1 General requirements and recommendations

General requirements and recommendations

Modern paper machines can be more than 10 metres wide, 20 metres high and 400 metres long. Generally, they consist of a forming or wire section, a press section, a drying section, a coating section, a calender and a reeler. Large machines incorporate as many as 1 500 bearings. Operating conditions for these bearings vary greatly depending on where they are installed.

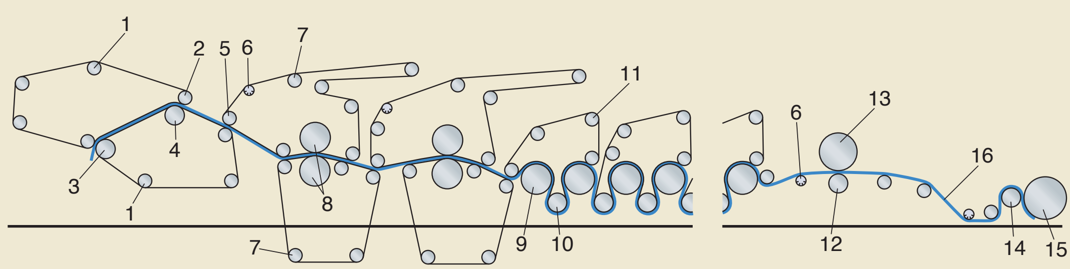
A paper machine has a large number of rolls equipped with medium and large-size rolling bearings (→ **fig. 1**). In a few applications, plain bearings are sometimes used.

The operating speeds of the different types of modern paper machines are as follows:

- Pulp drying machines 100–300 m/min
- Board machines 400–800 m/min
- Liner machines 500–1 300 m/min
- Fine paper machines 900–1 800 m/min
- Newsprint machines 1 000–2 000 m/min
- Tissue machines 1 500–2 200 m/min

Paper machines differ in design according to the grade of paper that is to be produced. For example, when it comes to the number of drying cylinders, board machines have the most, followed by liner and newsprint machines. A great number of drying cylinders are needed in liner and board machines on account of the product thickness, and in newsprint machines because of the very high speed. Tissue paper requires less drying and therefore the dryer section normally consists of only one large cylinder, called a Yankee cylinder. The web forming part also differs from machine to machine.

Fig.1



Basic layout of a newsprint or fine paper machine

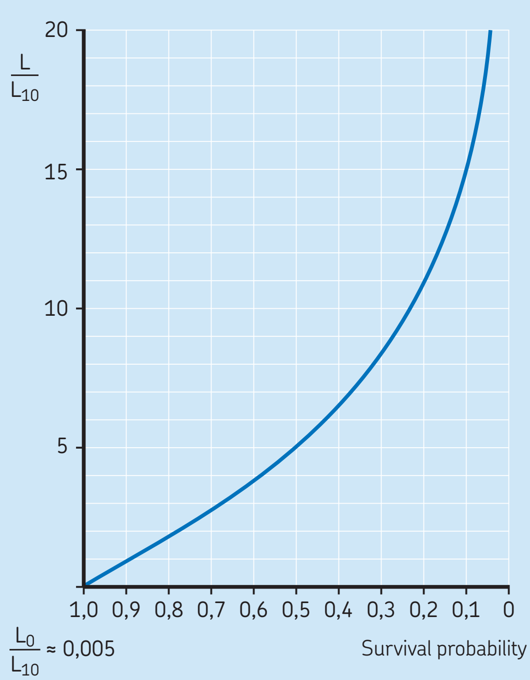
1 Wire roll
2 Forward drive roll
3 Forming roll (suction roll)
4 Suction couch roll
5 Pick-up roll
6 Spreader roll
7 Felt roll
8 Shoe press
9 Drying cylinder
10 Vacuum roll
11 Guide roll (wire roll)
12 Deflection compensating press roll (soft calender)
13 Thermo roll (soft calender)
14 Reel drum
15 Reel spool
16 Paper web

For modern newsprint paper machines, the steam temperature is around 140 to 150 °C. For liner and board machines, the maximum temperature is around 190 to 200 °C. Sometimes the machines operate with super-heated steam in which case temperatures up to 225 °C are common. Tissue machines normally have steam temperatures between 150 and 200 °C.

How these temperatures influence bearing temperatures is shown in the chapter *Lubrication examples*.

Bearing life dispersion

Diagram 1



L = Real bearing fatigue life
L_{10} = Basic rating life according to the ISO definition (the life that 90% of all bearings attain or exceed)
L_0 = Minimum life exceeded by all bearings

Selection of bearing size

Fatigue life – service life

By definition, a bearing is considered to have failed from fatigue as soon as flaking (spalling) occurs. Flaking can be detected by using a vibration-sensitive instrument. If operation is continued after the first sign of flaking has been recorded, the flaked area will increase in size and the vibration level will rise.

SKF has gathered a lot of statistics from endurance life testing of rolling bearings. The results of these tests are shown in **diagram 1**. The diagram shows that the fatigue life of one bearing can differ greatly from that of another bearing in a large population.

The length of time that a bearing can be left in service after reaching its defined fatigue life is generally difficult to specify. Under laboratory conditions, it has been possible to run bearings for 0,2 to 7 times their basic rating life, after flaking has been detected.

The replacement of failed bearings as soon as possible is always recommended, especially if they are in a critical position, mounted with excessive interference fits, subjected to heating through the journal, etc.

To the end-user of SKF bearings, the term “bearing life” means the time that the bearings work satisfactorily in the machine. SKF calls this the “service life” of the bearings. The service life of paper machine bearings is especially interesting as these bearings are usually replaced for reasons other than fatigue.

Recommended L_{10h} and L_{10ah} lives

As the service life is often shorter than the fatigue life, it is necessary to select somewhat “oversized” bearings. In the papermaking industry, SKF has many years of experience selecting bearing size using the L_{10h} and L_{10ah} bearing life equations.

When calculating the life of paper machine bearings, SKF recommends that both the basic rating life L_{10h} and the adjusted rating life L_{10ah} are taken into consideration. The calculated bearing lives L_{10h} and L_{10ah} should exceed 200 000 hours for dryer section bearings and 120 000 hours for bearings in other sections. In this way, the influence of possible insufficient lubrication on the calculated bearing life is taken into consideration, which is of particular importance for the dryer section bearings (→ *chapter 7*, *Lubrication*).

The Technical Association of the Pulp and Paper Industry (TAPPI) requires the L_{10ah} life to be calculated. Calculations for drying cylinders, for example, shall include an a_{23} factor between 0,26 and 0,5. The calculated L_{10ah} life must be 100 000 hours or more for all bearing positions.

Calculation of bearing life

The most common way to calculate the bearing life is to use the equations in the SKF General Catalogue. The equations to be used are

$$L_{10h} = \frac{1\,000\,000}{60\,n}\left(\frac{C}{P}\right)^p$$

and

$$L_{10ah} = a_{23}\,L_{10h}$$

where

L_{10h} = basic rating life, operating hours
n = rotational speed, r/min
C = basic dynamic load rating, N
P = equivalent dynamic bearing load, N
p = exponent of the life equation
$p = 3$ for ball bearings
$p = 10/3$ for roller bearings
L_{10ah} = adjusted rating life, operating hours
a_{23} = combined factor for material and lubrication

There are advantages and disadvantages with these conventional methods. For example, they enable comparison with previous bearing dimensioning and field experience. These methods are also easy to use because of the limited amount of input data needed.

