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. The operating conditions for these bearings vary greatly depending on where they are installed on the machine.

A paper machine has a large number of rolls equipped with medium and large-size rolling bearings (→ fig. 1.1). In a few applications, plain bearings are sometimes used.

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

- Pulp drying machines 100–300 m/min
- Board machines 250–1 400 m/min
- Liner machines 300–1 800 m/min
- Fine paper machines 700–2 200 m/min
- Newsprint machines 1 000–2 200 m/min
- Tissue machines 1 100–2 200 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.
General requirements and recommendations

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*.

**Selection of bearing size**

**Fatigue life – service life**

By definition, a bearing is considered to have failed from fatigue as soon as spalling occurs. Spalling can be detected by using a vibration-sensitive instrument. If operation is continued after the first sign of spalling 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 1.1. The diagram shows that the fatigue life of one bearing can differ greatly from that of another bearing in a large population. Diagram 1.1 can be presented in another way in diagram 1.2, which is more interesting for bearing users. It shows the number of bearings in a population that reach their fatigue life per unit of time.

The length of time that a bearing can be left in service after reaching its defined fatigue life is generally difficult to specify.

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.

![Diagram 1.1](image)

**Formula**

- $L$ = 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
To the end-user of SKF bearings, the term “bearing life” means the time that an individual bearing works satisfactorily in the machine. SKF calls this the “service life” of the bearing. 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 $L_{10mh}$ lives**

SKF has many years of experience selecting bearing size for the paper industry using the $L_{10h}$ and $L_{10mh}$ bearing life equations. When calculating the life of paper machine bearings, SKF recommends that both the basic rating life $L_{10h}$ and the SKF rating life $L_{10mh}$ are taken into consideration. The calculated bearing basic rating life $L_{10h}$ should exceed 200,000 hours for dryer section bearings and 120,000 hours for bearings in other sections. The calculated SKF rating life $L_{10mh}$ should be 100,000 hours or more for all bearing positions in the paper machine. There are some exceptions due to the fact that too low loaded bearings can fail even if the calculated life is over 100,000 hours. Rollers of a too lightly loaded bearing might slide instead of roll. For example, machine speed increase leads to increased wire and felt tension. This can add load on some bearings, but as well lift some rolls, decreasing the load on some bearings. SKF catalogue *Rolling bearings* contains formulas to calculate the minimum load in order to provide satisfactory operation.

Please note that in 2015, SKF launched the concept of the “SKF Generalized Bearing Life Model” (GBLM). This new bearing life rating model, contrary to current models including ISO 281, separates the calculation of bearing rating life in surface and subsurface terms. The surface term is calculated by using the results of explicit tribological models while the subsurface term is calculated with classical Hertzian rolling contact fatigue theory.

Surface performance factors are introduced with a direct influence on surface damage risk while the basic dynamic load rating (C-value) is retained according to its original purpose in the subsurface term. This new bearing life rating model is not yet included in the current SKF catalogue *Rolling bearings*.
The basic rating life $L_{10h}$

The most common way to calculate the bearing life is to use the equations in the SKF catalogue *Rolling Bearings*. The equation to be used is

$$L_{10h} = \frac{1,000,000 \times C^p}{60 \times n \times P}$$

where
- $L_{10h}$ = basic rating life (at 90% reliability), 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

The SKF rating life $L_{10mh}$

The SKF rating life highlights the significant influence of cleanliness and lubricant film thickness on the fatigue life of bearings. Even though bearings in pulp and paper machinery rarely run until they are fatigued, cleanliness and lubricant film thickness have 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 $\eta_c (P_u/P)$ in diagram 1.3, where
- $\eta_c$ = adjustment factor for contamination
- $P_u$ = fatigue load limit, N
- $P$ = equivalent dynamic bearing load, N

Similar diagrams for radial and axial ball bearings, as well as for axial roller bearings, are given in the SKF catalogue *Rolling Bearings*.

