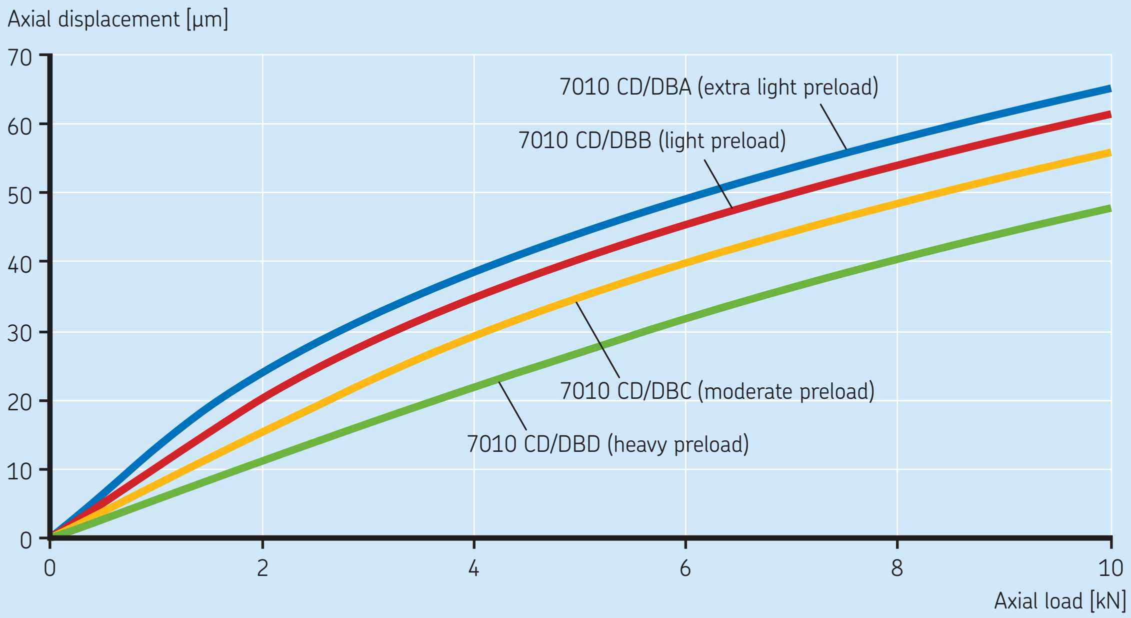


Diagram 12

Axial displacement of back-to-back bearing sets with different preload



Radial location of bearings

If the load carrying capacity of a bearing is to be fully exploited, its rings or washers should be fully supported around their complete circumference and across the entire width of the raceway. The support, which should be firm and even, can be provided by a cylindrical or tapered seat, as appropriate or, for thrust bearing washers, by a flat (plane) support surface. This means that bearing seats should be manufactured to adequate tolerance classes and uninterrupted by grooves, holes or other features, unless the seat is prepared for the oil injection method. This is particularly important for super-precision bearings that have relatively thin rings which tend to reproduce the shape of the shaft or housing seat. In addition, the bearing rings should be reliably secured to prevent them from turning on or in their seats under load.

In general, satisfactory radial location and adequate support can only be obtained when the rings are mounted with an appropriate degree of interference. Inadequately or incorrectly secured bearing rings generally cause damage to the bearing and mating components. However, when axial displacement (as with a non-locating bearing) or easy mounting and dismounting are required, an interference fit cannot always be used. In cases where a loose fit is necessary, but an interference fit would normally be required, special precautions are necessary to limit the fretting wear that inevitably results from creep (the bearing ring turning on its seat). This can be done, for example, by surface hardening the bearing seat and abutments.

Recommended shaft and housing fits

Diameter tolerances for bearing seats

Shaft and housing seats for super-precision angular contact ball bearings, cylindrical roller bearings and double direction angular contact thrust ball bearings should be manufactured to the diameter tolerances recommended in:

- **table 7** for shaft seat tolerances
- **table 8** (→ **page 70**) for housing seat tolerances

For recommendations for other super-precision bearings, refer to the relevant section of:

- angular contact thrust ball bearings for screw drives (→ *Associated components*, **page 70**)
- axial-radial cylindrical roller bearings (→ *Design considerations*, **page 70**)

Values of appropriate ISO tolerance classes for super-precision bearings are listed in:

- **table 9** (→ **page 70**) for shaft tolerances
- **table 10** (→ **page 70**) for housing tolerances

The location of the commonly used tolerance classes relative to the bearing bore and outside diameter surface are shown in **fig. 21**.

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Table 7

Diameter tolerances for bearing seats on steel shafts

Bearing type	Shaft diameter over	incl.	Tolerance class[1)] Bearings to tolerance class P4, P4A, P4C, SP	P2, PA9A, UP	Deviations high	low
–	mm		–		µm	
Angular contact ball bearings						
with rotating outer ring load	–	400	h4	h3	–	–
with rotating inner ring load	–	30	–	–	+1	–3
	30	80	–	–	+2	–3
	80	120	–	–	+3	–3
	120	180	–	–	+4	–4
	180	250	–	–	+5	–5
	250	315	–	–	+6	–6
	315	400	–	–	+6,5	–6,5
Cylindrical roller bearings						
with a cylindrical bore	–	40	js4	–	–	–
	40	280	k4	–	–	–
	280	500	k4[2)]	–	–	–
	500	–	Contact the SKF application engineering service.			
Double direction angular contact thrust ball bearings	–	200	h4	h3	–	–

For hollow shafts, when A > 1 000 000 mm/min, contact the SKF application engineering service.
1) All ISO tolerance classes are valid with the envelope requirement (such as h4Ⓔ) in accordance with ISO 14405-1.
2) General guideline only. SKF recommends contacting the SKF application engineering service.

Fig. 21

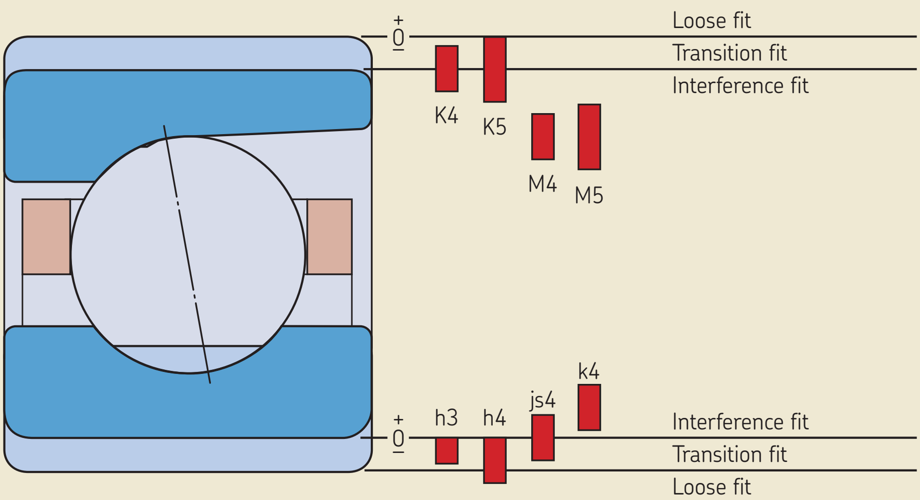

Table 8

Diameter tolerances for bearing seats in cast iron and steel housings

Bearing type	Conditions	Housing bore over	Housing bore incl.	Tolerance class[1)] Bearings to tolerance class P4, P4A, P4C, SP	P2, PA9A, UP	Deviations high	Deviations low
–	–	mm		–		µm	
Angular contact ball bearings	Locating bearings, axial displacement of outer ring unnecessary	–	18	–	–	+4	–1
		18	30	–	–	+5	–1
		30	50	–	–	+6	–1
		50	80	–	–	+7	–1
		80	120	–	–	+7	–3
		120	180	–	–	+9	–3
		180	250	–	–	+10	–4
		250	315	–	–	+12	–4
		315	400	–	–	+13	–5
		400	500	–	–	+14	–6
	Non-locating bearings, axial displacement of outer ring desirable	–	18	–	–	+7	+2
		18	30	–	–	+8	+2
		30	50	–	–	+9	+2
		50	80	–	–	+10	+2
		80	120	–	–	+13	+3
		120	180	–	–	+16	+4
		180	250	–	–	+19	+5
		250	315	–	–	+21	+5
		315	400	–	–	+24	+6
		400	500	–	–	+27	+7
	Rotating outer ring load	–	500	M5	M4	–	–
Cylindrical roller bearings	Light to normal loads (P ≤ 0,1 C)	–	900	K5	K4	–	–
	Heavy loads (0,1 C < P ≤ 0,15 C), rotating outer ring loads	–	900	M5	M4	–	–
Double direction angular contact thrust ball bearings		–	315	K5	K4	–	–

1) All ISO tolerance classes are valid with the envelope requirement (such as M4Ⓔ) in accordance with ISO 14405-1.

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Table 9

Values of ISO tolerance classes for shafts

Shaft diameter d Nominal over	incl.	Tolerance classes h3Ⓔ Deviations high	low	h4Ⓔ Deviations high	low	js4Ⓔ Deviations high	low	k4Ⓔ Deviations high	low
mm		µm							
–	**3**	0	–2	0	–3	+1,5	–1,5	+3	0
3	**6**	0	–2,5	0	–4	+2	–2	+5	+1
6	**10**	0	–2,5	0	–4	+2	–2	+5	+1
10	**18**	0	–3	0	–5	+2,5	–2,5	+6	+1
18	**30**	0	–4	0	–6	+3	–3	+8	+2
30	**50**	0	–4	0	–7	+3,5	–3,5	+9	+2
50	**80**	0	–5	0	–8	+4	–4	+10	+2
80	**120**	0	–6	0	–10	+5	–5	+13	+3
120	**180**	0	–8	0	–12	+6	–6	+15	+3
180	**250**	0	–10	0	–14	+7	–7	+18	+4
250	**315**	0	–12	0	–16	+8	–8	+20	+4
315	**400**	0	–13	0	–18	+9	–9	+22	+4
400	**500**	–	–	–	–	–	–	+25	+5

Table 10

Values of ISO tolerance classes for housings

Housing bore diameter D Nominal over	incl.	Tolerance classes K4Ⓔ Deviations high	low	K5Ⓔ Deviations high	low	M4Ⓔ Deviations high	low	M5Ⓔ Deviations high	low
mm		µm							
10	**18**	+1	–4	+2	–6	–5	–10	–4	–12
18	**30**	0	–6	+1	–8	–6	–12	–5	–14
30	**50**	+1	–6	+2	–9	–6	–13	–5	–16
50	**80**	+1	–7	+3	–10	–8	–16	–6	–19
80	**120**	+1	–9	+2	–13	–9	–19	–8	–23
120	**180**	+1	–11	+3	–15	–11	–23	–9	–27
180	**250**	0	–14	+2	–18	–13	–27	–11	–31
250	**315**	0	–16	+3	–20	–16	–32	–13	–36
315	**400**	+1	–17	+3	–22	–16	–34	–14	–39
400	**500**	0	–20	+2	–25	–18	–38	–16	–43
500	**630**	0	–22	0	–32	–26	–48	–26	–58
630	**800**	0	–25	0	–36	–30	–55	–30	–66
800	**1 000**	0	–28	0	–40	–34	–62	–34	–74

Selecting bearings to achieve preferred fits

Angular contact ball bearings and cylindrical roller bearings operating under normal loads and moderate speeds, should be selected to attain the interference/clearance values listed in:

- **table 11** for shaft fits
- **table 12** for housing fits

Diameter deviations of the bearings are provided on the package of super-precision angular contact ball bearings.

