



Fretting corrosion on the outside surface of a bearing outer ring due to a damaged raceway

“What’s the correct fit for this bearing?”

This is a question that any SKF application engineer is frequently asked. The answer is rarely straightforward, but it’s important to get it right.

From the bearing point of view, applications in the pulp and paper industry may be subject to demanding operating conditions, such as large temperature gradients, heavy loads, hollow journals, rotating outer rings, etc. In these cases, special attention should be paid to dimensional and geometrical tolerances of adjacent components, mainly to avoid costly unplanned stops.

SKF has acknowledged the influence of shaft and housing geometry on bearing performance for decades. By means of intensive

research, analytical calculations, custom software and continuous interaction with OEMs and end users, we have gathered more than enough information to help you tackle any problem regarding this particular aspect.

In this issue of SKF Pulp & Paper Practices, we are going to go through some phenomena which occur on bearing seats due to incorrect tolerances and fits. Wear, fretting corrosion and creep appear very often—too often in my experience with paper mills and root cause failure analysis—and are sometimes considered unavoidable. Not only do they definitively shorten bearing life, they may also cause them to fail catastrophically.

I hope these documents help you understand more about rolling bearings, improve

procedures and applications and, eventually, increase the reliability of your rotating machinery. Whatever question you may have, please don’t hesitate to contact SKF!

Regards,
Franco Gagliano
Application Engineer
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Fretting corrosion and wear in the bearing seat due to ring creep or micro movement

I have seen many damaged bearing seats in my time. Sometimes only the bore or the outside diameter of the bearing has fretting corrosion and/or wear, but mostly the bearing has internal damage. While this can be partly explained by customers only contacting SKF when they have a serious problem, my experience is that minor seat damage is common even when the bearings are in good condition. This can have a bigger impact on bearing life than many people think. The outer ring movement of the non-locating bearing on its seat can be hampered thereby increasing axial load, for example.

While undertaking root cause failure analysis in mills, I've seen many bearings in poor condition which have rotated on the shaft or in the housing. This can lead to heavy wear and high costs to repair or replace shafts or housings. Often, the finger of blame is pointed at the bearing but, in reality, it's not the cause.

Bearing ring creep on the seat or heavy fretting corrosion can be the root cause of bearing damage, but it can also be secondary damage. While I cannot say what the ratio between the two is, I can show you many cases where the fit was the root cause of the problem.

In this issue of SKF Pulp & Paper Practices, I will cover the reason why a bearing ring creeps on its seat, the cause of fretting corrosion and the impact on bearing life. There will be no formulas and no equations, just information to help the reader understand the phenomena.

What is fretting corrosion?

That rotation or creeping of a ring on its shaft seat or in the housing bore seats creates wear and perhaps smearing is readily understandable, but I'm sometimes asked about the cause of fretting corrosion.

Fretting corrosion occurs when there is relative movement between a bearing ring and its seat on a shaft or in the housing. This relative movement can be very small and occur due to the unique elastic deformation of the rings under load, for example (→ figure 1).

The relative movement may cause small particles of material to become detached from the bearing surface and its seat. They oxidize quickly when exposed to air and form iron oxide which is larger in volume than iron or steel. Therefore, and as a result of the fretting corrosion, the bearing may not be evenly supported. This can have a detrimental effect on the load distribution in the bear-

ing. Iron oxide particles will also act as abrasive particles increasing the wear rate and loosening the fit. In addition, the coefficient of friction increases in the mating surfaces and corroded areas also act as fracture notches.

Fretting corrosion appears as areas of rust on the outside surface of the outer ring (→ figure 1) or in the bore of the inner ring. The raceway path pattern could be heavily marked at corresponding positions. In some cases, fretting corrosion can be actually secondary damage due to heavy spalling on the raceway.

Depending on the chemical reaction, corrosion could appear as:

- red (hematite, Fe_2O_3)
- black (magnetite, Fe_3O_4)

Fretting corrosion damages not only the bearing outer surfaces, but also the bearing



Fig. 1 Fretting corrosion on the outer diameter of a spherical roller bearing

seats on the journal or in the housing. A new bearing mounted on damaged seats due to heavy fretting corrosion will probably have its service life decreased. This is especially true when the bearing has to displace axially to cope with thermal elongation of the shaft. Fretting corrosion increases the friction between the bearing and its seat and thus increases residual axial load on the bearing.

Why is a tight fit necessary?

First, let's look at → **figure 2** which shows a bearing mounted with a loose fit on the shaft. The bearing inner ring is rotating with the shaft and the load on it has a fixed direction i.e. from top to bottom. The contact between the inner ring and the shaft will always be on the top surface of the shaft, but the shaft and inner ring experience rotating load.