The main disadvantage is the limited ability to perform an accurate calculation where all influential factors are taken into account. Housings and journals, for example, are assumed to be stiff and perfectly round.

Therefore, SKF has developed advanced computer programs to enable in-depth analysis, including the influence of:

- internal design of the bearing
- clearance reduction due to heat generation in the bearing
- clearance reduction due to external heating
- clearance reduction due to housing or journal interference fit
- axial preloading
- errors of housing form
- bearing temperature due to heat generation in the bearing and external heating/cooling

This type of analysis is very useful for investigating bearing failures and also when designing housings etc.

Modern paper machine

The SKF Life Method calculating L_{10mh}

The SKF Life Method highlights the significant influence of cleanliness on the fatigue life of bearings. Even though bearings in pulp and paper machinery rarely run until they are fatigued, cleanliness has an important influence on service life.

The equation to be used is

$$L_{10mh} = a_{SKF} \, L_{10h}$$

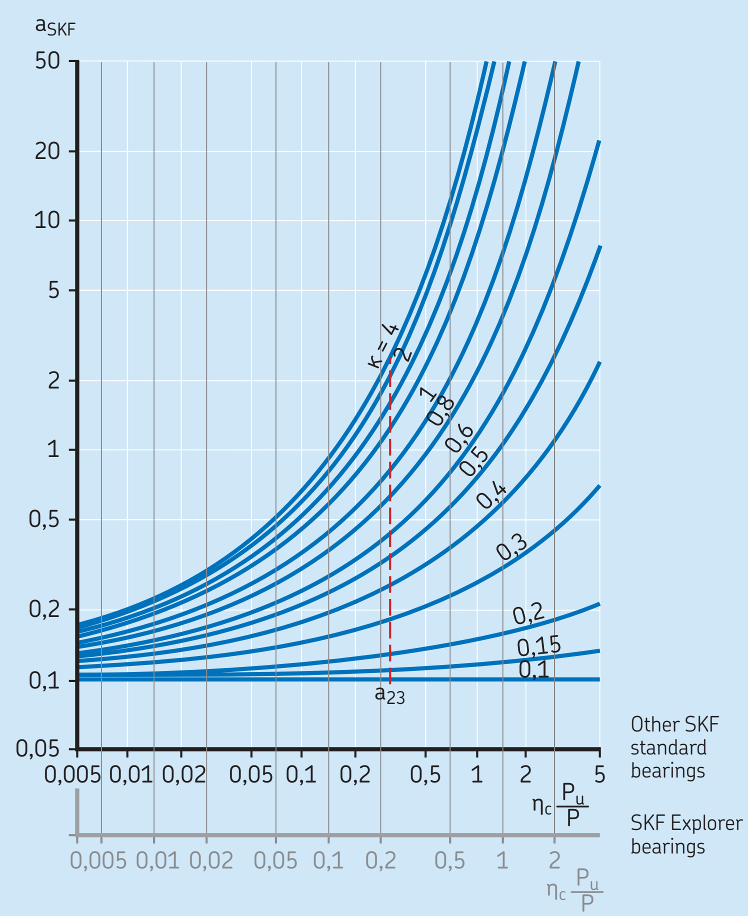
Values of a_{SKF} for roller bearings are given as a function of η_c (P_u/P) in **diagram 2**, where

η_c = adjustment factor for contamination
P_u = fatigue load limit, N
P = equivalent dynamic bearing load, N

More information is given in the SKF General Catalogue and the SKF Interactive Engineering Catalogue. The method can be used to evaluate the benefits of improving cleanliness and also to analyse the effects of higher lubricant viscosity.

SKF recommends the use of this method especially for downsizing and parametric studies. Contact SKF for more detailed information.

Diagram 2



If κ > 4, use curve for κ = 4
As the valued of η_c (P_u/P) tends to zero, a_{SKF} tends to 0,1 for all values of κ
The dotted line marks the position of the old a_{23} (κ) scale, where $a_{SKF} = a_{23}$

Factor a_{SKF} for radial roller bearings

Bearing types used in paper machines

Present trends in the papermaking industry indicate continuing increases in output, necessitating larger machines working at higher speeds. Therefore, the bearings must be able to stand up to these increased loads and speeds, i.e. reach a long service life, while at the same time keeping servicing and maintenance requirements to a minimum.

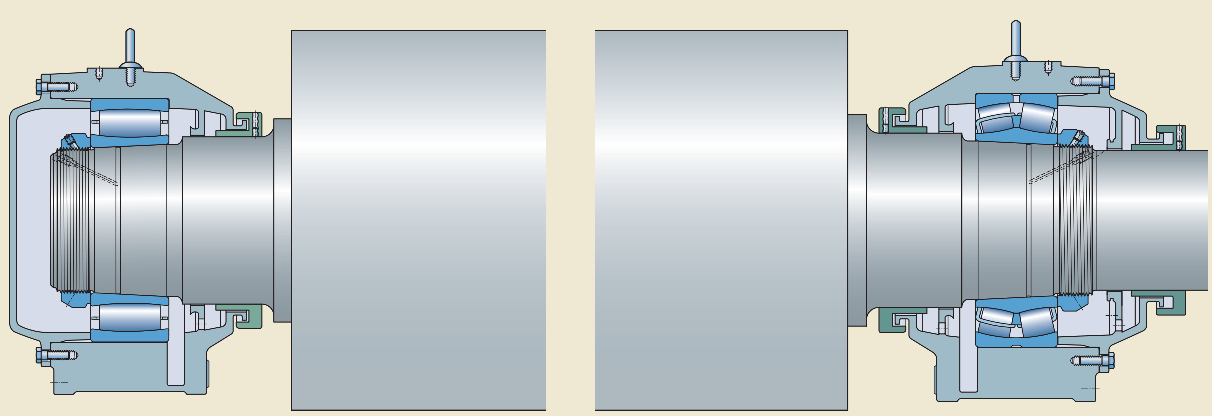
A high proportion of the bearings used in papermaking machinery are spherical roller bearings of standard design. Their ability to accommodate considerable radial loads in combination with axial loads makes these bearings very suitable for supporting the locating side (usually the drive side) of the various rolls and cylinders of paper machines. Spherical roller bearings also permit misalignment between shaft and housing, which is especially important for paper machines where bearings are mounted in separate housings spaced far apart.

In many cases, spherical roller bearings can also be used successfully at the non-locating side, usually the front side, of paper machines. However, in most cases, the ideal solution is to combine a spherical roller bearing at the drive side with a CARB toroidal roller bearing at the front side (→ **fig. 2**). This bearing arrangement accommodates both misalignment and axial displacement internally and without frictional resistance, with no possibility of generating internal axial forces in the bearing system ($F_a = 0$ for both bearings).

If a CARB toroidal roller bearing is used, it may be possible to downsize the bearing arrangements at both the drive and front sides. **Diagram 3**, **page 6**, shows the life of different bearing systems. The coefficient of friction μ for steel against cast iron is 0,15–0,20 for new housings of good quality. For used housings, the coefficient can be considerably higher. In the example μ = 0,15 is used.