For extreme conditions, such as very high speeds or heavy loads, contact the SKF application engineering service.

For double direction angular contact thrust ball bearings (BTM and BTW series), the outside diameter of the housing washer is manufactured to tolerances such that sufficient radial clearance in the housing seat is obtained. Therefore, for bearings in the BTW and BTM series mounted adjacent to an appropriate cylindrical roller bearing in the same housing seat, tolerances tighter than those recommended in **table 8** (**→ page 74**) should not be used. For additional information, refer to *Double direction angular contact thrust ball bearings* (**→ page 74**).

Table 11

Preferred shaft fits

Bearing type	Bearing bore over	incl.	Interference
–	mm		µm
Angular contact ball bearings	–	50	0 to 2
	50	80	1 to 3
	80	120	1 to 4
	120	180	2 to 5
	180	250	2 to 6
	250	315	2 to 7
	315	400	3 to 8

Table 12

Preferred housing fits

Bearing type	Bearing outside diameter over	incl.	Clearance locating	non-locating	Interference
–	mm		µm		µm
Angular contact ball bearings	–	50	2 to 6	6 to 10	–
	50	80	2 to 6	6 to 11	–
	80	120	2 to 7	8 to 13	–
	120	180	2 to 9	10 to 16	–
	180	250	4 to 10	12 to 19	–
	250	315	4 to 10	14 to 22	–
	315	500	5 to 12	16 to 25	–
Cylindrical roller bearings	–	460	–	–	0 to 2

Accuracy of seats and abutments

Geometrical and running accuracy

Maximum running accuracy, high speeds and low operating temperatures can only be achieved, even with super-precision bearings, if the mating parts and other associated components are made with equal precision as the bearings. Deviations from geometric form of associated seats and abutments should therefore be kept to a minimum when machining mating parts. Form and position recommendations in accordance with ISO 1101 are provided in **table 13** (→ **page 75**).

Thin-walled bearing rings adapt themselves to the form of their seat. Any errors of form on the shaft or housing seat can therefore affect the bearing raceways and bearing performance, e.g. angular misalignment of one bearing ring relative to the other, can cause loss of running accuracy, load concentration and high operating temperatures, particularly at high speeds.

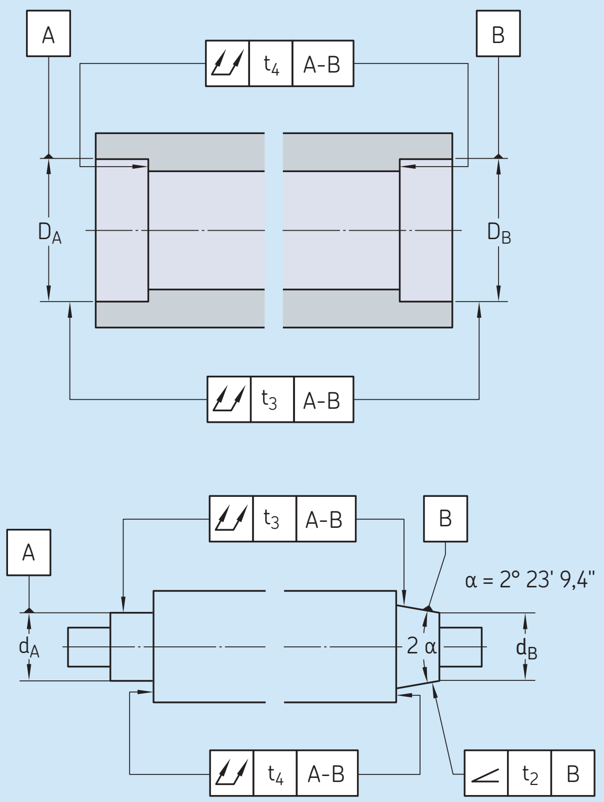
The numerical values of IT tolerance grades in accordance with ISO 286-1 are listed in **table 14** (→ **page 75**).

Surface roughness

The surface roughness of a bearing seat does not have the same degree of influence on bearing performance as the dimensional and geometrical tolerances of the seat. However, obtaining a desired interference fit depends on the roughness of the mating surfaces, which is directly proportional to fit accuracy. Guideline values for the mean surface roughness R_a are listed in **table 15** (→ **page 75**) for different bearing tolerance classes. These recommendations apply to ground seats.

Table 13

Geometrical tolerances for bearing seats on shafts and in housings



Surface Characteristic	Symbol	Tolerance zone	**Permissible deviations** Bearings to tolerance class P4, P4A, P4C, SP	 P2, PA9A, UP
Cylindrical seat Total radial run-out	⌰	t_3	IT2/2	IT1/2
Flat abutment Total axial run-out	⌰	t_4	IT1	IT0
Angularity	∠	t_2	IT3/2	IT2/2

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Table 14

Values of ISO tolerance grades

Nominal dimension		Tolerance grades					
		IT0	IT1	IT2	IT3	IT4	IT5
over	incl.	max.					
mm		µm					
–	**3**	0,5	0,8	1,2	2	3	4
3	**6**	0,6	1	1,5	2,5	4	5
6	**10**	0,6	1	1,5	2,5	4	6
10	**18**	0,8	1,2	2	3	5	8
18	**30**	1	1,5	2,5	4	6	9
30	**50**	1	1,5	2,5	4	7	11
50	**80**	1,2	2	3	5	8	13
80	**120**	1,5	2,5	4	6	10	15
120	**180**	2	3,5	5	8	12	18
180	**250**	3	4,5	7	10	14	20
250	**315**	4	6	8	12	16	23
315	**400**	5	7	9	13	18	25
400	**500**	6	8	10	15	20	27
500	**630**	–	9	11	16	22	32
630	**800**	–	10	13	18	25	36
800	**1 000**	–	11	15	21	28	40

Table 15

Surface roughness of bearing seats

Seat diameter		Recommended R_a value for ground seats			
		Shaft		Housing bore	
		Bearings to tolerance class		Bearings to tolerance class	
		P4, P4A, P4C, SP	P2, PA9A, UP	P4, P4A, P4C, SP	P2, PA9A, UP
over	incl.	max.		max.	
mm		µm		µm	
–	**80**	0,2	0,1	0,4	0,4
80	**250**	0,4	0,2	0,4	0,4
250	**500**	0,8	0,4	0,8	0,8
500	**800**	0,8	0,8	0,8	0,8
800	**1 000**	0,8	0,8	1,6	1,6

Axial location of bearings

In general, an interference fit alone is inadequate to locate a bearing ring on a cylindrical seat. Under load, a bearing ring can creep on its seat. Some suitable means to secure the bearing axially is needed.

For a locating bearing, both rings should be secured axially on both sides.

For non-separable bearings in the non-locating position, the ring with an interference fit, typically the inner ring, should be secured axially on both sides. The other ring must be free to move axially on its seat to accommodate axial displacement.

Cylindrical roller bearings in the non-locating position are exceptions. The inner and outer rings of these bearings must be secured axially in both directions.

In machine tool applications, bearings at the tool end generally locate the shaft by transmitting the axial load from the shaft to the housing. In general, then, tool end bearings are located axially, while non-tool end bearings are axially free.

Locating methods

Lock nuts

Bearing inner rings that are mounted with an interference fit typically abut a shoulder on the shaft on one side. On the opposite side, they are normally secured by a precision lock nut (→ **fig. 22**).

Bearings with a tapered bore, mounted directly on a tapered shaft seat, are generally retained on the shaft by a spacer seated against a fixed abutment at the large end of the taper and a precision lock nut at the small end of the taper. The spacer width is adjusted to limit the drive-up distance of the bearing on its tapered seat.

For detailed information about precision lock nuts, refer to *Precision lock nuts* (→ **page 78**).

Spacer sleeves

Instead of integral shaft or housing shoulders, spacer sleeves or collars can be used between the bearing rings or between a bearing ring and an adjacent component (→ **fig. 23**). In these cases, the dimensional and form tolerances for abutments apply.

Fig. 22

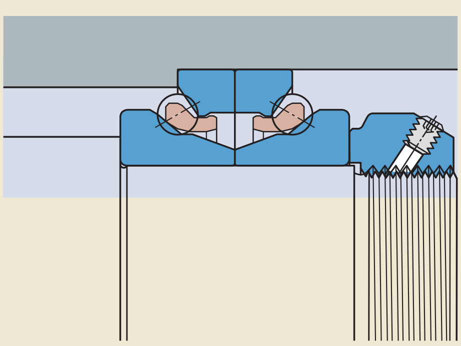
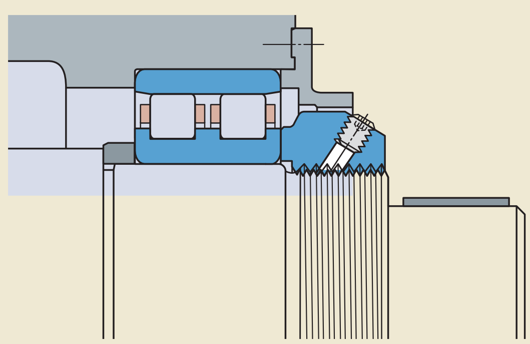


Fig. 23



Stepped sleeves

Another way to locate a bearing axially is to use a stepped sleeve (→ **fig. 24**) with a tight interference fit on the shaft. These sleeves are particularly suitable for super-precision bearing arrangements, as they have very small run-out and provide superior accuracy compared to threaded lock nuts. Therefore, stepped sleeves are typically used in very high-speed spindles where the accuracy provided by conventional locking devices may be inadequate.