With a loose fit and the different circumferences of the mating surfaces, there will be a permanent creeping movement comparable to that found in epicyclic gears.

If the radial clearance Δ of the loose fit is equal to 0.010 mm, the creeping distance is equal to $0,01 \pi = 0,0314$ mm at each revolution. If the rotational speed is 3 000 r/min, the distance after one hour would be 5 654 mm.

The creeping movement, of course, occurs between the inner ring face and the shaft shoulder. The reality is that there isn't just creeping, there's also sliding that creates wear and increases the problem.

Selecting the proper fit where there is a fully constant rotating load and the shaft and inner ring like in the case above is relatively straightforward and errors are quite rare. In cases where the load changes direction, there isn't constant rotation or the ring oscillates on or in its seat, fit selection errors are common. While this can have minor consequences and be acceptable in some applications, it can have serious consequences as you'll see in the following examples.

The first example is the wheel bearing stub axle on a four-wheel drive car (→ **figure 3**). The two tapered roller bearings experience outer ring rotation and are mounted with a press fit in the hub. The bearings inner rings are mounted with quite a small loose fit, like a g6, chosen for easy mounting/dismounting and bearing clearance adjustment. Load on the inner rings oscillates around the vertical line depending on torque due to acceleration, speed, braking

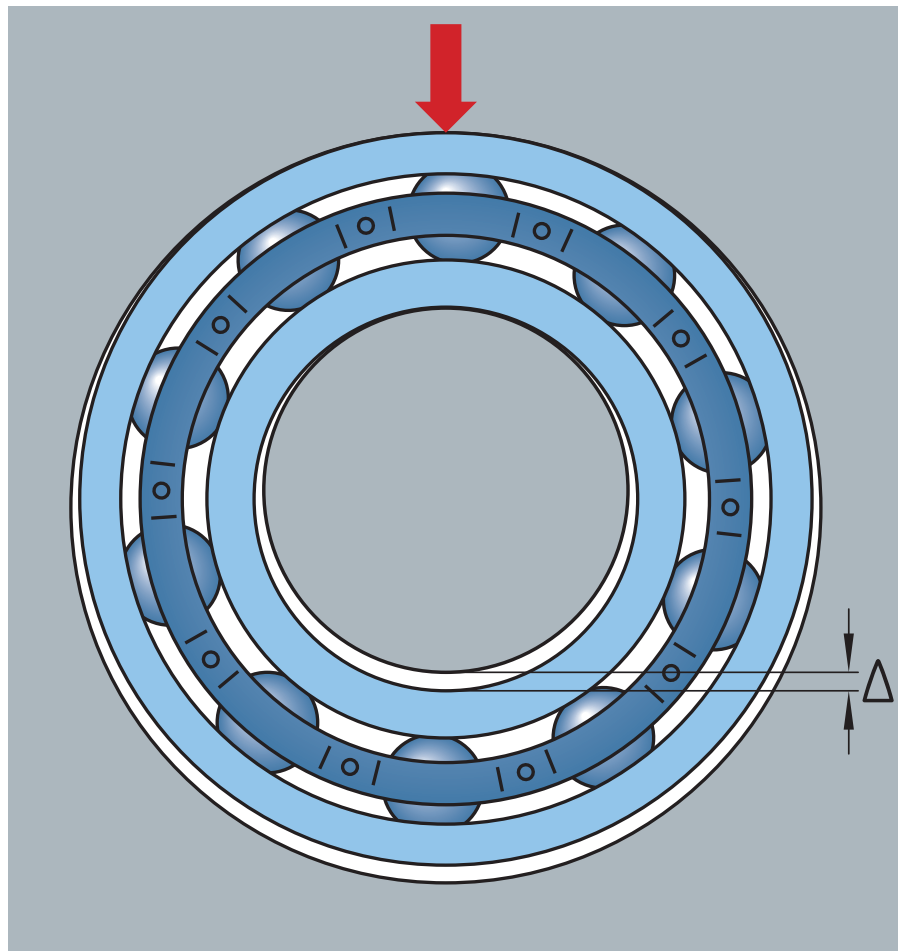


Fig. 2 Bearing inner ring mounted on a rotating shaft while the load has a fixed direction