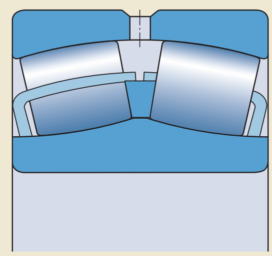
The standard solution – SKF spherical roller bearing on the drive side and a CARB toroidal roller bearing on the front side

Fig. 2



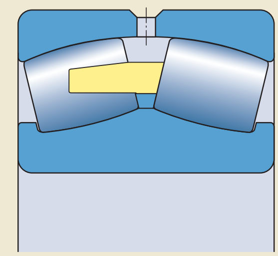
SKF spherical roller bearing of CC, C and EC designs

Fig. 3



SKF spherical roller bearings of CAC, ECAC, CA and ECA designs

Fig. 4



SKF spherical roller bearings of CC, C and EC designs

These bearings have symmetrical rollers, a flangeless inner ring and a pressed steel cage for each roller row (→ **fig. 3**). The guide ring is centred on the inner ring. EC design bearings incorporate reinforced roller sets for added load carrying capacity. The bearings of the CC design have been optimized to promote roller guidance which reduces friction.

SKF spherical roller bearings of CAC, ECAC, CA and ECA designs

These designs are used for large sizes of SKF spherical roller bearings (→ **fig. 4**). The rollers are symmetrical and the inner ring has retaining flanges. The guide ring is centred on the inner ring between the two rows of rollers and the cage is a one-piece, double pronged machined steel or brass cage. The CAC and ECAC designs incorporate the CC design, and the ECAC and ECA designs have reinforced roller sets for increased load carrying capacity.

Relative life of different bearing systems

Diagram 3

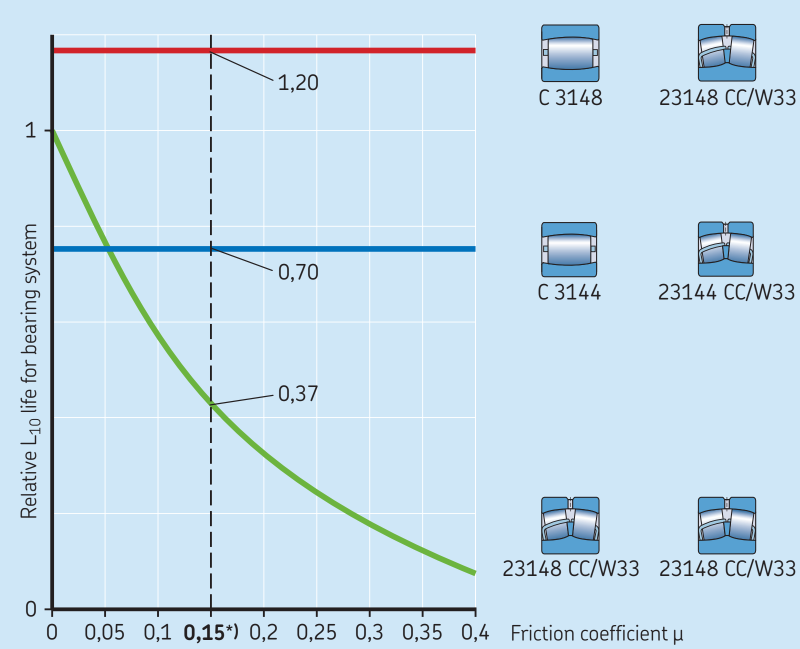
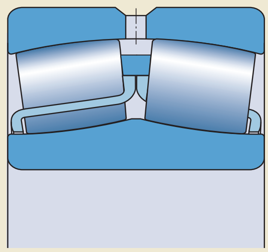
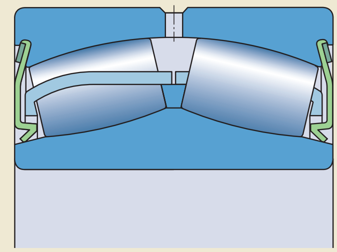


Fig. 5



SKF spherical roller bearing of E design

Fig. 6



SKF sealed spherical roller bearing

SKF spherical roller bearings of E design

These bearings have symmetrical rollers, a flangeless inner ring, and a guide ring centred on the hardened cages (→ **fig. 5**). The E design bearings incorporate all the advantages of the well-proven SKF CC bearings as well as additional refinements such as higher load carrying capacity.

SKF sealed spherical roller bearing

SKF has a large range of sealed spherical roller bearings from 25 mm up to 400 mm bore diameter. The integrated seals offer additional protection against contamination and permit relubrication (→ **fig. 6**). The bearings have the same load carrying capacity as equivalent open spherical roller bearings. The sealed E design is wider than the open E design while all the others have the same dimensions as equivalent open spherical roller bearings.

SKF Explorer

SKF introduced the SKF Explorer bearing in the late 1990s. Developments in steel production, new heat treatment procedures and manufacturing process are the factors behind the development of the SKF Explorer bearing. The main advantages with the bearing are longer life for existing machines and the possibility for downsizing on new machines. To enable users to predict bearing life more accurately, SKF has introduced increased basic dynamic load ratings and an additional factor to be considered when calculating L_{10mh} life using the SKF Life Method.

The SKF Explorer bearings retain the designations of the earlier standard bearings e.g. 22218 E or 23152 CC/W33.

However, each bearing and box is marked with the name SKF Explorer (→ **fig. 7**).

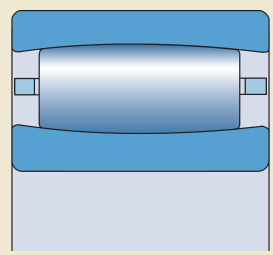
More information about SKF Explorer bearings and the present range can be obtained from your local SKF company.

Fig. 7

SKF Explorer bearing

CARB toroidal roller bearing

Fig. 8



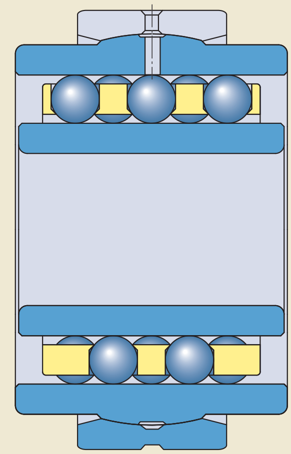
CARB toroidal roller bearing

The best solution for most rolls and cylinders is to combine a spherical roller bearing on the drive side with a CARB toroidal roller bearing on the front side, as this is the ideal non-locating bearing (→ **fig. 8**).

Like a spherical roller bearing, CARB toroidal roller bearing can accommodate misalignment and heavy radial loads, but is also able to take axial displacement without frictional resistance, like a cylindrical roller bearing. This is what makes CARB toroidal roller bearing the ideal non-locating solution for most paper machine applications. It has the same friction as a spherical roller bearing and should therefore be lubricated in the same way. However, CARB toroidal roller bearings must always be lubricated from the side since they have no lubrication groove in the outer ring.

SKF doctor bearing

Fig. 9



Designations

The most common supplementary designations for spherical roller bearings and CARB toroidal roller bearings are shown in **table 1**. The table also shows where in the machine the bearings are used.

Table 2 gives a larger number of supplementary designations that can be seen in a paper machine.