For detailed information about stepped sleeves, refer to *Stepped sleeves* (→ **page 79**).

Housing covers

Bearing outer rings that are mounted with an interference fit typically abut a shoulder in the housing on one side. On the opposite side, they are normally located by a housing cover.

Housing covers and their securing screws can, in some cases, have a negative impact on bearing form and performance. If the wall thickness between the bearing seat and the bolt holes is too small, and/or the bolts are tightened too much, the outer ring raceway may deform. Bearings in the lightest ISO dimension series 18 and 19 are more susceptible to this than those in the ISO dimension series 10 or above.

It is advisable to use a larger number of small diameter bolts. Using only three or four bolts should be avoided because a small number of tightening points may produce lobes in the housing bore. This can result in noise, vibration, unstable preload or premature failure due to load concentrations. For complex spindle designs where space is limited, only thin-section bearings and a limited number of bolts may be possible. In these cases, SKF recommends an FEM (finite element method) analysis to accurately predict deformation.

As a guideline to achieve an appropriate clamping force between the cover spigot end face and the side face of the bearing outer ring, the cover spigot length should be adjusted so that, before the bolts are tightened, the axial gap between the cover and the housing side face is between 15 and 20 µm per 100 mm housing bore diameter (→ **fig. 25**).

Fig. 24

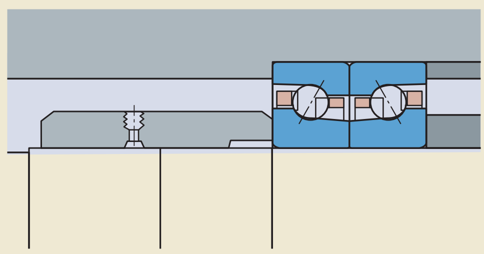
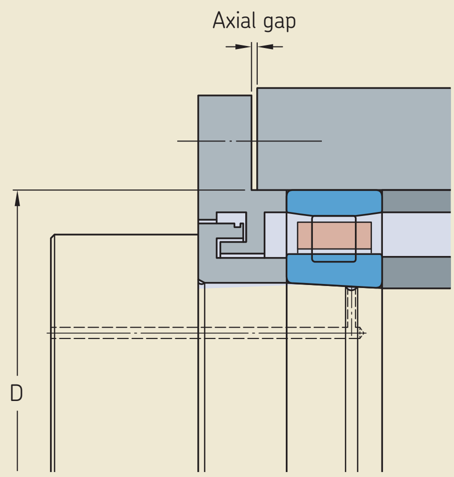


Fig. 25



Stepped sleeves

Stepped sleeves are pressure joints with two slightly different inside diameters that mate with a stepped shaft. An interference fit maintains the sleeve's position axially and determines its axial load carrying capacity. The stepped design of the fitting surface simplifies alignment during mounting but also facilitates dismounting when using the oil injection method.

Stepped sleeves do not create any stresses that might reduce the running accuracy of a shaft, but do enhance shaft stiffness. They are typically used in very high speed, lightly loaded applications where there are minimal shock loads. Compared to threaded lock nuts, stepped sleeves provide superior mounting accuracy, provided the sleeve and its seats are manufactured to the appropriate specifications, and the sleeve is mounted correctly.

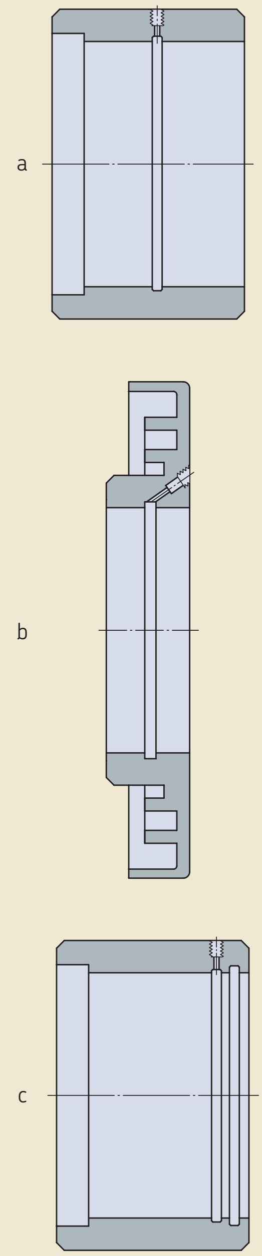
SKF does not supply or manufacture stepped sleeves, but design recommendations and suitable dimensions are provided on the pages that follow.

Designs

Stepped sleeves (→ **fig. 26**) can have either a conventional sleeve form (**a**) or they can be ring shaped (**b**). Ring-shaped stepped sleeves are typically used in applications where the sleeve will also be used to form part of a labyrinth seal (→ *Special stepped sleeve designs*, **page 80**).

In applications where there are relatively light axial loads, the end of the sleeve with the smaller diameter can have a loose fit on the shaft. However, if the oil injection method will be used to dismount the sleeve, the end of the sleeve with the loose fit should be sealed with an O-ring (**c**).

Fig. 26



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Recommended dimensions

Recommended dimensions are listed in:

- **table 16** (→ **page 81**) for stepped sleeves (without O-ring) and their seats (bearing arrangement example → **fig. 27**)
- **table 17** (→ **page 81**) for stepped sleeves with O-ring and their seats (bearing arrangement example → **fig. 28**)

When machining bores and shaft seats for stepped sleeves, it is very important that the actual degree of interference fit is as close as possible for both the major and minor diameters. Experience has shown that removal becomes much more difficult when there is even a small difference in interference.

Thin-walled hollow shafts may deform as a result of high contact pressures. Therefore, the sleeves for these shafts should have a relief closest to the bearing to avoid deformation of the bearing seat. The length of the relief should be 15 to 20% of the shaft diameter.

Fig. 27

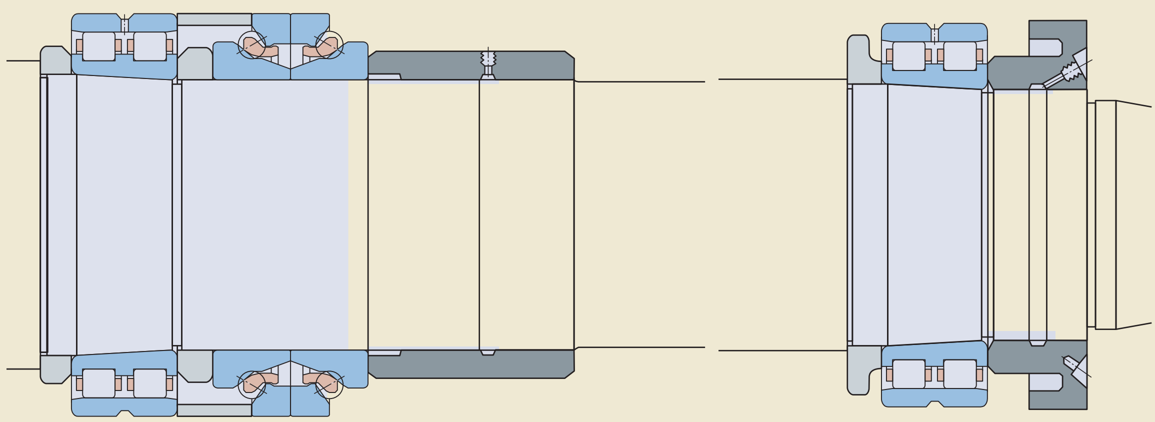


Fig. 28

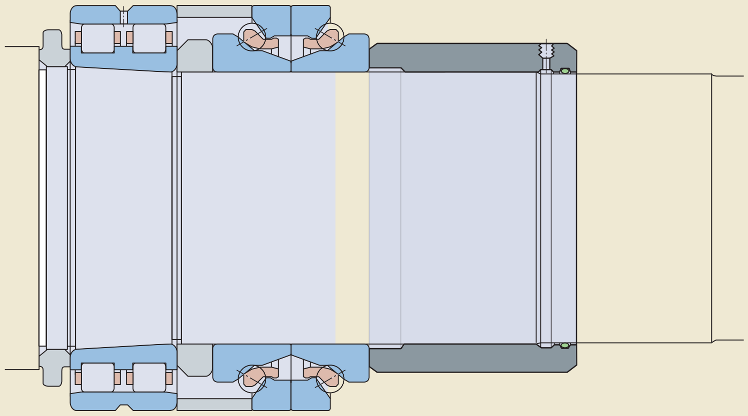
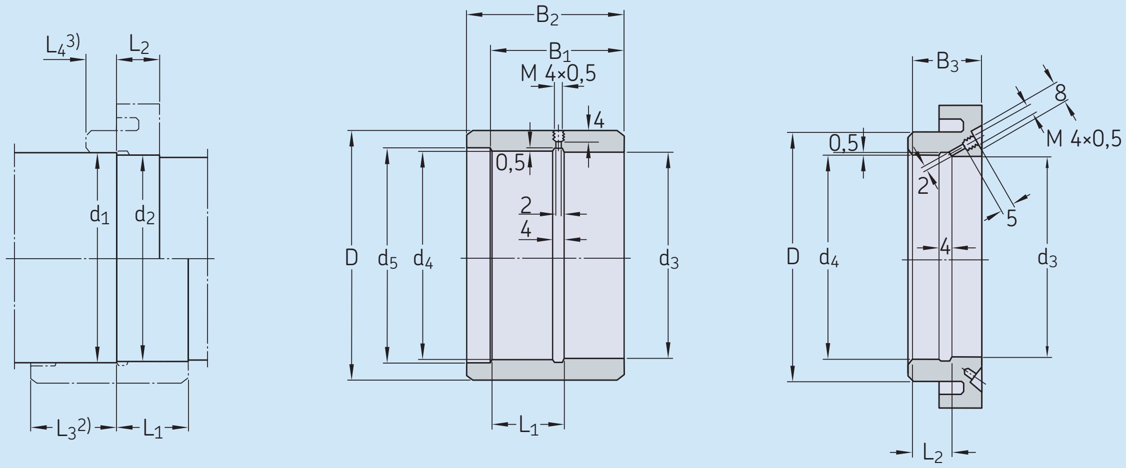