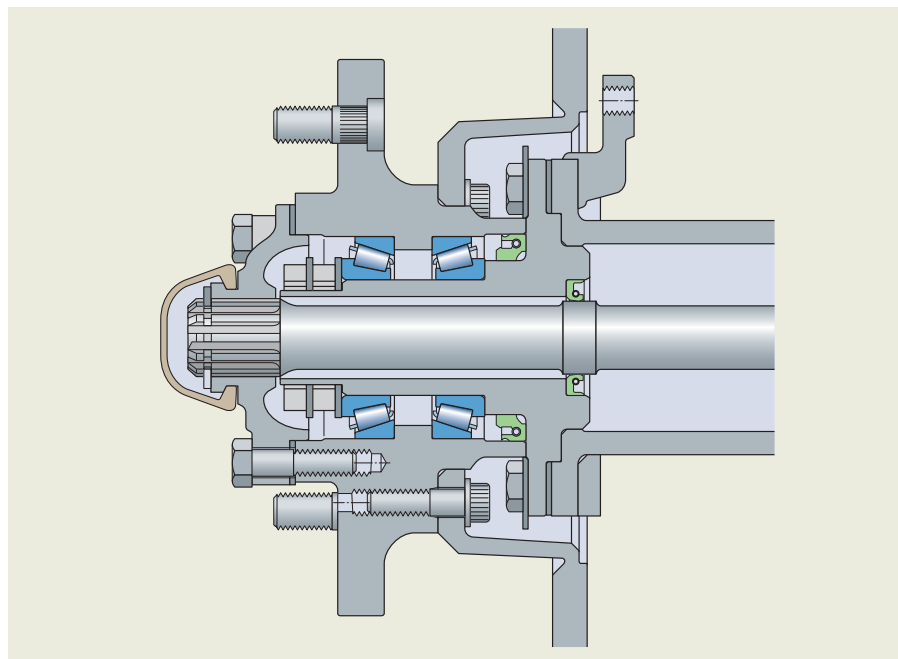


Fig. 3 Bearing assembly in a rear-driven wheel hub

etc. The inner rings roll back and forwards on the stub creating wear (→ **figure 4**).

Is this loose fit leading to acceptable wear? I would definitely say yes. After 200 000 km, there was just minor surface wear creating a mirror-like surface with some slight fretting corrosion. After 400 000 km, the wear could be felt with your fingernail, but it was not severe enough to make me decide to change the stub.

My second example is the intermediate gears used to drive groups of drying cylinders in some paper machines (→ **figures 5 and 6**). The typical bearing arrangement has two cross-located spherical roller bearings mounted with a tight fit on the inner rings and a loose fit on the outer rings. The outer rings are mounted like this to facilitate mounting and dismounting, for cost reasons, and to allow the bearings to find their position in operation. I've got a case in which there was on one side a double row tapered roller bearing and on the other side a cylindrical roller bearing, with tight fit for the inner rings and loose fit for the outer rings.

Depending on the radial run out of the drying cylinders, the felt tension and so on, the drying cylinders can be partly or fully driven by the paper and felt for short periods. When this happens, the load on the gears is modified and can sometimes even change direction. Load variation and load direction variation on the gear teeth when the gears drive or are driven make the bearings move in their housings creating heavy wear (→ **figures 7 and 8**).



Fig. 4 Wheel bearing stub axle showing wear in the contact surface with the tapered roller bearings due to a loose fit and changing load direction after 200 000 km



Fig. 5 Intermediate gears on a drying cylinder drive. Note that the blue covers show their position