Doctor bearing

Specially designed multi-row radial ball bearings are used for doctors, allowing both the axial oscillation of the doctor as well as rotating movement (→ **fig. 9**). Specially designed plain bearings can also be used. The rotating movement is necessary when the doctor is turned to a rest position during

Common supplementary designations for SKF spherical roller bearings and CARB toroidal roller bearings

Table 1

Features	Requirement	Rolls Forming section Forming	 Suction	 Wire	 Press section Suction	 Press	 Felt	 Dryer section Dryers	 Yankees	 Felt	 Calenders Thermo	 Others
Clearance	std	X	X	X								
	C3				X	X	X			X		X
	C4							X	X		X	
Running accuracy	std			X			X	X		X		
	C08	X	X		X				X		X	X
	VQ424					X					X	X
Heat treatment	std	X	X	X	X	X	X	X	X	X	X	X
	HA3							(X)	(X)		(X)	
Special features	L5DA				(X)						(X)	(X)

maintenance or changing of the blade. In addition to this degree of movement, the bearing is able to take shaft misalignment. This misalignment is accommodated either by a radius on the outer diameter which adjusts the misalignment between housing and bearing or, for another bearing execution, in the sphere between the two mating parts of the bearing outer ring.

Other bearing types

Other bearing types can also be seen in paper machines, e.g. cylindrical roller bearings in drying cylinder applications, tapered roller bearings in felt roll applications, deep groove ball bearings and self-aligning ball bearings in spreader rolls, and plain bearings in calender applications.

Table 2

C	Spherical roller bearing with symmetrical rollers and floating central guide ring
CA	Spherical roller bearing of C design but with two integral inner ring flanges and machined cage
CC	Spherical roller bearing of C design but with improved roller guidance and reduced friction
CAC	Spherical roller bearing of CA design but with improved roller guidance and reduced friction
C2	Radial internal clearance less than Normal
C3	Radial internal clearance greater than Normal
C4	Radial internal clearance greater than C3
C5	Radial internal clearance greater than C4
C08	Extra reduced tolerance for running accuracy (P5) of inner ring and outer ring of assembled bearing
C083	C08 + C3
C084	C08 + C4
E	Standard spherical roller bearing with modified internal design, increased carrying capacity and W33 features
F	Machined cage of steel or special cast iron
HA1	Case-hardened inner and outer rings
HA3	Case-hardened inner ring
J	Pressed steel cage
K	Tapered bore, taper 1:12 on diameter
K30	Tapered bore, taper 1:30 on diameter
M	Machined brass cage
S1	Bearing rings dimensionally stabilized for operating temperatures up to +200 °C (standard for SKF spherical roller bearings and CARB toroidal roller bearings)
VA405	Specially heat treated pressed steel cages centred on the guide ring, outer ring, centred guide ring and radial internal clearance C4
VA460	Spherical roller bearing and CARB toroidal rollerbearing designed for very high speeds
L5DA	NoWear anti-smearing coating on rollers
VQ424	Spherical roller bearing with running accuracy better than P5 (better than C08) and reduced width tolerance; additionally the bearing is manufactured according to W4 and W58 specifications and has a serial number
W4	Eccentricity high-point location marked on inner ring
W20	Three lubrication holes in outer ring
W26	Six lubrication holes in inner ring
W31	Bearing meets an old and obsolete Beloit quality standard
W33	Lubrication groove and three holes in outer ring
W58	Eccentricity high point location marked on outer ring
W77	Bearing with W33 holes plugged
W503	W33 + W4
W506	W31 + W33
W507	W4 + W31 + W33
W509	W26 + W31 + W33
W513	W26 + W33
W529	W33 + W58

Supplementary designations used for bearings in paper machines

Housings and journals

Due care must be given to the design of bearing housings and journals. For example, provision must be made for axial movement on the non-locating side. The space available for axial movement has to be greater than the thermal expansion of the roll.

The housings and journals should be strong enough to prevent excessive deformation under operating conditions. Additionally, the housings should fit properly into the frame of the paper machine and permit easy mounting, dismounting, and inspection of the bearings. In some positions, the housings must also allow for the changing of wires and felts.

SKF has a range of special housings for felt rolls, drying cylinders and Yankee cylinders, where all important functional aspects have been taken into consideration.

Housings

Historically, paper machines have been equipped with specially designed bearing housings. The manufacturer has designed a special housing for virtually every individual machine, which is costly in terms of pattern equipment and design time. Specially made housings have also been very difficult to find when a replacement has been required at the paper mill.

SKF moved into the lead in the early 1990s by introducing a standard range of bearing housings for felt rolls in the dryer section, drying cylinders and Yankee cylinders. All housings were designed for high flow circulating oil lubrication, had maintenance-free sealing arrangements and were prepared with connections for condition monitoring. In the early 2000s SKF introduced new felt and dryer bearing housings for modern paper machines with new seal designs for extra protection against liquid contamination due to high pressure cleaning.

Felt roll housings, dryer section

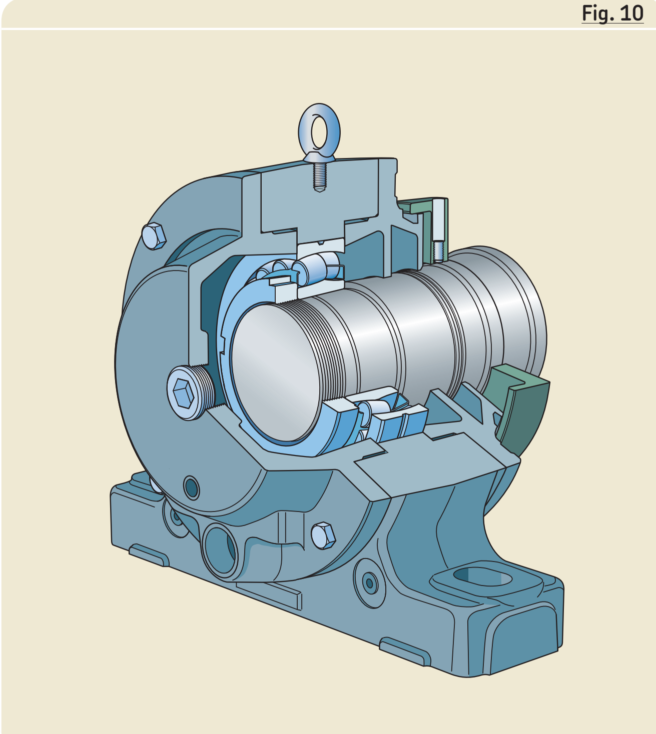
Felt roll housings are available in the following basic executions:

- Drive side: spherical roller bearing with located outer ring (→ **fig. 10**)
- Front side: CARB toroidal roller bearing with located outer ring.
- Front side: spherical roller bearing with non-located outer ring (not applicable for the SBFN design)

SKF recommends the use of a spherical roller bearing at the drive side and a CARB toroidal roller bearing at the front side.

SKF felt roll housing (latest SBFN design)

Fig. 10



SKF drying cylinder housing
The outside machine housing side seal is of the old design and the inside machine housing side is the new design seal. The old design seal is not recommended and is shown for information only.

