

## We all have a lot in common whether we see it or not

*While my background is in production and operations management in the paper industry in Europe, where I worked for several of the larger paper and tissue producers, I have had the opportunity to broaden my horizons after joining SKF as a process consultant. Since moving to Asia a couple of years ago, I have really enjoyed seeing how things are done in the various mills and countries here.*

It is fascinating to see how different mills manage their production processes and the availability of their equipment. Sometimes the differences are quite marked, but I'm very often struck by the similarities as well. Changing daily priorities and dryer section problems, both of which effect production, seem to be fairly universal, for instance.

I recall sitting in a management meeting some years ago, at a mill that I worked at, listening to how pleased everyone was that only one day's production had been lost to a Yankee bearing failure. I remember thinking that it should not have happened at all and

about what could have done to prevent it in the first place. The priority however had been to get production running again as quickly as possible and, to be fair, the team did a good job of doing this. They didn't do such a good job of considering what the service life of the bearing could and should be or on the root cause analysis needed to prevent it happening again. They had moved on to the next item on the list of daily priorities, of course.

This edition of the newsletter and the next are about drying cylinder and Yankee bearings. We will cover the operating conditions, the issues and our recommendations for dealing with them. I hope that you'll find these two newsletters interesting and useful even if they don't help you with your daily priorities!

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# Drying and Yankee cylinder bearings and their lubrication (Part 1)

**SKF engineers working with paper mills get asked a lot of questions about bearing clearance, inner ring heat treatment and lubrication for drying and Yankee cylinder applications. In fact, after issues relating to corrosion and contamination from process water in the wet section, these are probably the most common things they have to deal with. As such, this issue of SKF Pulp & Paper Practices will focus on them. It's a broad subject so, in order to cover this matter in sufficient depth, we will also dedicate the next issue of our newsletter to it as well.**

## Bearing operating conditions

From the bearing perspective, drying and Yankee cylinder applications are rather similar. Bearings don't rotate at high speeds and they aren't heavily loaded. The steam used to heat such cylinders does create some challenges however.

Steam passing through the bore of the journal on which the bearings are mounted (→ fig. 1) causes radial and axial thermal expansion of both the journal and the cylinder.

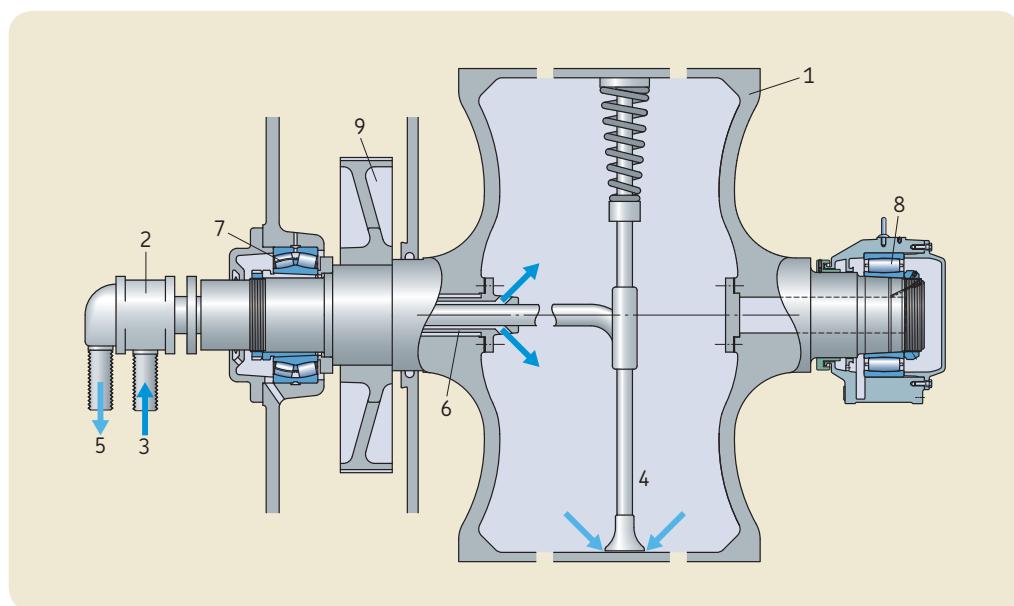
Axial thermal expansion creates the need for a bearing or housing that can accommodate relatively large axial expansion of the journal relative to the machine frame on the front side.

As steam also heats journals and bearings, and because the former will be hotter than the latter, bearing inner rings have to be able to withstand radial expansion. This creates additional stresses in inner rings on top of those created by mounting them with a tight fit on the seat. Due to the temperature difference between the inner and outer rings of the bearings, larger than normal radial internal clearance is required to maintain some clearance and to avoid preload.