Diagram 1.3

If $k > 4$, use curve for $k = 4$

As the valued of $\eta_c (P_u/P)$ tends to zero, $a_{SKF}$ tends to 0,1 for all values of $k$

Factor $a_{SKF}$ for radial roller bearings
There are advantages and disadvantages with these simplified methods. For example, it enables quick comparison with previous bearing dimensioning and field experience. This method is 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 additional 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 that considers 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
Bearing types used in paper machines

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. 1.2). This bearing arrangement, called the SKF self-aligning bearing system, accommodates both misalignment and axial displacement internally and without frictional resistance, with no possibility of generating internal axial forces in the bearing system.

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 1.4 shows the life of different bearing systems. The coefficient of friction $\mu$ 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 $\mu = 0.15$ is used.
SKF spherical roller bearings

All SKF spherical roller bearings have the C design to avoid edge stress and high friction under axial load which is typical for old bearing designs having a fixed middle flange on the inner ring. The C design, created by SKF in the early 50s, has symmetrical rollers and no fixed middle flange on the inner ring. The rollers are guided in the unloaded zone by a floating guide ring so that they enter the load zone in the optimal position (→ fig. 1.3).

To reduce further friction and frictional heat, rollers are self-guided by the CC principle (→ fig. 1.4). Today, all SKF spherical roller bearings have the CC principle even if this is not indicated in the designation. The CC principle, together with the manufacturing precision of the bearing and the adjacent elements, and also the optimized lubrication and heat removal, permits SKF bearings to run above catalogue limiting speeds in press roll applications.
General requirements and recommendations

**SKF spherical roller bearing of CC, C, EC and ECC designs**

These bearings have symmetrical rollers, a flangeless inner ring and a pressed steel cage for each roller row (fig. 1.5). The guide ring is centred on the inner ring. Bearings of EC and ECC designs incorporate reinforced roller sets for added load carrying capacity.

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

These designs are used for large sizes of SKF spherical roller bearings (fig. 1.6). 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 ECAC and ECA designs have reinforced roller sets for increased load carrying capacity.

**SKF spherical roller bearings of E design**

These bearings have symmetrical rollers, a flangeless inner ring, and a guide ring centered on the hardened cages (fig. 1.7). 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 and, for the bearings with bores larger than 65 mm, better roller guidance in the unloaded raceway zone. Smaller E design bearings, with bores less than or equal to 65 mm, look like CC design spherical roller bearings.

**SKF sealed spherical roller bearings**

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. 1.8). Such bearings have the same load carrying capacity as equivalent open spherical roller bearings. While the sealed E design is wider than the open E design, all the others have the same boundary dimensions as equivalent open bearings.
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 are longer life for existing machines and the possibility for downsizing on new machines. To enable users to evaluate how this influences bearing rating life, SKF has introduced increased basic dynamic load ratings and shifted the $\eta_c (P_u/P)$ axis in the $a_{SKF}$ diagram when calculating $L_{10\text{m},h}$ life using the SKF rating life.

In 2011, SKF introduced the upgraded SKF Explorer bearing. It is made with a new generation steel giving higher toughness (crack resistance) and higher hardness (better wear resistance). To estimate the influence on the SKF rating life, an additional factor has to be considered.

All Explorer bearings with a bore equal or less than 300 mm have P5 circular radial run-out, which is four times better than ISO Normal values.

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{1.9}).

Upgraded SKF Explorer spherical roller bearings and packaging are marked WR in addition to the Explorer marking.

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

**CARB toroidal roller bearings**

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{1.10}).

Like spherical roller bearings, CARB toroidal roller bearings can accommodate misalignment and heavy radial loads, but are also able to accommodate axial displacement without additional frictional resistance, like a cylindrical roller bearing. This is what makes CARB toroidal roller bearings 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.
General requirements and recommendations

Designations

The most common supplementary designations for spherical roller bearings and CARB toroidal roller bearings are shown in table 1.1. The table also shows where in the machine the bearings are used.

Table 1.2, gives a larger number of supplementary designations for bearings used on paper machines.

Doctor bearings

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. 1.11). Specially designed plain bearings can also be used. The rotating movement is necessary when the doctor is turned to a rest position during maintenance or when changing the blade. In addition to this degree of movement, the bearing is able to accommodate 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 or reel spools, deep groove ball bearings in rope sheaves, spreader rolls and shoe press and self-aligning ball bearings in spreader rolls, and plain bearings in calender applications.