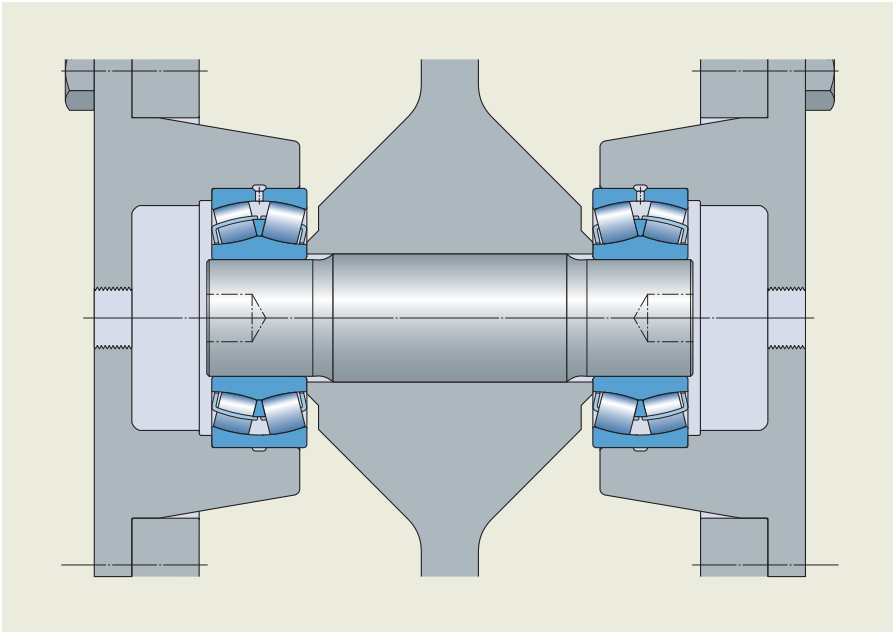


Fig. 6 Typical bearing arrangement for intermediate gears in the dryer section



Fig. 7 Fretting corrosion in the housing



Fig. 8 Fretting corrosion on the bearing outer diameter

While fretting corrosion creates particles that can contaminate the bearing, it can also lead to ring fractures as corroded areas act as fracture notches. Wear accelerates where helical gears are used and the loose fit can increase to such an extent that it is too great for tapered roller bearings and cylindrical roller bearings to tolerate as they cannot accept much misalignment.

In all cases, the bearing life is reduced and the housings need replacing. As do the gears which no longer mesh together properly. In my example, the wear rate was more or less the same in all positions so there were no issues until many years after the machine was built. However, when the problems started, the bearing failures and gear problems all happened over the course of a few years and led to a series of machine stops lasting 12–48 hours per position.

As a solution, SKF proposed an arrangement in which all the bearings are mounted with a tight fit in the housing and on the shaft. This meant that a cylindrical roller bearing could be used if a suitable CARB toroidal roller bearing wasn't available (→ figures 9 and 10)

Some customers asked SKF to modify their arrangements accordingly, but most decided to upgrade to “silent drive” i.e. removing the gears and having their drying cylinders driven by the felt rolls. This, however, created new bearing issues that I will cover later on.

While the issue of load direction changes in gears is well known and loose fits in the housing are avoided wherever possible (often H7 \oplus is used), too small loose fits can be problematic. We've seen this in gearboxes and in drying cylinders in the past too.

If non-locating bearings in gearboxes have to displace in their housings, they are often mounted with a H7 \oplus fit. Why is that fit chosen? Well, in theory, it's to provide a loose fit that allows for good gear meshing while reducing wear in the housing. However, quick start ups from cold with high viscosity oils can lead to the bearing heating up very quickly. This can lead to problems. Not only can the bearing inner ring heat up faster than the shaft and lose its tight fit, but the outer ring can heat up faster than the casing and the loose fit becomes a tight one. In such cases, no more axial displacement of the non-locating ring is possible and the bearing can fail due to excessive axial load.

With drying cylinder bearings the risk where spherical roller bearings were/are mounted as the non-locating bearing is that

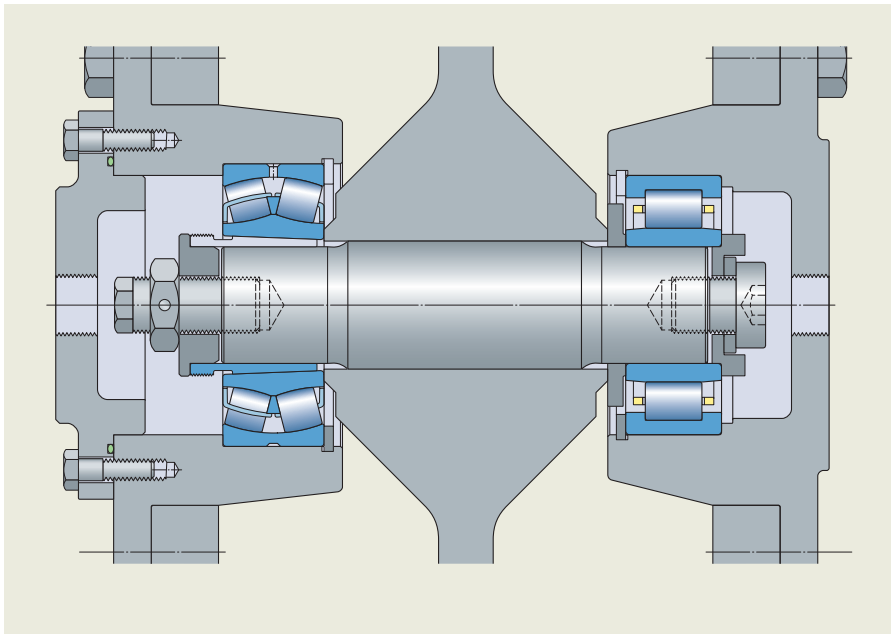


Fig. 9 SKF proposal with one spherical roller bearing and one cylindrical roller bearing