Fig. 11

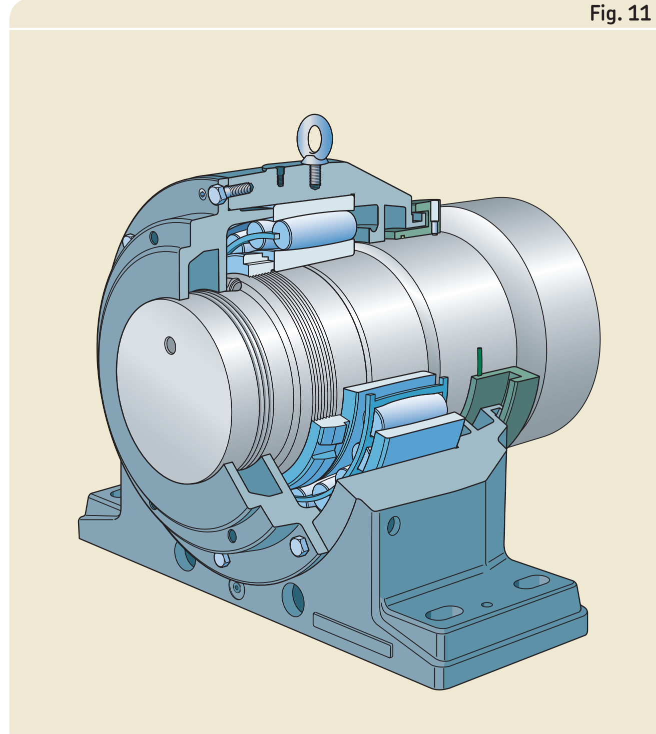
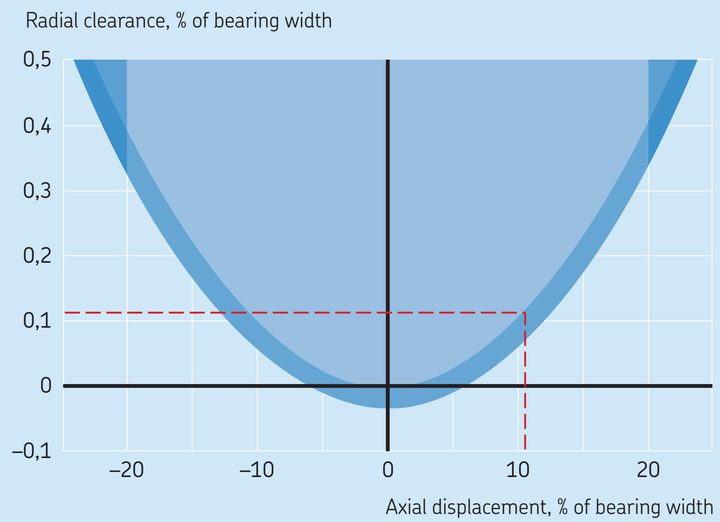


Diagram 4



CARB toroidal roller bearings: *Axial displacement depends on radial clearance. Rollers may protrude from the ring raceway at axial displacements above 20% of the bearing width*

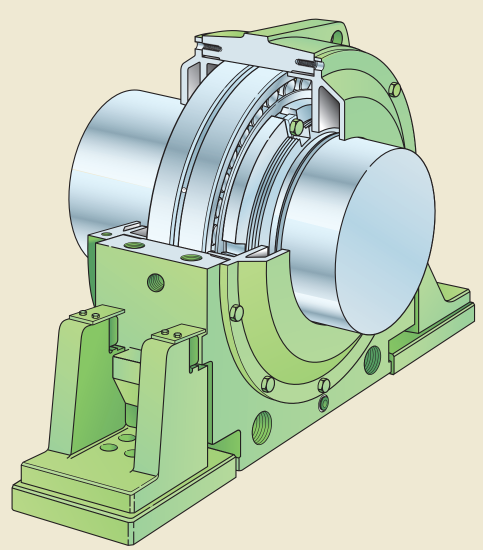
Drying cylinder housings

Drying cylinder housings are available in the following basic executions:

- Drive side: spherical roller bearing with located outer ring
- Front side: CARB toroidal roller bearing with located outer ring (→ **fig. 11**).
- Front side: spherical roller bearing with non-located outer ring (not applicable for the SBPN design)
- Front side: spherical roller bearing with located outer ring in housing on rockers (not applicable for the SBPN design)

SKF Yankee cylinder rocker housing

Fig. 12



SKF recommends the use of a spherical roller bearing at the drive side and a CARB toroidal roller bearing at the front side.

Yankee cylinder housing

Yankee cylinder housings are available in the following basic executions:

- Drive side: spherical roller bearing with located outer ring
- Front side: CARB toroidal roller bearing with located outer ring
- Front side: spherical roller bearing with non-located outer ring
- Front side: spherical roller bearing with located outer ring in housing on rockers
- Front side: spherical roller bearing with located outer ring in housing on rockers with two support rockers (→ **fig. 12**)

Axial displacement for CARB toroidal roller bearings

The relation between radial clearance and axial displacement from a central position is shown in **diagram 4**. The bearing may be further displaced without life reduction, into the dark blue area. In this area, friction increases by up to 50%. Axial displacement and radial clearance are given in relation to bearing width (B). This makes the diagram valid for all CARB toroidal roller bearings.

Example: Bearing C 3044/HA3C4 with bearing width B = 90 mm.

Assuming that the operational radial clearance during start-up is 0,1 mm. That is 0,11% of the bearing width.

Diagram 4, **page 11**, then shows (dotted line) that the bearing can be axially displaced up to 11% of bearing width, which is 0,11 × 90 = 9,9 mm from the centre.

Housing seals

A very important factor for the reliable functioning of bearings in paper machines is efficient sealing of the bearing arrangements. It is important that sealing arrangements adequately protect the bearings from contamination and also prevent the lubricant from escaping and running down the machine. A rolling bearing contaminated by water and/or solid particles will become unserviceable long before its calculated life has been attained.

When designing seals, consideration must be given to the environment of each specific bearing arrangement. The bearing arrangements may be subjected to flowing water, condensation, dry conditions, or a high ambient temperature, depending on where in the machine they are positioned. The seals of the housings on the non-locating side must allow for the required axial movement. The basic design of the seal depends upon whether the bearings are lubricated by grease or oil. The application drawings in this handbook show some examples of basic designs of bearing arrangements.

Different types of sealing arrangements are shown in the lubrication examples. The need for efficient seals is greatest in the wet section where most of the bearing arrangements are subjected to very wet conditions. Experience shows that a well-greased multi-stage labyrinth seal, whether it be axial or radial, affords good protection of the bearings in the wet section especially when it is reinforced by a splash guard (→ **fig. 13**). If the bearings are oil lubricated, the sealing arrangements have to be of a different design. **Fig. 14** shows an efficient seal for oil lubricated press roll bearings. The seal must prevent water from entering the bearing housing, even during hosing down, which is often carried out with water at high pressure.

In the dryer section of the machine, the bearing housings are exposed to moisture in the form of condensation or leaks from steam nozzles etc. Small soft fibres may enter the housings too. Nevertheless, simpler seals may be used for the housings in the dryer section. However, if problems occur, more efficient seals have to be applied. **Fig. 15** shows a proposal of how to improve the seals of dryer section housings.

SKF can provide a full range of garter seals and V-rings. SKF can also offer customized machined seals with short delivery times (→ **fig. 17**). Contact SKF for more information.