Table 1.1

<table>
<thead>
<tr>
<th>Features</th>
<th>Requirement</th>
<th>Rolls</th>
<th>Press section</th>
<th>Dryer section</th>
<th>Heat treatment</th>
<th>Special features</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Forming section</td>
<td>Press section</td>
<td>Dryer section</td>
<td>Heat treatment</td>
<td>Special features</td>
</tr>
<tr>
<td>Clearance</td>
<td>std C3 C4</td>
<td>++ X X X</td>
<td>++ X X X</td>
<td>++ X X X</td>
<td>++ X X X</td>
<td>L5DA (X)</td>
</tr>
<tr>
<td>Running accuracy</td>
<td>std C08 V0424</td>
<td>X X ++ X</td>
<td>X X X X X</td>
<td>X X X X X X</td>
<td>X X X X X X</td>
<td>(X) Recommended only for the specific operating conditions detailed in the relevant chapters of this handbook</td>
</tr>
<tr>
<td>Heat treatment</td>
<td>std HA3</td>
<td>X X X X X X X X</td>
<td>X X X X X X</td>
<td>X X X X X X</td>
<td>X X X X X X</td>
<td>(X)</td>
</tr>
</tbody>
</table>

The clearance requirement is a guideline that can vary depending on the effect of actual operating conditions and fit values.
### Supplementary designations used for bearings in paper machines

Table 1.2

<table>
<thead>
<tr>
<th>Designation</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>342460</td>
<td>Special design cylindrical roller bearing for drying cylinders. SKF recommends that such bearings are replaced with CARB toroidal roller bearings.</td>
</tr>
<tr>
<td>C2</td>
<td>Radial internal clearance class less than Normal</td>
</tr>
<tr>
<td>C3</td>
<td>Radial internal clearance class greater than Normal</td>
</tr>
<tr>
<td>C4</td>
<td>Radial internal clearance class greater than C3</td>
</tr>
<tr>
<td>C5</td>
<td>Radial internal clearance class greater than C4</td>
</tr>
<tr>
<td>C08</td>
<td>Extra reduced tolerance for circular radial run-out (P5) of inner ring and outer ring of assembled bearing. Standard for Explorer spherical roller bearings and CARB toroidal bearings with bores equal or less than 300 mm.</td>
</tr>
<tr>
<td>C083</td>
<td>C08 + C3</td>
</tr>
<tr>
<td>C084</td>
<td>C08 + C4</td>
</tr>
<tr>
<td>C10</td>
<td>Old suffix. Reduced and displaced tolerances for bore and outside diameter. For bearing with tapered bore refers to outside diameter only.</td>
</tr>
<tr>
<td>C103</td>
<td>C10 + C3</td>
</tr>
<tr>
<td>ECB</td>
<td>Spherical roller bearing with case hardened inner ring, USA production</td>
</tr>
<tr>
<td>F</td>
<td>Machined cage of steel or special cast iron</td>
</tr>
<tr>
<td>HA3</td>
<td>Case hardened inner ring</td>
</tr>
<tr>
<td>K</td>
<td>Tapered bore, taper 1:12 on diameter</td>
</tr>
<tr>
<td>K30</td>
<td>Tapered bore, taper 1:30 on diameter</td>
</tr>
<tr>
<td>M</td>
<td>Machined brass cage, roller guided.</td>
</tr>
<tr>
<td>S1</td>
<td>Bearing rings dimensionally stabilized for operating temperature up to +200 °C. Standard for SKF spherical roller bearings and CARB toroidal bearings.</td>
</tr>
<tr>
<td>S2</td>
<td>Bearing rings dimensionally stabilized for operating temperature up to +250 °C.</td>
</tr>
<tr>
<td>VA405</td>
<td>Spherical roller bearing design for vibrating applications such as vibrating screens.</td>
</tr>
<tr>
<td>VA460</td>
<td>Spherical roller bearing and CARB toroidal roller bearing designed for very high speeds.</td>
</tr>
<tr>
<td>VA701</td>
<td>Special design cylindrical roller bearing for drying cylinders. SKF recommends that such bearings are replaced with CARB toroidal roller bearings.</td>
</tr>
<tr>
<td>L4B</td>
<td>Black oxidized bearing, rollers and rings</td>
</tr>
<tr>
<td>L5DA</td>
<td>NoWear anti-smearing coating on rollers</td>
</tr>
<tr>
<td>VDKx4</td>
<td>Circular radial run-out better than C08 and reduced width tolerance + W4 + W58 + serial number</td>
</tr>
<tr>
<td>W</td>
<td>Without W33 lubrication feature (when W33 standard)</td>
</tr>
<tr>
<td>W4</td>
<td>Eccentricity high point location marked on inner ring</td>
</tr>
<tr>
<td>W20</td>
<td>Three lubricating holes in outer ring of spherical roller bearing</td>
</tr>
<tr>
<td>W26</td>
<td>Spherical roller bearing with 6 lubricating holes drilled through the inner ring</td>
</tr>
<tr>
<td>W31</td>
<td>Bearing specification according to an old and obsolete Beloit quality standard</td>
</tr>
<tr>
<td>W33</td>
<td>Rolling bearings with 3 lubricating holes and circumferential groove in outer diameter</td>
</tr>
<tr>
<td>W58</td>
<td>Eccentricity high point location marked on outer ring</td>
</tr>
<tr>
<td>W77</td>
<td>Rolling bearings with W33 holes plugged</td>
</tr>
<tr>
<td>W503</td>
<td>W33 + W4</td>
</tr>
<tr>
<td>W506</td>
<td>W31 + W33</td>
</tr>
<tr>
<td>W507</td>
<td>W4 + W31 + W33</td>
</tr>
<tr>
<td>W509</td>
<td>W26 + W31 + W33</td>
</tr>
<tr>
<td>W513</td>
<td>W26 + W33</td>
</tr>
<tr>
<td>W529</td>
<td>W33 + W58</td>
</tr>
<tr>
<td>ZE</td>
<td>SKF SensorMount sensor positioned on the small bore diameter side</td>
</tr>
<tr>
<td>ZEB</td>
<td>SKF SensorMount sensor positioned on the large bore diameter side</td>
</tr>
</tbody>
</table>
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 elongation 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