Table 16

Recommended dimensions for stepped sleeves and their seats



Dimensions Shaft d_1 h4Ⓔ	d_2 h4Ⓔ	Stepped sleeve d_3 H4Ⓔ	d_4 H4Ⓔ	d_5 +0,5	D	B_1	B_2	B_3	L_1 ±0,1	L_2 ±0,1	**Temperature difference**[1] °C	°F
mm											°C	°F
17	16,968	16,95	16,977	19	27	26	31	13	15	8,5	150	*270*
20	19,964	19,94	19,971	22	30	28	33	14	16	9	150	*270*
25	24,956	24,92	24,954	27	35	30	35	15	17	9,5	150	*270*
30	29,946	29,91	29,954	32	40	32	38	16	18	10	140	*252*
35	34,937	34,9	34,943	37	47	34	40	17	19	10,5	140	*252*
40	39,937	39,9	39,943	42	52	36	42	18	20	11	130	*234*
45	44,927	44,88	44,933	47	58	38	46	19	21	11,5	130	*234*
50	49,917	49,86	49,923	52	63	40	48	20	22	12	130	*234*
55	54,908	54,85	54,922	57	70	42	50	21	23	12,5	120	*216*
60	59,908	59,85	59,922	62	75	44	54	22	24	13	120	*216*
65	64,898	64,83	64,912	67	80	46	56	23	25	13,5	120	*216*
70	69,898	69,83	69,912	72	86	48	58	24	26	14	110	*198*
75	74,898	74,83	74,912	77	91	50	60	25	27	14,5	100	*180*
80	79,888	79,82	79,912	82	97	52	62	26	28	15	100	*180*
85	84,88	84,81	84,9	87	102	54	64	27	29	15,5	100	*180*
90	89,88	89,8	89,9	92	110	56	68	28	30	16	100	*180*
95	94,87	94,79	94,9	97	114	58	70	29	31	16,5	90	*162*
100	99,87	99,79	99,9	102	120	60	72	30	32	17	90	*162*
105	104,87	104,78	104,89	107	125	62	74	31	33	17,5	90	*162*
110	109,86	109,77	109,89	112	132	64	76	32	34	18	90	*162*
120	119,86	119,77	119,89	122	142	68	80	34	36	19	80	*144*
130	129,852	129,75	129,868	132	156	72	84	36	38	20	90	*162*
140	139,852	139,74	139,858	142	166	76	88	38	40	21	90	*162*
150	149,842	149,73	149,858	152	180	80	95	40	42	22	80	*144*
160	159,842	159,73	159,858	162	190	84	99	42	44	23	80	*144*
170	169,842	169,72	169,848	172	205	88	103	44	46	24	80	*144*
180	179,832	179,71	179,848	182	220	92	110	46	48	25	80	*144*
190	189,834	189,7	189,836	192	230	96	114	48	50	26	80	*144*
200	199,834	199,7	199,836	202	245	100	118	50	52	27	70	*126*

[1] The difference in temperature between shaft and sleeve or ring when installing
[2] L_3 = length of stepped sleeve over diameter $d_1 = L_1 + B_2 - B_1 - 4$ [mm]
[3] L_4 = length of stepped ring over diameter $d_1 = L_2 - 4$ + recessed d_4 section [mm]

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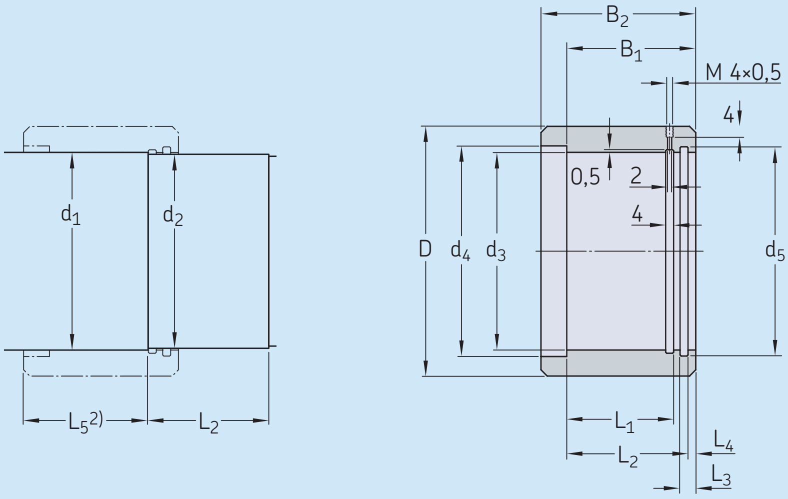
Table 17

Recommended dimensions for stepped sleeves with O-ring and their seats



Dimensions Shaft		Stepped sleeve										**Appropriate O-ring**	**Temperature difference**[1]	
d_1 h4Ⓔ	d_2 f7Ⓔ	d_3 H4Ⓔ	d_4 +0,5	d_5 H9	D	B_1	B_2	L_1 ±0,1	L_2 ±0,1	L_3	L_4 +0,2			
mm												–	°C	°F
17	16,95	16,977	19	20,6	27	26	31	17	22,9	6,5	3,1	16,3x2,4	150	*270*
20	19,95	19,971	22	23,6	30	28	33	19	24,9	6,5	3,1	19,3x2,4	150	*270*
25	24,9	24,954	27	29,5	35	30	35	21	26,1	7	3,9	24,2x3	150	*270*
30	29,9	29,954	32	34,5	40	32	38	24	28,1	7	3,9	29,2x3	140	*252*
35	34,9	34,943	37	39,5	47	34	40	26	30,1	7	3,9	34,2x3	140	*252*
40	39,9	39,943	42	44,5	52	36	42	28	32,1	7	3,9	39,2x3	130	*234*
45	44,9	44,933	47	49,5	58	38	46	32	34,1	7	3,9	44,2x3	130	*234*
50	49,9	49,923	52	54,5	63	40	48	34	36,1	7	3,9	49,2x3	130	*234*
55	54,9	54,922	57	59,5	70	42	50	36	38,1	7	3,9	54,2x3	120	*216*
60	59,9	59,922	62	64,5	75	44	54	40	40,1	7	3,9	60x3	120	*216*
65	64,85	64,912	67	69,5	80	46	56	42	42,1	7	3,9	65x3	120	*216*
70	69,85	69,912	72	74,5	86	48	58	42	44,1	8	3,9	69,5x3	110	*198*
75	74,85	74,912	77	79,5	91	50	60	44	46,1	8	3,9	74,5x3	100	*180*
80	79,85	79,912	82	84,5	97	52	62	46	48,1	8	3,9	79,5x3	100	*180*
85	84,85	84,9	87	89,5	102	54	64	48	50,1	8	3,9	85x3	100	*180*
90	89,85	89,9	92	94,5	110	56	68	52	52,1	8	3,9	90x3	100	*180*
95	94,85	94,9	97	99,5	114	58	70	54	54,1	8	3,9	94,5x3	90	*162*
100	99,85	99,9	102	104,5	120	60	72	54	56,1	9	3,9	100x3	90	*162*
105	104,85	104,89	107	109,5	125	62	74	56	58,1	9	3,9	105x3	90	*162*
110	109,85	109,89	112	114,5	132	64	76	58	60,1	9	3,9	110x3	90	*162*
120	119,85	119,89	122	124,5	142	68	80	62	64,1	9	3,9	120x3	80	*144*
130	129,8	129,868	132	134,4	156	72	84	66	68,1	9	3,9	130x3	90	*162*
140	139,8	139,858	142	144,4	166	76	88	70	72,1	9	3,9	140x3	90	*162*
150	149,8	149,858	152	159	180	80	95	73	72,6	13	7,4	149,2x5,7	80	*144*
160	159,8	159,858	162	169	190	84	99	77	76,6	13	7,4	159,2x5,7	80	*144*
170	169,8	169,848	172	179	205	88	103	81	80,6	13	7,4	169,2x5,7	80	*144*
180	179,8	179,848	182	189	220	92	110	88	84,6	13	7,4	179,2x5,7	80	*144*
190	189,8	189,836	192	199	230	96	114	92	88,6	13	7,4	189,2x5,7	80	*144*
200	199,8	199,836	202	209	245	100	118	96	92,6	13	7,4	199,2x5,7	70	*126*

[1] The difference in temperature between shaft and sleeve when installing
[2] L_5 = length of stepped sleeve over diameter $d_1 = L_1 + B_2 - B_1 - 4$ [mm]

Material

SKF recommends using a heat-treatable steel with a yield point of at least 550 N/mm^2. The mating surfaces of both the sleeve and shaft should be hardened and ground.

Axial load carrying capacity

The degree of the actual interference fit(s) determines the axial load carrying capacity of a stepped sleeve. When stepped sleeves are made to the recommended dimensions listed in **tables 16** and **17** (→ **pages 84** and **84**), the surface pressure between a solid or thick-walled hollow shaft and sleeve, and the axial retaining force per millimetre hub width can be estimated using the approximate values listed in **table 18**. Stepped sleeves with a loose fit for the smaller diameter, exert only half of the axial retaining force of stepped sleeves with an interference fit for both diameters.

When designing stepped sleeves, axial shock forces on the sleeve must also be taken into consideration. If necessary, a threaded nut which is lightly tightened and which can also serve as a mounting aid can be used to secure the sleeve.

Special stepped sleeve designs

Stepped sleeves are used to secure and join other components. They enable hubs to be mounted and dismounted simply and can also replace various types of driver plates, dogs etc. The V-belt pulley shown in **fig. 29**, for example, is designed as a stepped sleeve with an integral labyrinth seal. In this case, the sleeve not only locates the bearing axially, it is also used to transmit torque.