Dimensioning of outlets in bearing housings

Many bearing positions in modern paper machines are lubricated by circulating oil. For many years, SKF has recommended larger oil flows than those normally used in older machines. One problem with older machines is draining increased circulating oil flow

Figs. 13–15 Sealing arrangements

Fig. 13

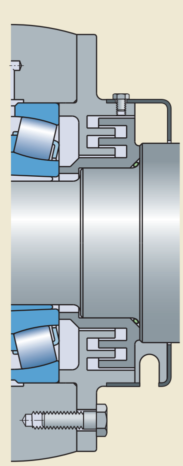


Fig. 14

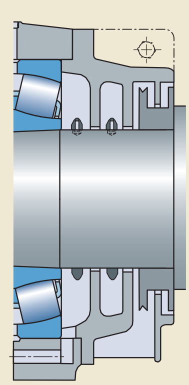
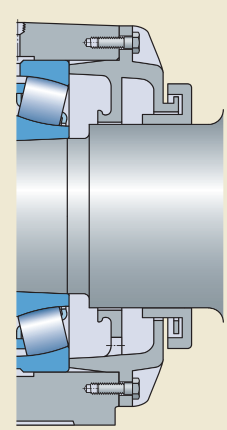


Fig. 15



through small dimensions oil outlets. Old machines without a heating system in the oil tank have great difficulty starting after a lengthy standstill. The problem is high oil viscosity due to low oil temperature.

It is difficult to accurately calculate the required outlet diameter because many variables influence oil drainage, e.g. oil level difference, length and diameter of the pipe, number of bends, and oil viscosity. Generally, the outlet diameters are selected from experience or by rule of thumb. **Fig. 16** shows a sketch of an outlet pipe with the relevant dimensions indicated.

An approximate calculation of the required minimum outlet diameter can be performed as follows

$$d = 2,2 \left(\frac{(2,5 + 0,2\ n)\ Q^2 \times 10^3 + 3\ \nu\ lQ}{h} \right)^{1/4}$$

where

d = minimum bore of outlet pipe, mm
n = number of 90° bends
Q = oil flow, l/min
ν = kinematic viscosity of oil at lowest operating temperature (mostly at start-up), mm^2/s
l = pipe length, mm
h = oil level difference, mm

The equation is valid when the outlet from the housing has no restrictions. Practical experience shows that if there are restrictions close to the outlet, e.g. walls in bearing housings, the resistance to the inflow increases considerably. The calculated diameter d should then be increased by 50%.

Example

A drying cylinder bearing housing has an outlet pipe with a length of 3 000 mm to the first connecting main pipe. The oil level difference to this connection is 1 000 mm and there are two bends. When starting up the machine, the oil viscosity can be 220 mm^2/s if the temperature is around 40 °C. Select minimum bore diameter for the outlet pipe to avoid flooding when the circulating oil flow is 4 l/min.

$$d = 2,2 \left(\frac{(2,5 + 0,2 \times 2) \times 4^2 \times 10^3 + 3 \times 220 \times 3\,000 \times 4}{1\,000} \right)^{1/4} = 20,8 \text{ mm}$$

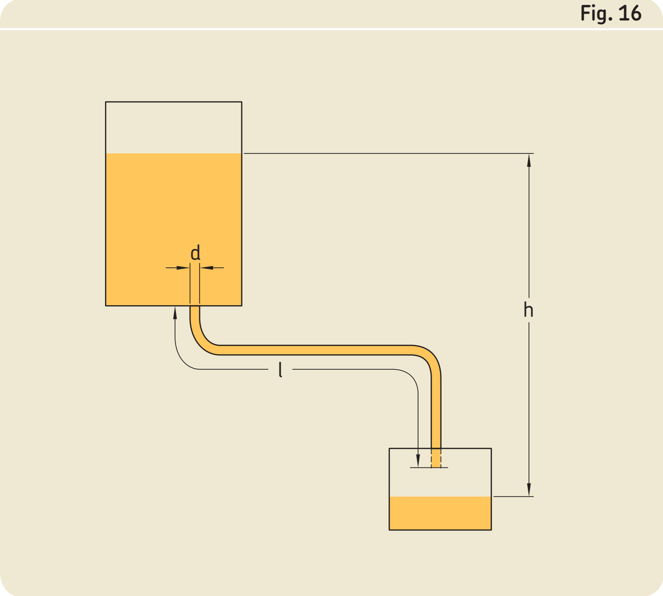
With a restricted oil inflow, the recommended minimum outlet pipe bore diameter is

d = 1,5 × 20,8 = 31,2 mm

Select a pipe with a bore diameter larger than 32 mm.

Oil outlet definition

Fig. 16



Custom seals machined to customer dimensions

Fig. 17

Tolerances

General

From a bearing function point of view, the main aspects of the housing and journal design in paper machines are the form and dimensional tolerances.

The accuracy of cylindrical bearing seatings on shafts and in housing bores should correspond to the accuracy of the bearings used. In the following pages, guideline values for the dimensional, form and running accuracies are given and these should be adhered to when machining the seatings and abutments.

Dimensional tolerances

For bearings made to normal tolerances, the dimensional accuracy of the cylindrical seatings on the shaft should be at least to grade 6, and in the housing to at least grade 7. Where adapter or withdrawal sleeves are used on cylindrical shafts, grade 9 (h9) can be permitted.

Tolerances for cylindrical form

Since cylindricity is very difficult to measure, circularity and straightness are measured instead. The circularity and straightness tolerances as defined in ISO 1101-1983 should be one to two IT grades better than the prescribed dimensional tolerance, depending on requirements. For example, if a bearing seating on a shaft has been machined to tolerance m6, then the accuracy of circularity and straightness form should be to IT5/2 or IT4/2. Note that the tolerances shown in this section are only half of the tolerance grades. This is because the total tolerance grade is valid for the diameter and the definition is the radial deviation.

Two IT grades better than the prescribed dimensional tolerance is recommended when particularly stringent running accuracy requirements are stipulated, e.g. when bearings with extra close running accuracy tolerance C08, VA460 or VQ424 are used.

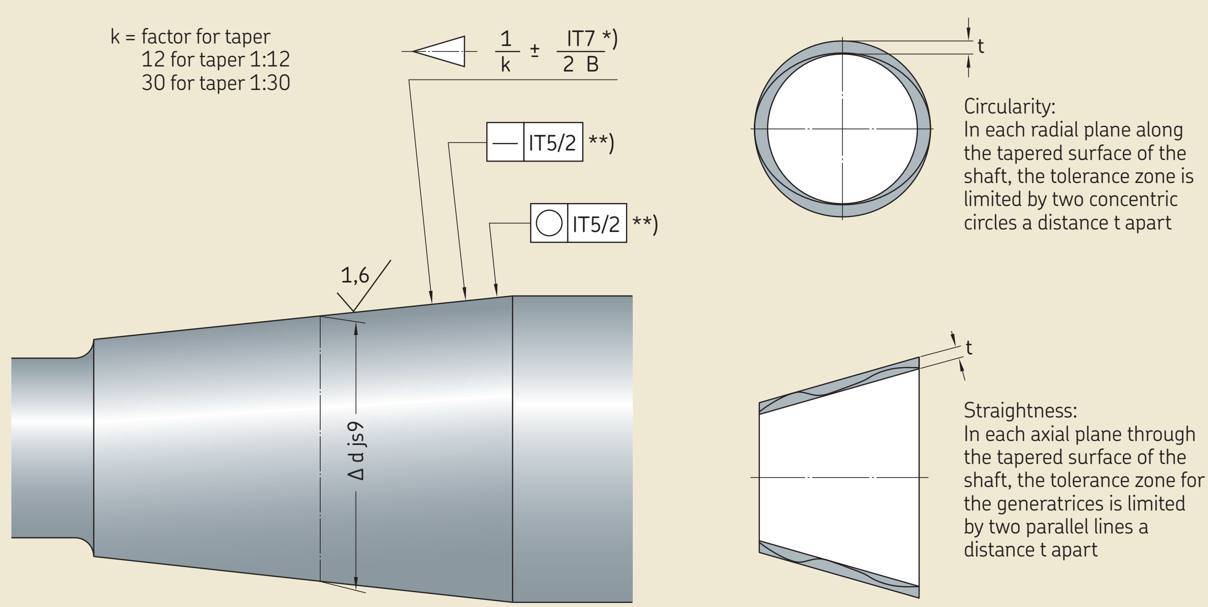
When bearings are to be mounted on adapter or withdrawal sleeves, the circularity and straightness of the sleeve seatings should be IT5/2.