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.

The SBFN design can be mounted in the wet section with some slight modifications such as additional covers.
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. 1.13).
- 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 recommends the use of a spherical roller bearing at the drive side and a CARB toroidal roller bearing at the front side.

Yankee cylinder housings

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 side support rockers (→ fig. 1.14)

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 normally not recommended unless it’s combined with the bolted on steam box. The figure shows a cover designed for a steam box.

SKF Yankee cylinder rocker housing

Fig. 1.13

Fig. 1.14
Axial displacement for CARB toroidal roller bearings

The relation between radial clearance and axial displacement from a central position is shown in diagram 1.5. 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/C4 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 1.5, 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.
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. Depending on where they are in the machine, bearing arrangements may be subjected to flowing water, condensation, dry conditions or a high ambient temperature. The seals of the housings on the non-locating side must allow for the required axial movement due to shaft elongation. 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. 1.15). If the bearings are oil lubricated, the sealing arrangements have to be of a different design. Fig. 1.16 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, 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. 1.17 shows a design of how to improve the seals of dryer section housings.
General requirements and recommendations

SKF can provide a full range of radial shaft seals and V-rings. SKF can also offer customized machined seals with short delivery times (→ fig. 1.18). 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 the increased circulating oil flow through the original small 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. 1.19 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

\[ d = 2.2 \left( \frac{(2.5 + 0.2 \times n) \times 10^{3} + 3 \times v \times Q}{h} \right)^{1/4} \]

where
- \( d \) = minimum bore of outlet pipe, mm
- \( n \) = number of 90° bends
- \( Q \) = oil flow, l/min
- \( v \) = kinematic viscosity of oil at lowest operating temperature (mostly at start-up), mm²/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 mm²/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.

\[ d = 2.2 \left( \frac{(2.5 + 0.2 \times 2) \times 4 \times 10^{3} + 3 \times 220 \times 3 \times 1000 \times 4}{1000} \right)^{1/4} = 20.8 \text{ mm} \]

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

\[ d = 1.5 \times 20.8 = 31.2 \text{ mm} \]

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

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

The tolerances for cylindrical bearing seats on shafts and in housings should correspond to the tolerance class of the bearings. Guideline values for the dimensional and geometrical tolerances are provided hereafter.