Fig. 29

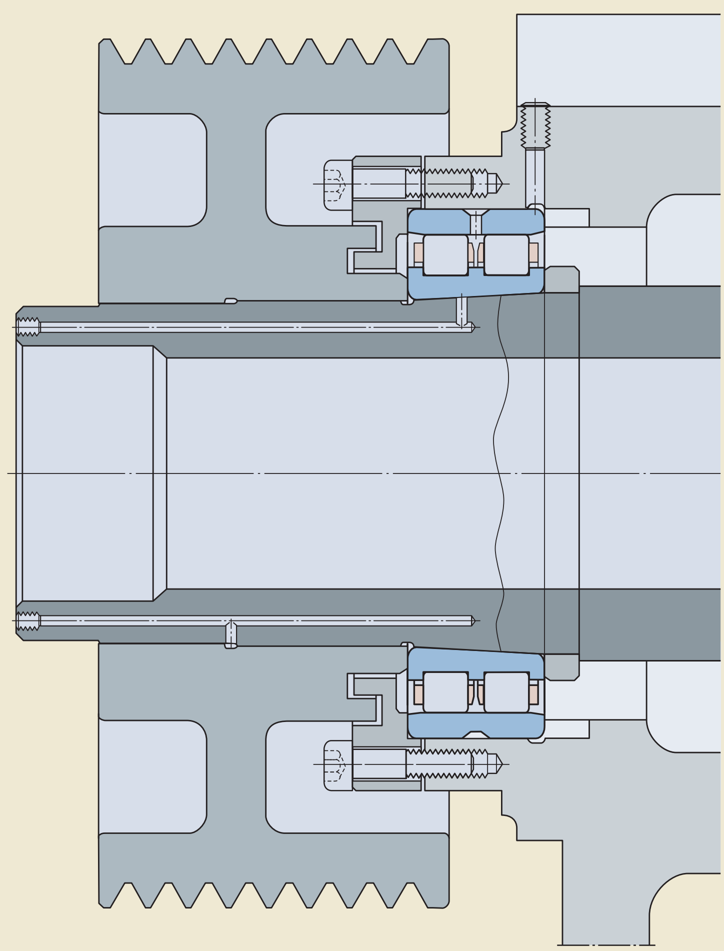


Table 18

Approximate surface pressure and axial retaining force of stepped sleeves[1)]

Approximate shaft diameter d	Approximate surface pressure	Approximate axial retaining force per mm hub width
mm	N/mm^2	N/mm
30	40	300
100	35	550
200	22	1 000

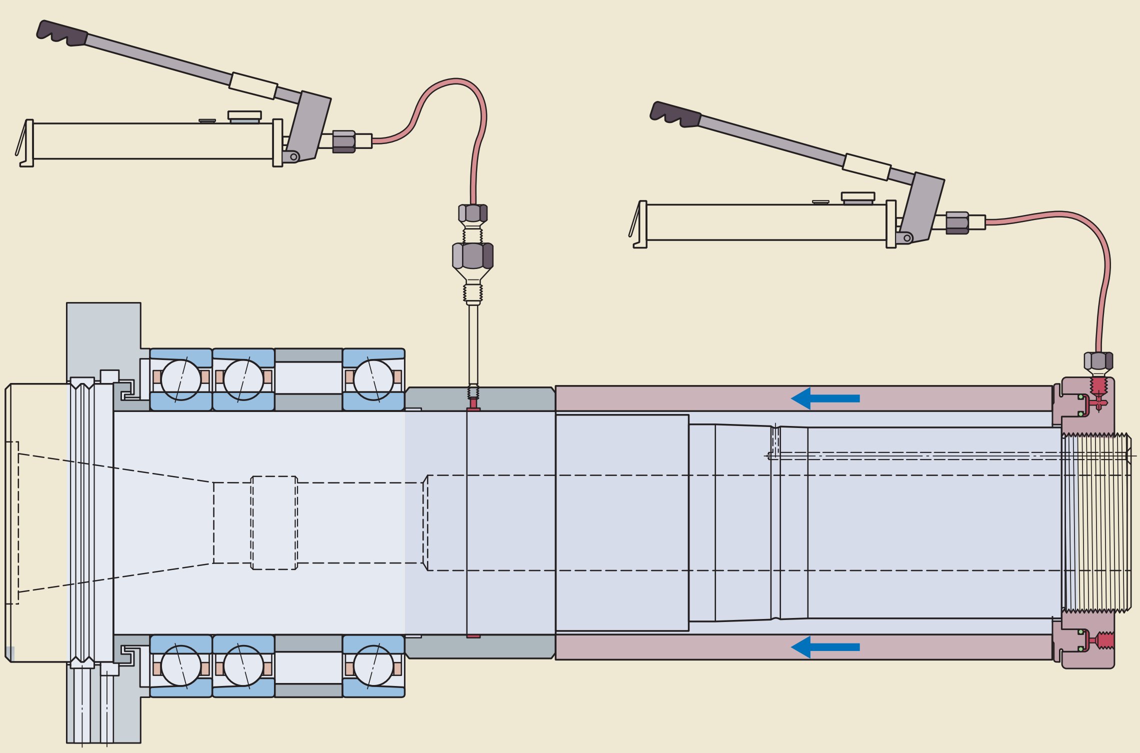
1) When made to the recommended dimensions listed in **tables 16** and **17** (→ **pages 85** and **85**).

Installation

The following procedure can be used to install stepped sleeves. If stepped sleeves are to be installed against bearings that are already greased, care should be taken that the injected oil / mounting fluid does not mix with the grease and impair its lubricating properties.

1 Heat the sleeve to obtain the required temperature difference listed in **tables 16** and **17** (→ **pages 86** and **86**).
2 Push the sleeve onto the shaft seat.
3 After the sleeve has cooled, inject oil or an SKF mounting fluid between the sleeve and shaft using suitable oil injection equipment (→ **fig. 30** and *Oil injection equipment and pressure media*). To avoid local stress peaks, the oil should be injected slowly and the oil pressure regulated.
4 Use a hydraulic nut and suitable distance sleeve to bring the sleeve to its final position (→ **fig. 30**). When using a hydraulic nut, the force of the nut against the bearing arrangement can be controlled by the oil pressure. As the sleeve “floats” on the oil film, any stresses produced during the shrinking of the sleeve (produced as the sleeve cooled) are relieved and the components can be correctly positioned relative to each other. When the required axial force has been obtained, the final position is reached.
5 With the tool still in position, release the oil pressure between the mating surfaces and allow the oil to drain. Normally it takes about 24 hours before the sleeve can support its full load.

Fig. 30



Removal

To remove a stepped sleeve, inject oil or an SKF dismounting fluid between the sleeve and shaft using suitable oil injection equipment (→ *Oil injection equipment and pressure media*). When sufficient oil pressure has been built up to separate the mating surfaces, an axial force will result due to the different bore diameters, and the sleeve will slide from its seat without requiring any additional external force.

WARNING
To avoid the risk of serious injury, attach a provision such as a lock nut to the shaft end to limit the sleeve travel when it suddenly comes loose.

Oil injection equipment and pressure media

SKF supplies oil injection equipment for installing and removing sleeves. For additional information, visit skf.com/mapro.

When selecting a suitable pump, keep in mind that the maximum permissible pressure should be considerably higher than the calculated surface pressure.

For installation, SKF recommends using the SKF mounting fluid LHMF 300. The fluid has a viscosity of 300 mm^2/s at 20 °C (*70 °F*). The advantage of this mounting fluid is that when installation is complete, the fluid will leave the joint quickly and completely so that metal-to-metal contact is restored relatively quickly.

For removal, SKF recommends using the SKF dismounting fluid LHDF 900. With a viscosity of 900 mm^2/s at 20 °C (*70 °F*), the fluid will provide an adequate oil film, even if the mating surface of the sleeve or shaft is scratched. Keep in mind that the fluid has a low flow rate and the permissible pressure of the oil injection equipment should never be exceeded.

Provisions for mounting and dismounting

It is often necessary to make provisions during the design stage to facilitate mounting and dismounting of a bearing. If, for example, slots or recesses are machined in the shaft and/or housing shoulders, it is possible to apply withdrawal tools (→ **fig. 31**). Threaded holes in the housing shoulders also enable the use of bolts to push a bearing from its seat (→ **fig. 32**).

If the oil injection method is to be used to mount or dismount bearings on a tapered seat, or to dismount bearings from a cylindrical seat, ducts and grooves should be provided in the shaft (→ **fig. 33**). Recommended dimensions for the appropriate grooves, ducts and threaded holes to connect the oil supply are listed in **tables 19** and **20**.

Fig. 31

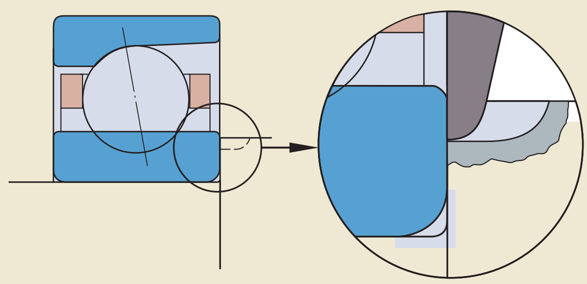


Fig. 32

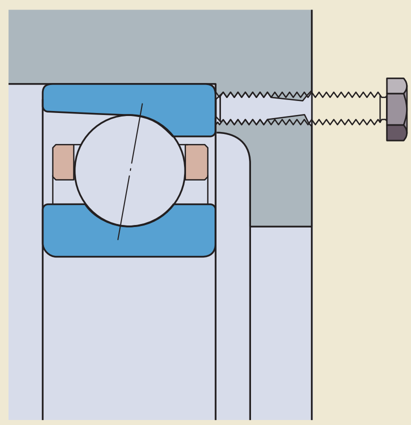


Fig. 33

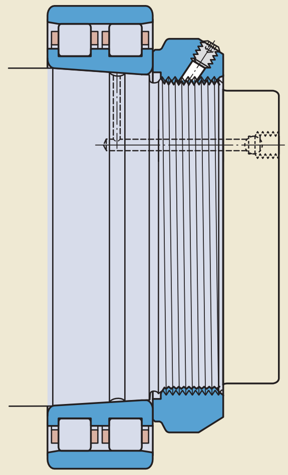
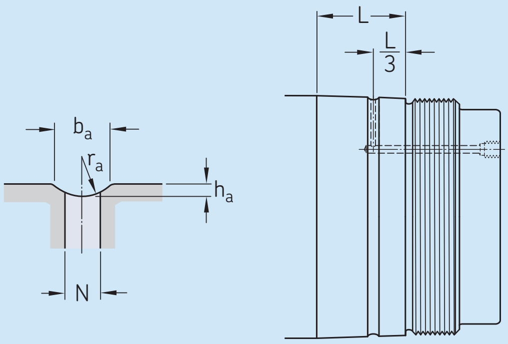


Table 19

Recommended dimensions for oil supply ducts and distribution grooves

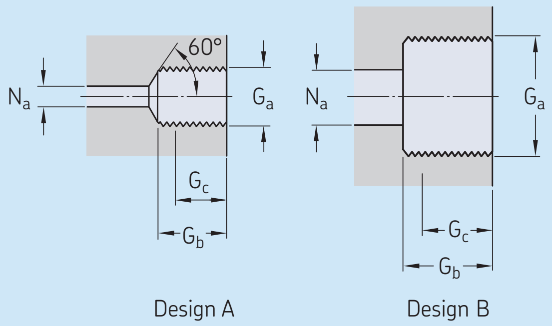


Seat diameter		Dimensions			
		b_a	h_a	r_a	N
over	incl.				
mm		mm			
–	**50**	2,5	0,5	2	2
50	**100**	3	0,5	2,5	2,5
100	**150**	4	0,8	3	3
150	**200**	4	0,8	3	3
200	**250**	5	1	4	4
250	**300**	5	1	4	4
300	**400**	6	1,25	4,5	5
400	**500**	7	1,5	5	5
500	**650**	8	1,5	6	6
650	**800**	10	2	7	7

L = width of bearing seat

Table 20

Design and recommended dimensions for threaded holes for connecting oil supply



Thread G_a	Design	Dimensions G_b	G_c[1]	N_a max.
–	–	mm		
M 4x0,5	A	5	4	2
M 6	A	10	8	3
G 1/8	A	12	10	3
G 1/4	A	15	12	5
G 3/8	B	15	12	8
G 1/2	B	18	14	8
G 3/4	B	20	16	8

[1] Effective threaded length

Bearing preload

Preload is a force acting between the rolling elements and bearing rings that is not caused by an external load. Preload can be regarded as negative internal clearance. Reasons to apply preload include:

- enhanced stiffness
- reduced noise level
- improved shaft guidance
- extended bearing service life
- improved running accuracy
- prevent skidding in high-speed applications during rapid starts and stops and under very light or no-load conditions

In the majority of high-precision applications, preload is needed to enhance system rigidity.