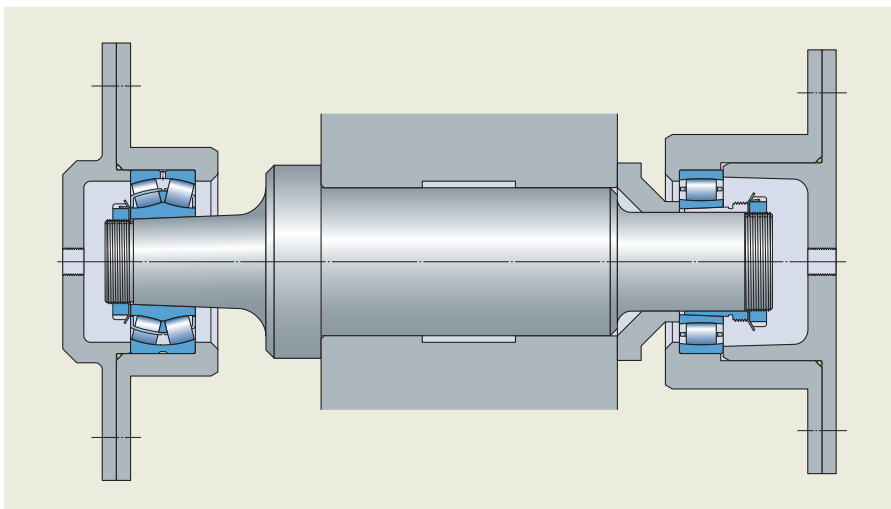


Fig. 10 SKF proposal with one spherical roller bearing and one CARB toroidal roller bearing

the outer ring can expand faster than the housing during start up and what are supposed to be non-locating bearings become locating ones. In such cases, F7 \oplus tolerance instead of G7 \oplus is recommended.

Tight fits do not always stop relative movement

Surprisingly for many, a ring mounted with a tight fit on the shaft can still creep under certain conditions. In fact, load on a bearing creates bearing, shaft and housing deformation.

Let's look at what happens when a bearing inner ring is mounted with a tight fit on a shaft. The load pushes the rollers into the rings and the rings deform. The bearing ring elongates so that the circumference of its bore gets larger. This explains why a tight fit can become a loose fit under load allowing a ring to creep on the shaft.

Even if the tight fit is sufficient to stop the ring creeping under load, the issue has not disappeared. There is still the possibility of micro movement between the ring and the shaft. This can happen if the ring is thin and the load is very high. Localized sliding may

then occur in the vicinity of the rolling element contacts between the ring and shaft that will create fretting corrosion without creeping.

It's worth noting that the race to have the highest catalogue ISO load capacity has led some bearing manufacturers to increase the diameter of their rollers as this is one factor in the calculation of the dynamic load rating value. The danger is that too large rollers means too thin rings resulting in an increased risk of fretting corrosion and loss of tight fit under high load. Keep in mind that while there is an ISO norm to calculate the dynamic load rating, bearing manufacturers are free to set the steel performance factor value for the calculation and there is no ISO procedure to check that claimed values are based on facts rather than marketing.

Let's look at an example of the loss of tight fit under load using a silent drive case. It concerned a Beloit machine built in 1974 with drying cylinder gear drives and grease-lubricated felt roll bearings mounted on adapter sleeves in the dryer section. In the 1990s, the mill decided to upgrade the dryer section to silent drive and to have the felt roll bearings lubricated by a circulating oil system.

A few years later, felt roll bearings started to fail (→ **figure 11**) while others exhibited heavy fretting corrosion in the bore, the sleeve bore and on the shaft (→ **figure 12**).

Analysis of the bearings, sleeves and shafts indicated that the fit wasn't tight enough for the application. The failed bearings would, in fact, have been heavily preloaded and inadequately lubricated as the result of significant sliding of adapter sleeves on shafts leading to high friction and inner rings heating up.

This wasn't easy to explain to the mill since experienced fitters had been mounting the same bearings in the same way for more than 20 years. The simple fact is that the feeler gauge mounting method and clearance reduction value used were fine for the load applied on the bearings prior to the upgrade to silent drive. This wasn't the case after the upgrade as increased felt tension increased the load on the bearings and the clearance reduction was no longer sufficient to give tight enough fits.