Dimensional tolerances
For bearings made to normal tolerances, the dimensional tolerance of the cylindrical seatings on the shaft should be at least to ISO grade IT6 and in the housing to at least grade IT7. Where adapter or withdrawal sleeves are used on cylindrical shafts, grade IT9 (h9) can be permitted.

Tolerances for total radial run-out
Total radial run-out tolerances as defined in ISO 1101 should be one to two IT grades tighter than the prescribed dimensional tolerance.

For example, assuming a bearing seat with shaft diameter tolerance m6, corresponding to IT6, the required total radial run-out is then IT5/2 or IT4/2 because ISO 1101 defines the total radial run-out as a difference in radii of two coaxial cylinders.

Two IT grades better than the prescribed dimensional tolerance is recommended when particularly stringent run-out requirements are stipulated e.g. when bearings with extra close circular radial run-out 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 total axial run-out
Abutments for bearing rings should have a total axial run-out tolerance, as defined in ISO 1101, which is better by at least one IT grade than the diameter tolerance of the associated cylindrical seat. The axial run-out of the abutments corresponds to the required axial run-out of the mounted inner ring. The latter run-out requirement applies even when the bearing is mounted on a tapered journal without abutment.

Tolerances for tapered journal seatings
When the bearing is mounted directly on a tapered journal seat, the seating diameter tolerance is permitted to be wider than in the case of a cylindrical seat. Fig. 1.20 shows a grade 9 diameter tolerance, while the form tolerance stipulations are the same as for cylindrical journal seats.
When establishing tolerances for tapered journal seats 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, which are also valid for CARB toroidal roller bearings, are as follows:

- The permissible taper deviation for machining the taper seats is a \( \pm \) tolerance in accordance with IT7/2 based on the bearing width \( B \). The IT7/2 tolerance is divided by the bearing width \( B \), in order to convert this length tolerance into a corresponding angle tolerance. \( \rightarrow \text{fig. 1.20} \).

- The straightness tolerance is IT5/2 and is defined in accordance with \text{fig. 1.20}. In each axial plane through the tapered surface of the shaft, the tolerance zone is limited by two parallel lines a distance IT5/2 apart.

- The radial deviation from circularity, defined in accordance with \text{fig. 1.20}, is to comply with IT5/2. In each radial plane along the tapered shaft, the tolerance zone is limited by two concentric circles a distance IT5/2 apart. When particularly stringent run-out requirements are stipulated e.g. when spherical roller bearings with extra reduced circular radial run-out tolerance C08, VA460 or VO424 are used, IT4/2 should be applied 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 seats up to around 150 mm in diameter are generally checked with ring gauges, and those above this size with special taper gauges. When Prussian blue is used, the area in contact should be at least 90% when shaft is new. At least 80% is accepted for an already used shaft. Using a new bearing inner ring as a ring gauge can give lower contact area than 80% even if the bearing and journal are within tolerances.

The gauge recommended by SKF in Europe can be seen in \text{fig. 1.21}. The taper deviation and the diameter of the seat in relation to a reference surface can be measured with this gauge. The tolerance \( M_2 - M \) is calculated by means of the equation

\[
M_2 - M = \pm \left( \frac{\text{IT7}}{2} \times \frac{G}{B} \right)
\]

where

- \( G \) = distance between the points of measurement, mm
- \( B \) = bearing width, mm

![Fig. 1.21](gauge-for-tapered-journal-european-design.png)
Example: Spherical roller bearing 23152 CCK/C4W33 (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. 1.21, page 1:19.

If a gauge with 80 mm distance between the measuring points (G) is used, the taper deviation (M₂ – M) is allowed to be

\[ \pm 0.020 \times \frac{80}{144} = \pm 0.011 \text{ mm} \]

The gauge supplied by SKF in North America can be seen in fig. 1.22. It is called the sine bar gauge and the taper deviation can be measured with this tool.