Angular contact ball bearings

Single row angular contact ball bearings are generally mounted as sets, in a back-to-back (→ **figs. 34** and **35**) or face-to-face arrangement (→ **fig. 36**), that are normally subjected to an axial preload. The preload is produced by displacing one bearing ring axially, relative to the other (→ **figs. 34** and **36**), by an amount corresponding to the desired preload force or by springs (→ **fig. 35**).

The standout of matched and universally matchable bearings is precision ground so that when two bearings are mounted immediately adjacent to each other, a given preload is obtained without further adjustment. Keep in mind that this preload is also influenced by the interference fit and the operating conditions. For additional information, refer to *Preload in mounted bearing sets* (→ **page 90**).

If it is necessary to change the preload, spacers between the bearing rings can be used. For additional information, refer to *Individual adjustment of preload* (→ **page 90**).

Fig. 34

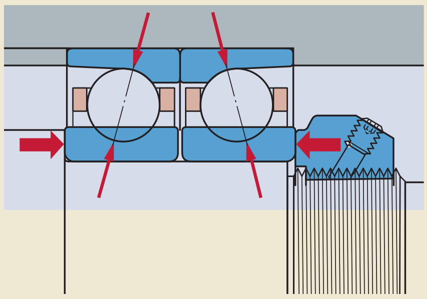


Fig. 35

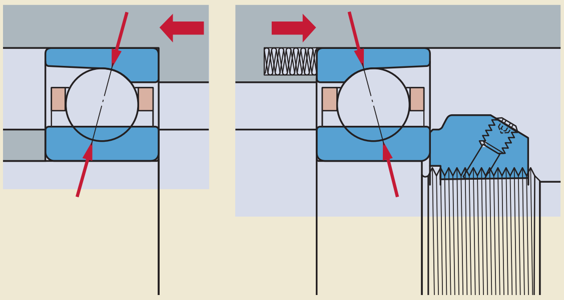
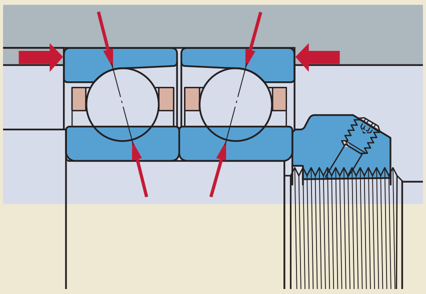


Fig. 36



Influence of an external load on preloaded bearing sets

The influence of an external axial load on preloaded bearing sets is illustrated in **diagram 13**. The curves represent the spring characteristics of two bearings in a back-to-back arrangement. The blue curve represents bearing A, which is subjected to an external axial force K_a. The red curve represents bearing B, which becomes unloaded by the axial force.

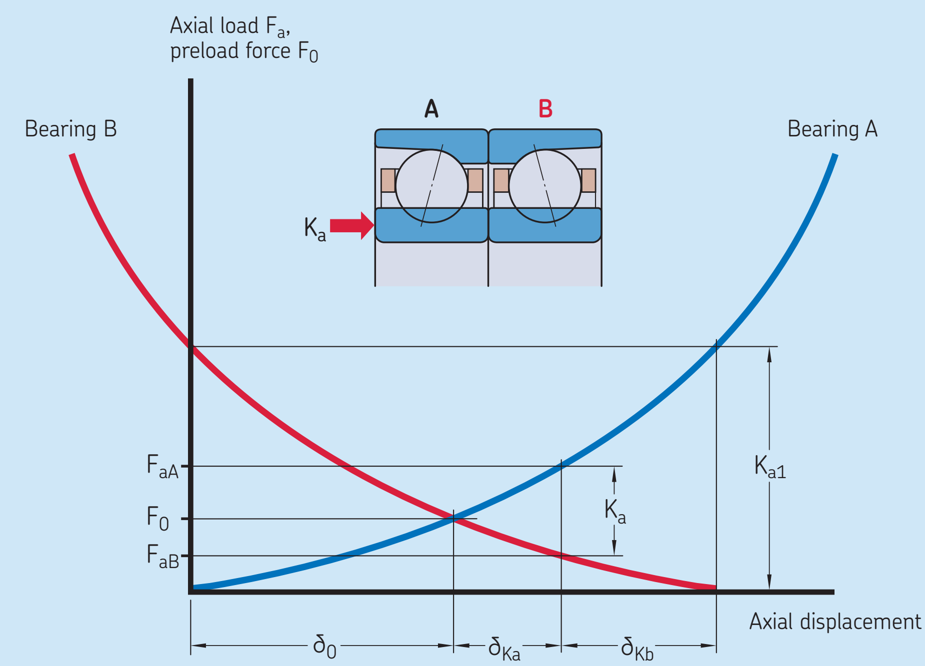
The two bearings are each preloaded by an axial displacement δ_0 of one bearing ring relative to the other, resulting in a preload force F_0 acting on both bearings. When bearing A is subjected to an external axial force K_a, the load on that bearing increases to F_{aA} while load on bearing B decreases to F_{aB}. Axial displacement of the bearing rings follows the spring curves. δ_{Ka} is the displacement of the bearing set while δ_{Kb} is the remaining preload [µm] on bearing B.

When the axial forces on the spindle reach the natural lifting force K_{a1}, bearing B becomes completely unloaded. When this happens, there is a significant risk that the unloaded balls stop rolling and start skidding, which if it occurs for any length of time will result in premature bearing failure.

The lifting force varies depending on the preload and bearing arrangement (→ **table 21**, **page 91**). It is possible to avoid the lifting force phenomena in one of two ways: either increase the preload, or use bearing sets with different contact angles. For additional information, contact the SKF application engineering service.

Diagram 13

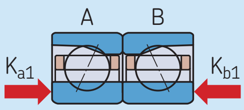
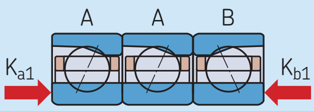
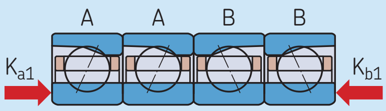
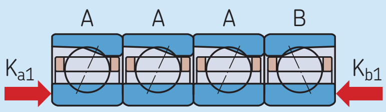
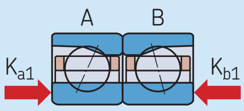
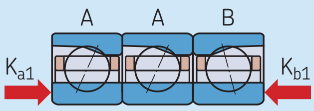
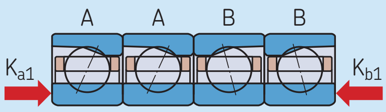
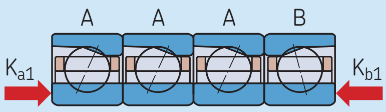
Influence of an external load on preloaded bearing sets



Principles of bearing selection and application

Table 21

Lifting forces for angular contact ball bearing sets

Arrangement	Lifting forces K_{a1}	K_{b1}
Same contact angles ($\alpha_A = \alpha_B$)		
	2,83 F_0	2,83 F_0
	4,16 F_0	2,08 F_0
	2,83 F_0	2,83 F_0
	5,4 F_0	1,8 F_0
Different contact angles (α_A = 25°, α_B = 15°)		
	5,9 F_0	1,75 F_0
	9,85 F_0	1,45 F_0
	5,9 F_0	1,75 F_0
	13,66 F_0	1,33 F_0

F_0 = preload force

Preloading with springs

Using springs to apply preload to angular contact ball bearings is common, especially in high-speed grinding spindles. The springs act on the outer ring of one of the two bearings. This outer ring must be able to be displaced axially. The preload force remains practically constant, even when there is axial displacement of the bearing as a result of thermal shaft expansion. For additional information concerning preloading with springs and values for preload force, refer to *Preload with a constant force* (→ **page 93**).

Preloading with springs is not suitable for applications where a high degree of stiffness is required, where the direction of load changes, or where indeterminate shock loads can occur.

Cylindrical roller bearings

Cylindrical roller bearings can only be preloaded radially (→ **fig. 37**). Bearings with a tapered bore are preloaded by driving the bearing inner ring up onto its tapered seat. The resulting interference fit causes the inner ring to expand and to obtain the necessary preload. To accurately set preload, internal clearance gauges should be used. For additional information, refer to *Mounting* (→ **page 94**) or *Adjusting for clearance or preload* (→ **page 94**).

Angular contact thrust ball bearings

Angular contact thrust ball bearings can only be preloaded axially (→ **fig. 38**). The standout of angular contact thrust ball bearings is precision ground so that when the two halves of the bearing are assembled, a given preload is obtained without further adjustment. Keep in mind that preload is also influenced by the interference fit and the operating conditions.

Under load, angular contact thrust ball bearings exhibit similar characteristics as angular contact ball bearings. Therefore, the information provided for angular contact ball bearings is also valid for these bearings. The lifting force for single direction angular contact thrust ball bearings for screw drives in the BSA and BSD series is the same as for angular contact ball bearings (→ **table 21**, **page 94**).