Look at the SKF's *Rolling bearings* catalogue where you'll see that the higher the load, the tighter the recommended fit. Furthermore, over the years load capacities (basic dynamic load ratings) have increased. For the same calculated basic rating life, the



Fig. 11 Part of a bearing inner ring on an adapter sleeve following heavy damage

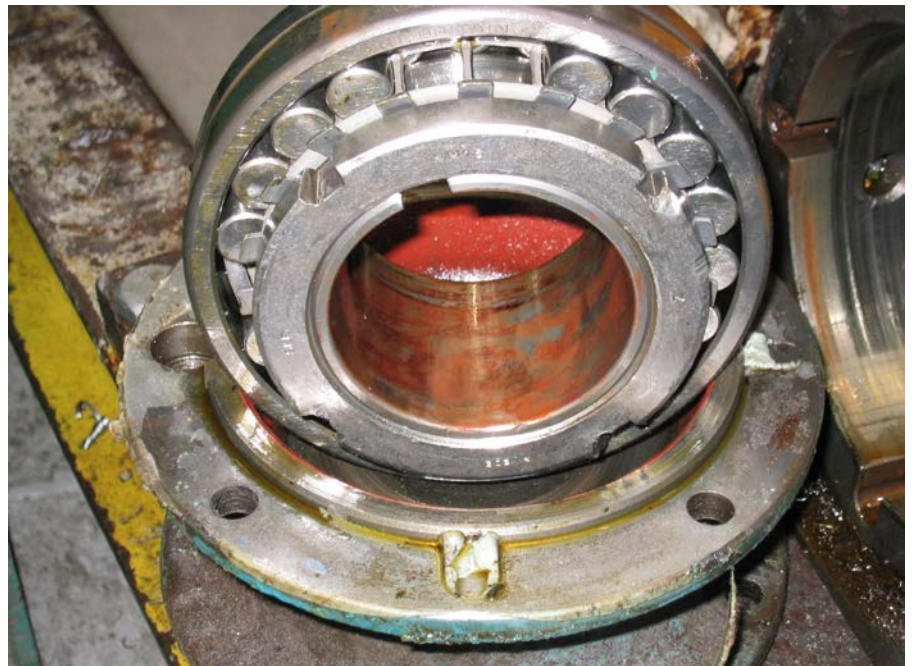


Fig. 12 Heavy fretting corrosion in an adapter sleeve bore, but the bearing raceway is in quite good condition which gives a clue about the root cause

load is increased by the same value as the basic dynamic load capacity and new recommendations for fits had to be given. Using the example of a 22316 E felt roll bearing operating under “normal load”, m6 was recommended in 1990, but n6[Ⓔ] is recommended today. For the same bearing under “heavy load”, SKF now recommends p6[Ⓔ]. Note that with tighter fits, higher radial clearance classes may be needed.

There is another example in paper machines where deformation leads to the demand for tighter fits than normal to avoid micro movement between the bearing inner ring and the journal. In some cases, they cannot be avoided even with very tight fits and often lead to bearing seat damage (fretting corrosion, wear and smearing) and short bearing service lives.

The application I’m talking about is suction rolls of similar design to the one shown in → **figure 13**. The bearing is mounted on a shaft with a bore diameter close to 80% or more of the bearing bore diameter. Under load, especially in the case of suction press rolls, the shaft ovalizes as does the bearing inner ring. Consequently, the diameter of the shaft and bearing inner ring varies during rotation creating micro movements between the shaft and the ring.