Tolerances for abutments

Abutments for bearing rings should have a total axial runout tolerance, as defined in ISO 1101-1983, which is better by at least one IT grade than the diameter tolerance of the associated cylindrical seating. The axial runout of the abutments corresponds to the required axial runout of the mounted inner ring. The latter runout requirement applies even when the bearing is mounted on a tapered journal without abutment.

Definition of tapered journal tolerances

Fig. 18



*) The tolerance is based on the bearing width B
**) The tolerance is based on the diameter d

Tolerances for tapered journal seatings

When the bearing is mounted directly on a tapered journal seating, the seating diameter tolerance is permitted to be wider than in the case of cylindrical seatings. **Fig 18** shows a grade 9 diameter tolerance, while the form tolerance stipulations are the same as for cylindrical journal seatings.

When establishing tolerances for tapered journal seatings for spherical roller bearings, different systems have been applied in Europe and the USA.

The European system was based on the permissible angle deviation for the journal taper being on the plus side of the nominal value, i.e. following the practice applied to bearings. Moreover, the tolerance value was related to the nominal diameter of the journal.

In the USA, the corresponding permissible deviation was located on the minus side instead and the value was coupled to the nominal width of the bearing.

These divergent methods have naturally led to practical difficulties. Consequently, a common SKF recommendation was agreed upon in 1986 and this recommendation conforms well with the ISO tolerance tables. The main points of the uniform SKF recommendations for tapered journals for spherical roller bearings, also valid for CARB toroidal roller bearings, are as follows

- The permissible taper deviation for machining the taper seatings is a ± tolerance in accordance with IT7/2 based on the bearing width. The permissible deviation per mm is determined by dividing the IT7/2 value in mm by the bearing width (→ **fig. 18**). See also example on **page 16**.
- The straightness tolerance is IT5/2 and is defined in accordance with **fig. 18**.
- The radial deviation from circularity, defined in accordance with **fig. 18**, is to comply with IT5/2. When particularly stringent running accuracy requirements are stipulated, e.g. when spherical roller bearings with extra reduced running accuracy tolerance C08, VA460 or VQ424 are used, IT4/2 is to apply instead.

Gauging the taper deviation

The best way to check that the taper is within the recommended tolerances is to measure with dial gauges. A more practical, but less accurate, method is to use ring gauges or special taper gauges. Tapered seatings up to around 150 mm in diameter are generally checked with ring gauges, and those above this size with special taper gauges. When indelible ink is used, the area in contact should be at least 90%.

The gauge recommended by SKF in Europe can be seen in **fig. 19**. The taper deviation and the diameter of the seating in relation to a reference surface can be measured with this gauge. The tolerance $M_1 - M$ is calculated by means of the equation

$$M_1 - M = \pm \left(\frac{IT7}{2} \times \frac{G}{B} \right)$$

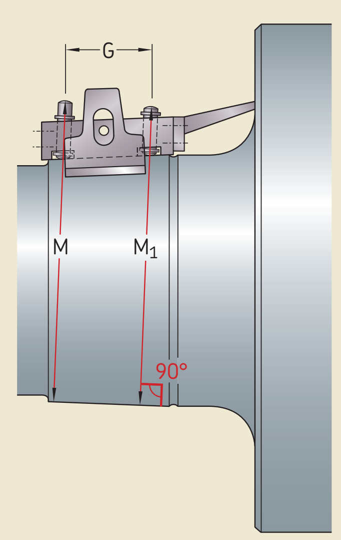
where

G = distance between the points of measurement, mm

B = bearing width, mm

Gauge for tapered journal, European design

Fig. 19



The gauge supplied by SKF in North America can be seen in **fig. 20**. It is called the sine bar gauge and the taper deviation can be measured with this tool.

Example: Spherical roller bearing 23152 CCK/HA3C4W33 (bearing width 144 mm, IT7/2 for 144 mm is 0,020 mm). The taper is to be measured using our recommended gauge in **fig. 18**, **page 14**. If a gauge with 80 mm distance between the measuring points (G) is used, the taper deviation (M_1 – M) is allowed to be

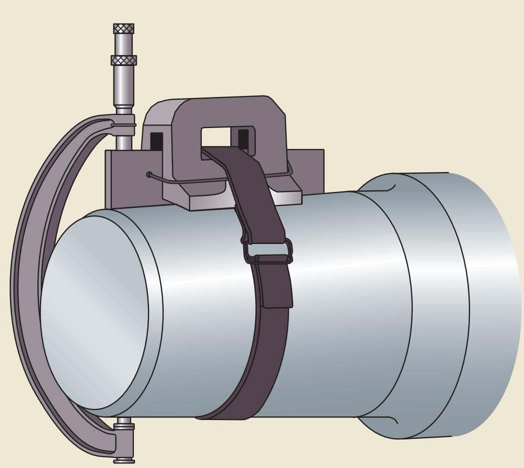
$$\pm 0{,}020 \times \frac{80}{144} = \pm 0{,}011 \text{ mm}$$

Support surface for housing base

It is recommended that the support surface for the housing is finished to $R_a \leq 12{,}5$ µm. The flatness (planicity) tolerance should be to IT7 on the length of the support surface.

SKF gauge for tapered journal, American design

Fig. 20



Oil flow resistance

Normally, oil flow resistance in a bearing is insignificant. Sometimes, however, the question arises as to what pressure is needed to force oil with a certain viscosity through the duct formed by the W33 lubrication groove and the housing into the interior of the bearing.

The oil pressure required to overcome the oil flow resistance of the duct can be calculated with the following equation

$$\Delta p = \frac{Q\,D\,\nu}{6\,132\,d_h^{\,4}}$$

where
- Δp = required oil pressure, MPa
- Q = oil flow, l/min
- D = bearing outside diameter, mm
- ν = kinematic viscosity of oil at lowest operating temperature (mostly at start-up), mm^2/s
- d_h = hydraulic diameter, mm

The hydraulic diameter d_h is a calculated value describing a virtual diameter which is equivalent to the groove cross section.

The calculation takes into consideration the resistance of the duct only. The length of the holes is very short, compared with the length of the duct, and therefore the resistance of the holes has been ignored.

The hydraulic diameter of the duct formed with different sizes of groove, as well as the groove dimensions, can be obtained from **table 3**. The groove numbers used for different spherical roller bearings are also listed in **table 3**.