For double direction angular contact thrust ball bearings in the BTW and BTM series, the lifting force can be estimated from

$$K_{a1} = 2,85\ F_0$$

where

K_{a1} = lifting force

F_0 = preload on bearings before external axial load is applied

Fig. 37

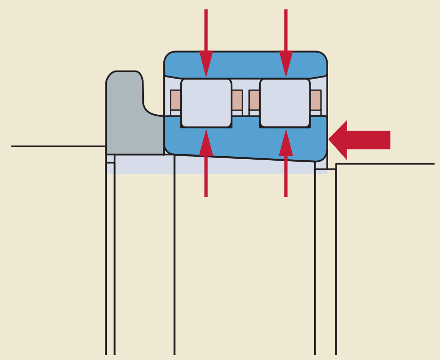
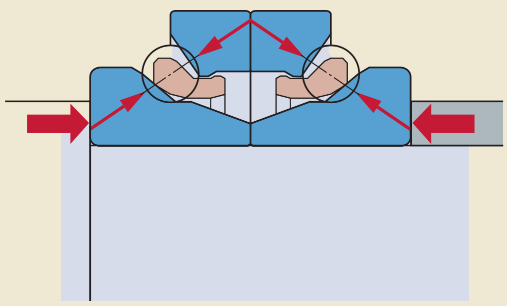


Fig. 38



Sealing solutions

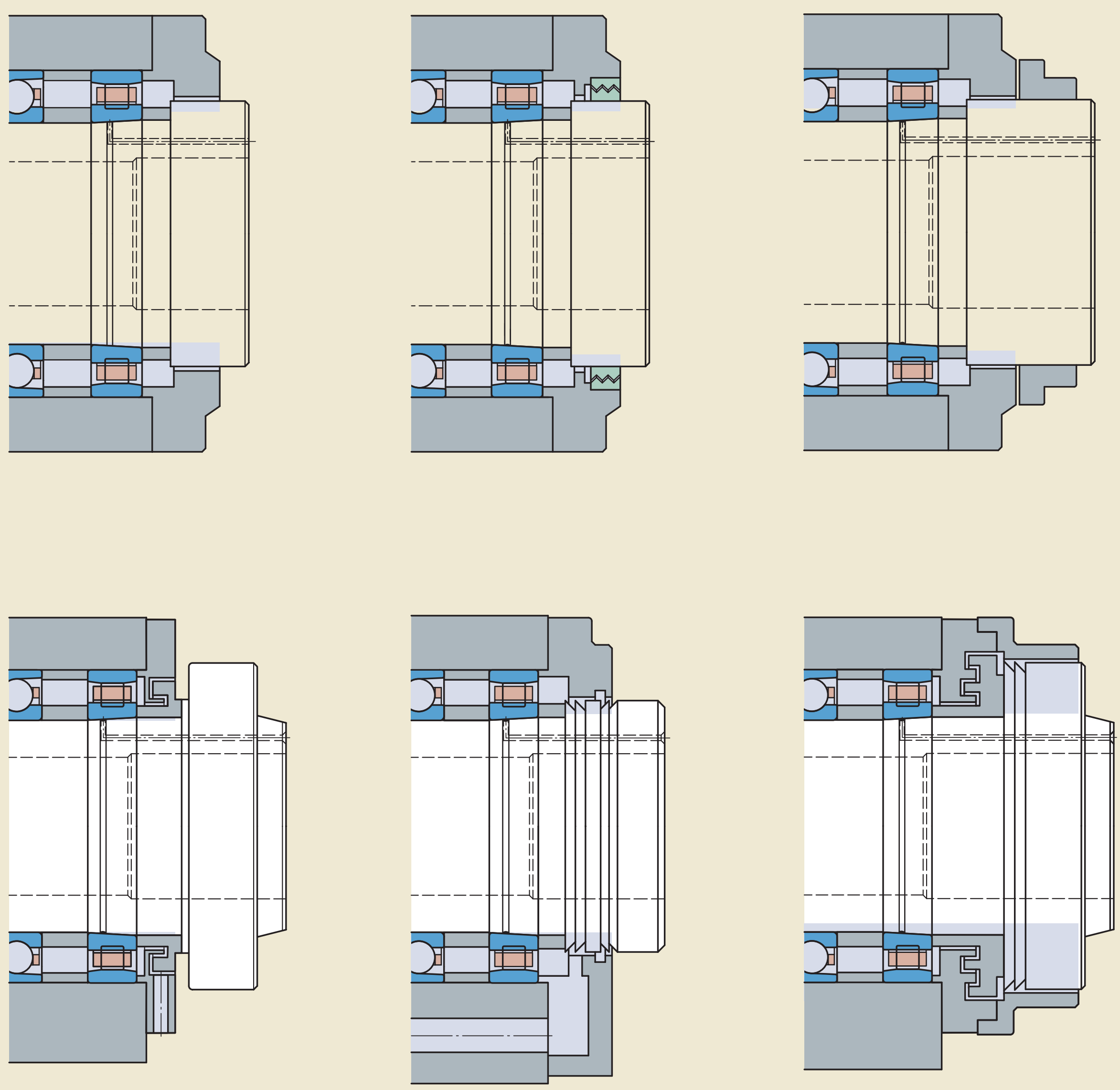
Contaminants and moisture can negatively affect bearing service life and performance. This is particularly important for machine tool applications where coolant and swarf are an integral part of the operating environment. Therefore, an effective sealing arrangement is essential if a spindle is to operate reliably. To protect the bearings, SKF offers a wide assortment of external and integral seals.

External seals

For bearing arrangements where the effectiveness of the seal under specific operating conditions is more important than space considerations or cost, there are two types of external seals available: non-contact seals (→ **fig. 39**) and contact seals (→ **fig. 41**, **page 95**).

For seals that are not supplied by SKF, the information provided in the following section should be used as a guideline only. Make sure to understand the seal's performance criteria before incorporating that seal into an application. SKF does not accept liability for the performance of any products not supplied by SKF.

Fig. 39



Non-contact seals

Non-contact seals are almost always used in high-speed precision applications. Their effectiveness depends, in principle, on the sealing action of the narrow gap between the shaft and housing. Because there is no contact, these seals generate almost no friction and do not, in practice, limit speeds, making them an excellent solution for machine tool applications.

Seal variants range from simple gap-type seals to multi-stage labyrinth seals (→ **fig. 39**, **page 96**). Compared to gap-type seals, multi-stage labyrinth seals are considerably more effective as their series of axially and radially intersecting components make it more difficult for contaminants and cutting fluid to enter the bearing.

In highly contaminated environments, a complex labyrinth seal design is often required. Labyrinth seals can have three or more stages to keep lubricant in and contaminants out of the bearing arrangement. The principle of a highly effective labyrinth seal, outlined in **fig. 40**, consists of three stages:

- the primary stage
- the secondary stage
- the final stage

This design, with drainage chambers and collecting provisions, is derived from studies done by the Technical University of Stuttgart, Germany.

The primary stage consists of a splash guard (**1**), a housing cover (**2**) and the shaft to form a labyrinth. The splash guard uses centrifugal force to direct contaminants away from the cover, while the housing cover prevents contaminants from entering the labyrinth directly. A radial gap (**3**) between the housing cover and the shaft should be between 0,1 and 0,2 mm.

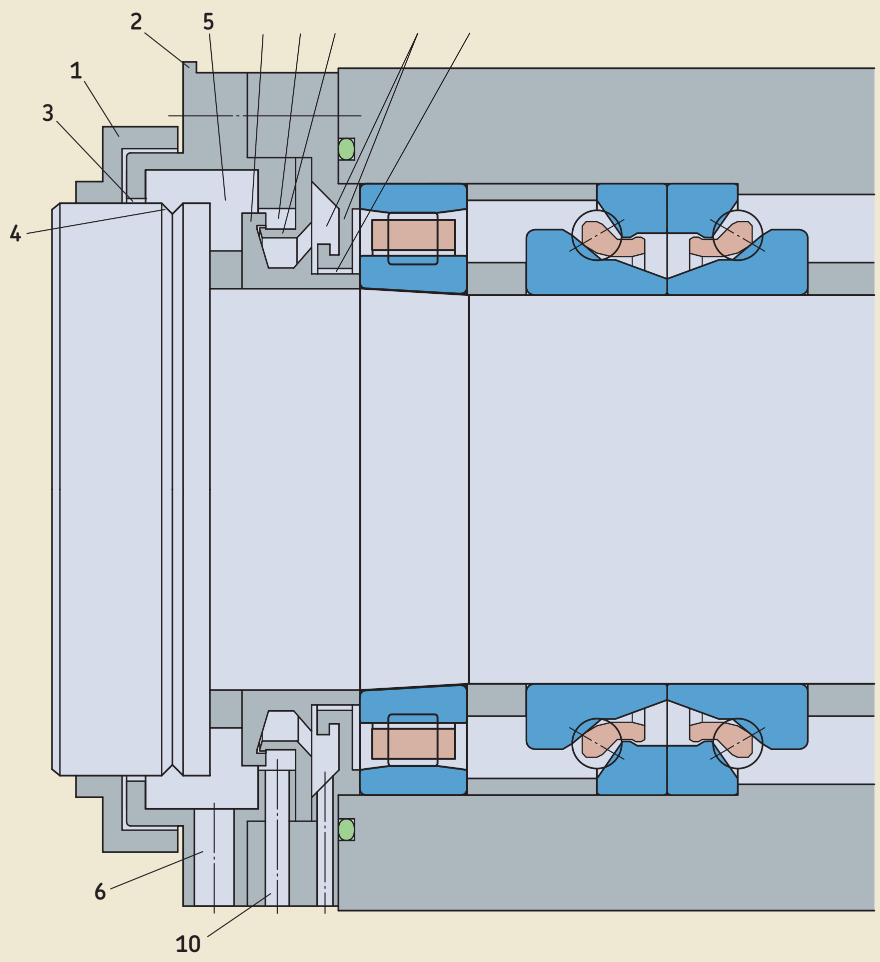
The secondary stage is designed to collect any fluid that manages to pass the primary barrier and drain it away. Starting with annular groove(s) in the shaft (**4**), the main design features of this stage include a large drainage chamber (**5**) and an outlet hole (**6**). Annular groove(s) deter fluid from travelling along the shaft under non-rotating conditions, causing it to drip into the drainage chamber instead. When the shaft is rotating, fluid is flung from it and collected in the drainage chamber and drained through the outlet hole. Large drainage holes (~ 250 mm^2) in the collection area limit the amount of fluid that collects in the chamber.