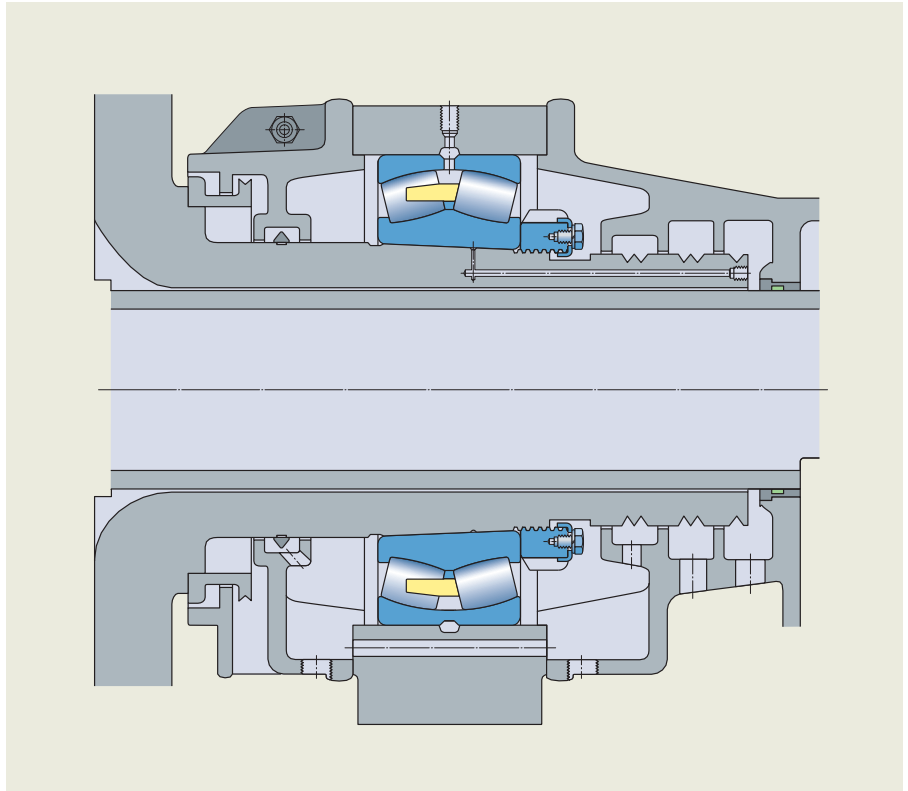


Fig. 13 Spherical roller bearing mounted on a very large bore shaft

When a bearing's bore diameter is close to 80% of the outer diameter of the shaft, the clearance reduction should be 0,00065 of the bearing bore diameter rather than the 0,0005 that is normally recommended. For example, the clearance reduction for a 230/600 CAK/W33 bearing (600 mm bore diameter) is $600 \times 0,00065 = 0,390$ mm. Due to the tighter fit, a higher radial clearance class than would normally be recommended for the operating conditions should be used. If a 230/600 CAK/W33 was initially selected based on the speed, load and operating temperature, a 230/600 CAK/C3W33 should actually be used.

Once you get above the 80–82% range, and depending on the shaft material, you are faced with micro movement and/or creeping regardless of the tightness of the fit. Increasing the tight fit and mounting case hardened bearings is pointless and experience has shown that glue doesn't help either.

A tight fit can be lost or reduced for other reasons such as the bearing heating up much more quickly than its shaft. This can happen with bearings with integrated friction seals running at high speed, when there is excessive lubrication or if the lubricant is too high viscosity. It can also happen if the shaft bends under the ring (→ figure 15).

The influence of tight fits on bearing life

Several things need to be taken into account. That tight fits reduce bearing clearance or increase preload. Also that tight fits on the inner ring increase hoop stress and reduce fatigue life.

There is a balance to be struck between fits and fatigue life. Fits should not be tighter than necessary because this reduces bearing life and could potentially lead to ring cracking (→ figure 16). Consider drying cylinder bearings. They are mounted on shafts that expand more quickly than their inner rings during start up due to steam temperature. During operation, the shaft is always hotter than the bearing which is the opposite of the situation found in most applications. The temperature gradient increases the tight fit. However, I would not recommend looser fits in an attempt to increase fatigue life since bearings can fail much earlier if they creep on their seats.

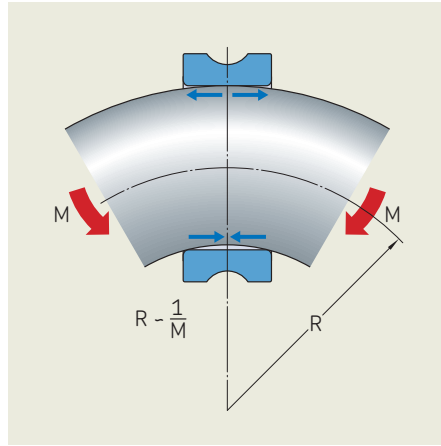


Fig. 15 Shaft bending under the bearing inner ring



Fig. 16 The fractured inner ring of a spherical roller bearing resulting from excessive drive-up

Loose fits are inadequate, but often necessary

Loose fits aren't adequate. I imagine that some people would disagree and argue that they have been used for decades on bearings that experience a fixed load direction. While it is certainly true that they are used, they are still inadequate. The main reason they are used is for ease of mounting/dismounting and to allow the non-locating bearing to move axially.

Our earlier wheel bearing and intermediate gear bearing examples showed that the desire for easy mounting can be acceptable, but also that it might not be. Looking for the easiest way can lead to unexpected fit selection errors. At the end of this issue, you will find something on a common error that occurs during maintenance on standard split plummer block housings.

It's the same for the desire for loose fits to accommodate displacement on non-locating bearings. Even if there is a stationary load of constant magnitude on a ring, fretting corrosion will occur if the fit is not tight enough. The speed at which the fretting appears and its intensity will depend on the load magnitude and the friction between the mating surfaces. Fretting corrosion will increase friction between the ring and its seat increasing the axial load caused by thermal elongation (→ page 6 of *SKF Pulp & Paper Practices issue 6*). This can be acceptable if the bearing does not suffer from the fretting corrosion and the increased friction between the mating surfaces or if the service life is limited by other causes. A non-locating sealed deep groove ball bearing in an electrical motor rarely fails due to very slight fretting corrosion, but it has been an issue for axially-free spherical roller bearings mounted in a housing fixed to the machine frame on drying cylinders. In this application, significant thermal elongation of the cylinder creates residual axial loads due to friction between the bearing and the housing and has a large effect on bearing life. Few mills still use such bearing arrangements as better options like CARB have long been available.