When the required oil pressure is considered to be too high, and to ensure oil supply into the non-locating bearings, an extra groove can be turned in the bearing housing. The hydraulic diameter for the enlarged duct can be calculated from

$$D_h = \frac{4\,A}{O_a}$$

where
- d_h = hydraulic diameter, mm
- A = enlarged duct area, mm^2
- O_a = circumference of enlarged duct area, mm

Example

What oil pressure is needed to pump an oil flow of 5 l/min through the duct formed by the W33 groove and the housing, into the bearing 23052 CCK/C4W33? The maximum kinematic viscosity of the oil is 220 mm²/s.

The table shows that the groove number is 5, and thus d_h = 5,18 mm.

$$\Delta p = \frac{5 \times 400 \times 220}{6\,132 \times 5{,}18^4} = 0{,}1 \text{ MPa}$$

By turning a 25 mm wide and 6 mm deep groove in the housing seating, the enlarged duct area will be (→ **fig. 21**)

$$A = 25 \times 6 + 3{,}6\,(16{,}7 - 2 \times 3{,}6) + 3{,}6^2 = 197{,}2 \text{ mm}^2$$

and the circumference

$$O_a = 25 + 2 \times 6 + 25 - 2 \times 3{,}6 + \frac{2 \times 3{,}6}{\cos 45} = 65 \text{ mm}$$

The hydraulic diameter thus becomes

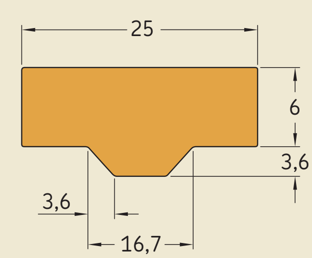
$$d_h = \frac{4 \times 197{,}2}{65} = 12{,}14 \text{ mm}$$

and the required pump pressure

$$\Delta p = \frac{5 \times 400 \times 220}{6\,132 \times 12{,}14^4} = 0{,}0033 \text{ MPa}$$

The required pump pressure without a groove is 0,1 MPa. By turning a groove 25 × 6 mm in the housing seating, a considerable reduction, to 0,0033 MPa, is obtained.

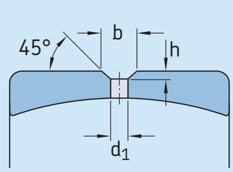
Fig. 21

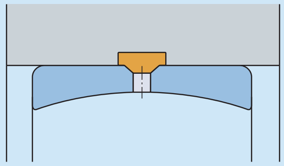


Example: dimensions of enlarged area

Groove sizes and dimensions and hydraulic diameter for spherical roller bearings

Table 3





Groove No.	Groove dimension b	h	d_1	Hydraulic diameter d_h
–	mm			mm
1	5,5	1,2	3,0	1,72
2	8,3	1,8	4,6	2,59
3	11,1	2,4	6,0	3,45
4	13,9	3,0	7,5	4,32
5	16,7	3,6	9,0	5,18
6	22,3	4,8	12,0	6,92

Bearing size[1)]

Series 239 over	incl.	230 over	incl.	240 over	incl.	231 over	incl.	241 over	incl.	222 over	incl.	232 over	incl.	223 over	incl.	**Groove no.**
32	38	20	24	22	30	19	20	20	26	07	18	17	18	08	11	1
38	52	24	30	30	38	20	28	26	34	18	22	18	26	11	17	2
52	72	30	34	38	56	28	30	34	48	22	28	26	30	17	20	3
72	80	34	48	56	64	30	38	48	60	28	32	30	36	20	24	4
80	96	48	64	64	76	3	60	60	76	32	44	36	44	24	34	5
96		64		76		60		76		44		44		34		6

1) The figures in the table represent the last two figures of the designation; thus, bearing 23024 has groove no.1

High-speed machines

The operating speed of paper machines has increased significantly over the years.

Increased running accuracy

With production speeds higher than 900 m/min, there is an increased demand for bearings with extra-reduced tolerances for running accuracy. The main reasons for these are to keep high paper quality and to avoid felt wear as well as paper tears. These aims can be achieved by using C08, VQ424 or VA460 bearings to obtain low vibration levels and a constant nip pressure. Press rolls, calender rolls and suction rolls are examples of high speed applications where these high precision bearings are often used.

C08 means that dimensional runout of the inner and outer rings correspond to ISO tolerance class P5. Note that all SKF spherical roller bearings and CARB toroidal roller bearings up to and including 300 mm bore diameter have running accuracy tolerance class P5.

VQ424 means that the bearing has a radial runout at least 20% better than P5 (C08) and reduced width tolerance. Additionally, the bearing is according to W4 and W58 specifications, carrying a serial number. VQ424 and C08 bearings are an advantage in all rolls that form a nip. VQ424 and C08 bearings are also an advantage when regrinding the rolls. By using such bearings, less time is needed and higher accuracy is achieved.

VA460 means that the bearing has VQ424 features and is modified to withstand the effects of centrifugals forces due to very high speeds.

Increased running accuracy of the bearing is not the only way to reduce vibrations in paper machines. Another way is to decrease the runout of the journal, see *recommendations* on **pages 14–16**.

Bearings mounted on adapter or withdrawal sleeves are therefore mainly seen in old machines.

The use of a spherical roller bearing as the locating bearing, in combination with a CARB toroidal roller bearing as the non-locating bearing, has often resulted in less vibration compared to the traditional solution using two spherical roller bearings.

NoWear bearings

One way to improve the performance of a bearing is to provide a beneficial contact condition in cases where sufficient lubrication is difficult to obtain. Surface engineering to obtain a low coefficient of friction is a means of achieving this. A commonly used method in industry is surface coating. For a coating to work effectively in a bearing, it has to meet a set of requirements such as hardness, ductility and fatigue resistance, in order to stay on the surface during operation. The low friction ceramic coating in NoWear bearings from SKF is specially developed for rolling bearings.

NoWear bearings provide long-term low friction and low wear properties by having a surface layer with a hardness of 1 200 HV. The coefficient of friction between coated rollers and steel is roughly one third of the friction between two steel components. NoWear bearings prevent wear and smearing in bearings which operate at heavy load as well as bearings which operate at radial loads less than the recommendations in the SKF General Catalogue.

In fast machines with large and heavy bearings which may operate at radial loads less than the recommendations in the SKF General Catalogue, SKF recommends NoWear bearings with coated rollers (L5DA). One example of such an application can be the upper thermo roll in soft calenders.

Speed rating – cooling

Sometimes the limiting speed in the SKF General Catalogue is mistakenly taken to be the maximum operating speed for the bearing. The limiting speed values in product tables are practical recommendations for “general” applications. They are a rather conservative safety margin.

SKF has run a 230/500 spherical roller bearing with C08 running accuracy at twice the SKF General Catalogue speed limit.

So, speed limits are not the absolute maximum permissible speeds. They can be exceeded provided necessary measures have been taken regarding bearing design (e.g. running accuracy, cage), lubrication, cooling or precision of surrounding parts.

As a guideline, SKF recommends bearings with increased running accuracy, such as C08 and VQ424, be used for speeds above the speed rating indicated in the SKF General Catalogue and VA460 bearings for speeds above the limiting speed. Please contact SKF application engineers for more information.

High speed machine