Features used in the previous stages are incorporated again in the final stage. This section consists of labyrinth rings (**7**) with radial gaps between 0,2 and 0,3 mm, a fluid retardation chamber (**8**), a collector (**9**) to guide the fluid toward the drainage area and an outlet hole (**10**) with a drainage area of ~ 150 mm^2. An additional chamber, collector and a ~ 50 mm^2 drainage hole (**11**) can be incorporated if space permits. A final radial labyrinth gap (**12**) of ~ 1 mm avoids capillary action.

When designing these types of sealing arrangements, the following should be taken into consideration:

- In order to avoid inward pumping effects, the labyrinth components should progressively decrease in diameter from the outside.
- Machine lead on rotating components can move fluids in either axial direction very effectively depending on the hand of the lead and the direction of rotation. This can, in uni-directional applications, be exploited to reinforce the effectiveness of gap or labyrinth seals if carefully incorporated into the design. Machine lead on rotating components of gap and labyrinth seals should be avoided when the application rotates in both directions or for uni-directional applications where its action would work against the effectiveness of the seal.
- Under severe operating conditions, an air barrier can be created by applying air, under pressure, between the labyrinth gaps or inside the spindle itself. The air flow must however be balanced so that the dominant flow is always outward.
- A sealing system that takes up considerable axial space is favourable, as this enables large drainage areas and collectors to be incorporated into the system. In these cases, however, the spindle is less rigid as a result of the long overhang from the front bearings (and cutting force position).

Fig. 40



Contact seals

Contact seals (→ **fig. 41**) are generally very reliable. Their effectiveness, however, depends on a number of factors including:

- the seal design
- the seal material
- the contact pressure
- the surface finish of the seal counterface
- the condition of the seal lip
- the presence of lubricant between the seal lip and counterface

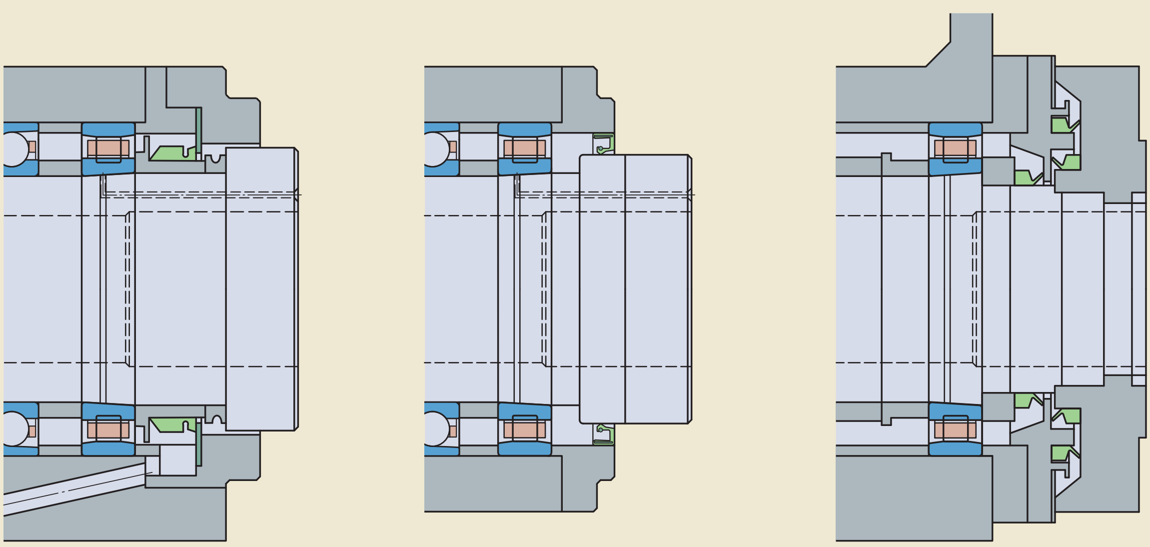
Friction between the seal lip and counterface can generate a significant amount of heat at higher speeds (A ≥ 200 000 mm/min). As a result, these seals can only be used in lower speed spindles and/or in applications where the additional heat does not significantly affect spindle performance.

Integral seals

Sealed bearings are generally used for arrangements where a sufficiently effective external sealing solution cannot be provided for cost reasons or because of space limitations.

SKF supplies a wide assortment of super-precision bearings fitted with a seal on each side. For details, refer to *Sealing solutions* in the relevant product chapter.

Fig. 41



Mounting and dismounting

When mounting or dismounting super-precision bearings, all recommendations and guidelines valid for rolling bearings should be considered. For recommendations and guidelines, refer to *Mounting, dismounting and bearing care* in the SKF catalogue *Rolling bearings* or at skf.com and to the *SKF bearing maintenance handbook* (ISBN 978-91-978966-4-1). For mounting and dismounting instructions for individual bearings, visit skf.com/mount.

Where to mount

Bearings should be mounted in a dry, dust-free area away from machines producing swarf and dust. When bearings have to be mounted in an unprotected area, steps should be taken to protect the bearing and mounting position from contaminants like dust, dirt and moisture. This can be done by covering or wrapping the bearings and machine components with plastic or foil.

Methods and tools

Super-precision bearings are reliable machine elements that can provide long service life, provided they are mounted and maintained properly. Proper mounting requires experience, accuracy, a clean work environment and the appropriate tools.

To promote proper mounting techniques, speed, accuracy and safety, SKF offers a comprehensive assortment of high-quality mounting and maintenance products. The assortment includes everything from mechanical and hydraulic tools to bearing heaters and grease. Detailed information about maintenance products is available online at skf.com.

To be sure that bearings are mounted and maintained properly, SKF offers seminars and hands-on training courses as part of the SKF Reliability Systems concept. Mounting and maintenance assistance may also be available from your local SKF company or SKF Authorized Distributor.

Mounting recommendations

Compared to other rolling bearings, mounting super-precision bearings requires more accuracy, more caution and more advanced skills.

Mounting bearings with thin-walled rings

Super-precision bearings often have rings that are thin relative to their size. For these bearings, only limited mounting forces should be applied. Therefore, SKF recommends using hot mounting methods for all super-precision bearings with thin-walled rings. For bearings in the NNU 49 series with a tapered bore, SKF recommends using the oil injection method.

Hot mounting

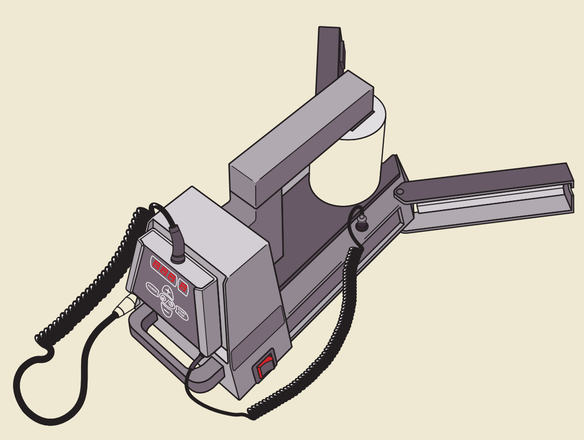
Super-precision bearings are typically mounted with a low degree of interference. That means a relatively small difference in temperature between the bearing ring and its mating components is required. The following temperature differences are often sufficient:

- 20 to 30 °C *(35 to 55 °F)* between the inner ring and shaft
- 10 to 30 °C *(20 to 55 °F)* between the housing bore and outer ring

To heat bearings evenly and reliably, SKF recommends using SKF electric induction heaters (→ **fig. 47**).

Stepped sleeves are sometimes used to locate bearings on a shaft and are therefore installed with a tight interference fit. Because of this, stepped sleeves require a greater dif-

Fig. 47



ference in temperature between mating components during installation. Temperature differences for installation are listed for:

- stepped sleeves without O-rings (→ **table 16**, **page 124**)
- stepped sleeves with O-rings (→ **table 17**, **page 124**)

Test running

Once assembly is complete, an application should undergo a test run to determine that all components are operating properly. During a test run, the bearing(s) should run under partial load and, where there is a wide speed range, at low or moderate speeds. A rolling bearing should never be started up unloaded and then accelerated to high speed, as there is a significant risk that the rolling elements will slide and damage the raceways, or that the cage will be subjected to impermissible stresses.

Any noise or vibration can be checked using an SKF electronic stethoscope. Normally, bearings produce an even "purring" noise. Whistling or screeching indicates inadequate lubrication. An uneven rumbling or hammering is in most cases due to the presence of contaminants in the bearing or to bearing damage caused during mounting.

An increase in bearing temperature immediately after start-up is normal. In the case of grease lubrication, the temperature does not drop until the grease has been evenly distributed in the bearing arrangement, after which an equilibrium temperature is reached. For additional information about running-in of grease lubricated bearings, refer to *Running-in of grease lubricated bearings* (→ **page 124**).

Unusually high temperatures or constant peaking indicate that the preload is too heavy, that there is too much lubricant in the arrangement or that the bearing is radially or axially distorted. Other causes could be that associated components have not been made or mounted correctly, or that the seals are generating too much heat.

During the test run, or immediately afterwards, check the seals, any lubrication systems and all fluid levels. If noise and vibration levels are severe, it is advisable to check the lubricant for signs of contamination.

Dismounting

Because the degree of the interference fit is relatively low for super-precision bearings, lower ring dismounting forces are needed compared to other rolling bearings.

Dismounting forces

For bearings in spindle applications, the dismounting forces can be estimated as follows:

- dismounting a set of three angular contact ball bearings from the housing → F ~ 0,02 D
- dismounting a set of three angular contact ball bearings from the shaft → F ~ 0,07 d
- dismounting a cylindrical roller bearing from its tapered seat → F ~ 0,3 d

where
F = dismounting force [kN]
D = bearing outside diameter [mm]
d = bearing bore diameter [mm]

Reusing bearings

To determine if a bearing can be reused, it must be inspected carefully. A detailed inspection requires disassembling the bearing. Angular contact ball bearings cannot be disassembled without damage unless special tools are used. Cylindrical roller bearings can only be partly disassembled.

SKF does not recommend reusing super-precision bearings. In most cases, the risk for unplanned downtime or unsatisfactory performance outweighs the cost of new bearings.

Bearings should be dismounted carefully, regardless of whether they will be reused, because careless dismounting could damage associated components. Also, if the bearing is dismounted carefully, it can then be used for condition and damage analysis if required.