Fit selection

I won't go into details about how to select a fit since I believe that each case is a special case. The *SKF Rolling bearings* catalogue has guidelines, but thought needs to be given about whether they are followed or if they

should be adapted for the application in question.

Fit selection needs to balance several criteria and often involves compromises. You need to consider:

- Bearing rotation condition
- Load direction and magnitude
- Bearing internal clearance or preload
- Ring hoop stress limit (this depends on material and heat treatment)
- Temperature gradient conditions (especially during start up)
- Running accuracy requirements
- Design of shaft and housing and surrounding parts
- Ease of mounting and dismounting
- Displacement of the non-locating bearing
- Seal design: be careful about contacting seals creating friction and heat that makes components expand

The fact of the matter is that in some applications it can be harder to select the right fit that to size the bearing based on rating life requirements. In case of difficulties, I recommend contacting your local SKF application engineering department for help.

Conclusion

The best option is to have all bearing rings mounted with a tight fit and adjacent elements that do not deform under load or with temperature changes. Unfortunately, this isn't always possible for cost and mounting/dismounting practicality reasons.

If there is fretting corrosion, with or without creeping, between mating surfaces that supposedly have a tight fit and there is little or no bearing raceway surface damage then the fit is not tight enough.

We don't recommend mounting a bearing that has to displace axially in or on a seat for rings which have to slide to accommodate thermal elongation if there is fretting corrosion or wear no matter how slight.

To stop or slow fretting corrosion, a special anti-fretting paste (e.g. SKF LGAF 3E) or coating (e.g. SKF black oxide) can be applied. A special coating or surface hardening of the bearing seat can also help. As can lubrication. Grease can be forced into the mating surfaces via a direct supply duct and grooves. SKF can also supply spherical roller bearing designed for vibrating screens which have the option of a PTFE coating in the bore

to prevent fretting corrosion. Such bearings have a VA406 suffix or a VA408 one if coated.

To avoid a ring rotating due to a loose fit, the best option is a locating pin in the ring locating slot. Where the rotating load is sufficient to make the ring rotate, but small compared to the existing fixed radial load, one or two O-rings can be mounted in a groove in the seat (→ figure 17). One O-ring should be used for single row bearings or two for double row ones.

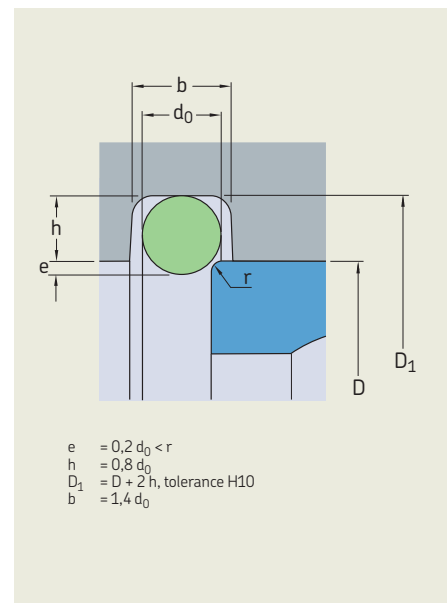


Fig. 17 O-ring in a bearing seat to reduce the risk of rotation in case of a loose fit

Regards,
Philippe Gachet
Senior technical consultant
SKF Pulp & Paper
global segment



Plummer block housing mounting error

As the cap and base of a split plummer block housing bearing seat are machined in the same operation, they should be kept together so that the dimensional and geometrical tolerances of the housing bore are met.

A common error is that caps and bases are exchanged during bearing mounting. → **Figure 18** shows a bearing outer ring where this has happened. The photograph shows part of the ring with fretting corrosion and thus contact, and one part without fretting corrosion and therefore no contact. On the opposite side of the ring, fretting corrosion is on the right and there's an undamaged surface on the left. When this happens, it creates oval clamping of the outer ring and can block the bearing creating axial overload in non-locating bearings that need to move in their housings and/or create premature fatigue.

To help prevent such problems, SKF SNL and SE housing have matching cap and base markings (→ **figure 19**). The markings are horizontal on SE housings and vertical on SNL ones. When mounting, care should be taken to ensure that the matching caps and bases are used.



Fig. 18 Oval clamping due to mismatched cap and base on a split plummer block housing



Fig. 19 Cap and base marking on a SKF SE Housing

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