Support surface for housing base

It is recommended that the support surface for the housing is finished to \( R_a \leq 12.5 \mu \text{m} \). The flatness tolerance should be to IT7 on the length of the support surface.
Oil flow resistance in a spherical roller bearing

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

\[
\Delta p = \frac{Q \cdot D \cdot \nu}{6 \cdot 132 \cdot d_h^4}
\]

where

- \(\Delta p\) = required oil pressure, MPa
- \(Q\) = oil flow, l/min
- \(D\) = bearing outside diameter, mm
- \(\nu\) = kinematic viscosity of oil at lowest operating temperature (generally 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 1.3. The groove numbers used for different spherical roller bearings are also listed in table 1.3.

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

\[
d_h = \frac{4 \cdot A}{O_a}
\]

where

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

---

**Table 1.3**

<table>
<thead>
<tr>
<th>Groove No.</th>
<th>Groove dimension</th>
<th>Hydraulic diameter</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>b</td>
<td>h</td>
</tr>
<tr>
<td>1</td>
<td>5.5</td>
<td>1.2</td>
</tr>
<tr>
<td>2</td>
<td>8.3</td>
<td>1.8</td>
</tr>
<tr>
<td>3</td>
<td>11.1</td>
<td>2.4</td>
</tr>
<tr>
<td>4</td>
<td>13.9</td>
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<tr>
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<td>3.6</td>
</tr>
<tr>
<td>6</td>
<td>22.3</td>
<td>4.8</td>
</tr>
</tbody>
</table>

---

**Table 1.4**

<table>
<thead>
<tr>
<th>Bearing size(^1)</th>
<th>Groove no.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Series</td>
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<tr>
<td>239 over incl.</td>
<td>230 over incl.</td>
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<td>80</td>
<td>96</td>
</tr>
<tr>
<td>96</td>
<td>64</td>
</tr>
</tbody>
</table>

\(^1\) The figures in the table represent the last two figures of the designation; thus, bearing 23024 has groove no.1.
Example: dimensions of enlarged area

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.

$$\Delta p = \frac{5 \times 400 \times 220}{6 \times 132 \times 5.18^4} = 0.1 \text{ MPa}$$

By turning a 25 mm wide and 6 mm deep groove in the housing seating, the enlarged duct area will be ($\rightarrow$ fig. 1.23)

$$A = 25 \times 6 + 3.6 (16.7 - 2 \times 3.6) + 3.6^2 = 197.2 \text{ mm}^2$$

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

$$\Delta p = \frac{5 \times 400 \times 220}{6 \times 132 \times 12.14^4} = 0.0033 \text{ MPa}$$

The required pump pressure without a groove is 0.1 MPa. By turning a groove 25 x 6 mm in the housing seating, a considerable reduction, to 0.0033 MPa, is obtained.
High-speed machines

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

Increased requirements on run-out tolerances

With production speeds higher than 900 m/min, there is an increased demand for bearings with extra-reduced circular radial run-out tolerances. 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 circular radial run-out 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 circular radial run-out tolerance class P5.

VQ424 means that the bearing has a circular radial run-out 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 bearings are also an advantage when regrinding the rolls. By using such bearings, less time is needed and better total run-out of the roll is achieved.

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

Reduced circular radial run-out of the bearing is not the only way to reduce vibrations in paper machines. Another way is to decrease the total run-out of the journal.

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 adequate 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 catalogue Rolling Bearings.

In fast machines with large and heavy bearings which may operate at radial loads less than the recommendations in the SKF catalogue Rolling Bearings, SKF recommends NoWear bearings with coated rollers (designation suffix 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 catalogue Rolling Bearings 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 have a rather conservative safety margin.

SKF has run a 230/500 spherical roller bearing with C08 running accuracy at twice the SKF catalogue Rolling Bearings 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.
General requirements and recommendations

Experience has shown that for heavy spherical roller bearings and CARB toroidal roller bearings above 500 mm bore in high speed press rolls, a higher clearance class than normally recommended may be necessary to avoid uncontrolled radial preload during machine start up. Also, above a certain oil flow, oil doesn’t remove more heat from the bearing assembly, but instead will create more heat due to increased drag losses.

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 catalogue Rolling bearings and VA460 bearings for speeds above the limiting speed. Please contact SKF application engineering for more information.

Modern paper machine

Picture from Voith GmbH