The maximum internal clearance reduction and inner ring stress are experienced during start up with a cold machine. The accompanying drawings (→ fig. 2, 3, 5 and 6) show the calculated temperature distribution over the cross section of an arrangement during start up. These results were tested against an actual drying cylinder – on which temperatures were monitored – and confirmed for oil flows of between one and two litres per minute with slight deviations at high and low oil flow rates. The bearing in our simulation model is a 23052 CCK/C4W33 spherical roller bearing with a rotational speed of 130 rpm and an oil flow rate of 2 l/min. Our model assumes a steam temperature of 180 °C (356 °F) during start up and 130 °C (266 °F) under normal operating conditions.

With the temperature distribution shown in fig. 2, the hoop stress in the inner ring is increased by some 60% i.e. nearly 220 Mpa instead of 136 Mpa after mounting.

Fig. 1 A typical drying cylinder bearing arrangement.



### Drying cylinder arrangement

- 1 Drying cylinder
- 2 Steam joint
- 3 Steam inlet
- 4 Siphon
- 5 Condensation
- 6 Journal insulation
- 7 Drive side bearing
- 8 Front side bearing
- 9 Gear drive

Bearing internal radial clearance is reduced by 0,28 mm in **fig. 2** and 0,12 mm in **fig. 3**. A C4 radial internal clearance class bearing could run preloaded during start up. This does not necessarily impair the function of the bearing, but any error of form of the housing and shaft seating etc. – which are generally compensated for by the radial clearance of the bearing – may make their presence felt when the radial internal clearance is eliminated. This can have a negative effect on bearing life and lead to bearing damage.

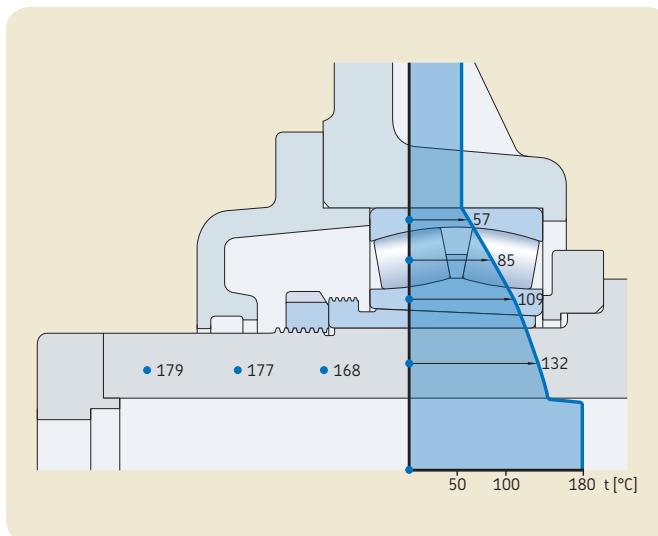
If, in our example, the bearing inner ring temperature is near 107–109 °C (225–228 °F), we should remember that where steam is above 170 °C (338 °F) during normal operation, without journal insulation, we can add approximately 20 °C (68 °F) to the bearing inner ring temperature.

As the steam heats up the bearing, the lubricant is also heated and there is a significant difference between the kinematic viscosity of oil under cold and hot conditions.

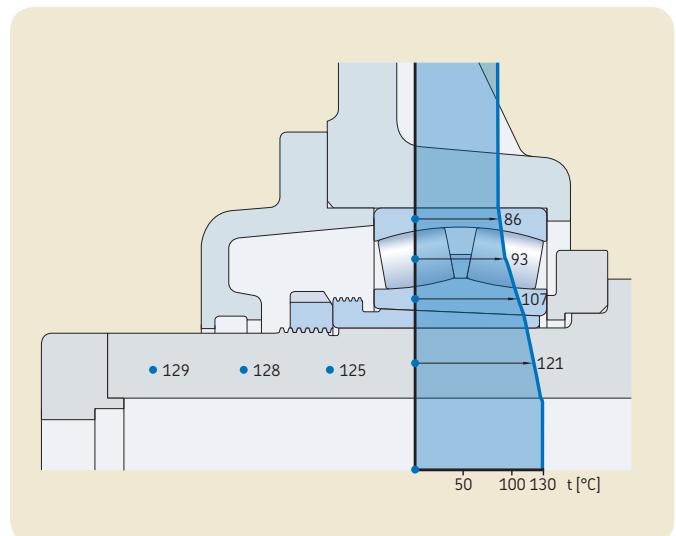
An air gap between the journal bore and the pipe through which the steam passes (→ **fig. 4**) reduces heat transfer to the bearings. Note that there is also an air gap at the end face of the journal and that without this the temperatures shown in **fig. 5** and **6** would be higher.

By insulating the bore and end face journals, bearing temperatures can be decreased by some 35 °C (95 °F). This has an enormous effect on the lubricant in terms of oil film thickness and service life.

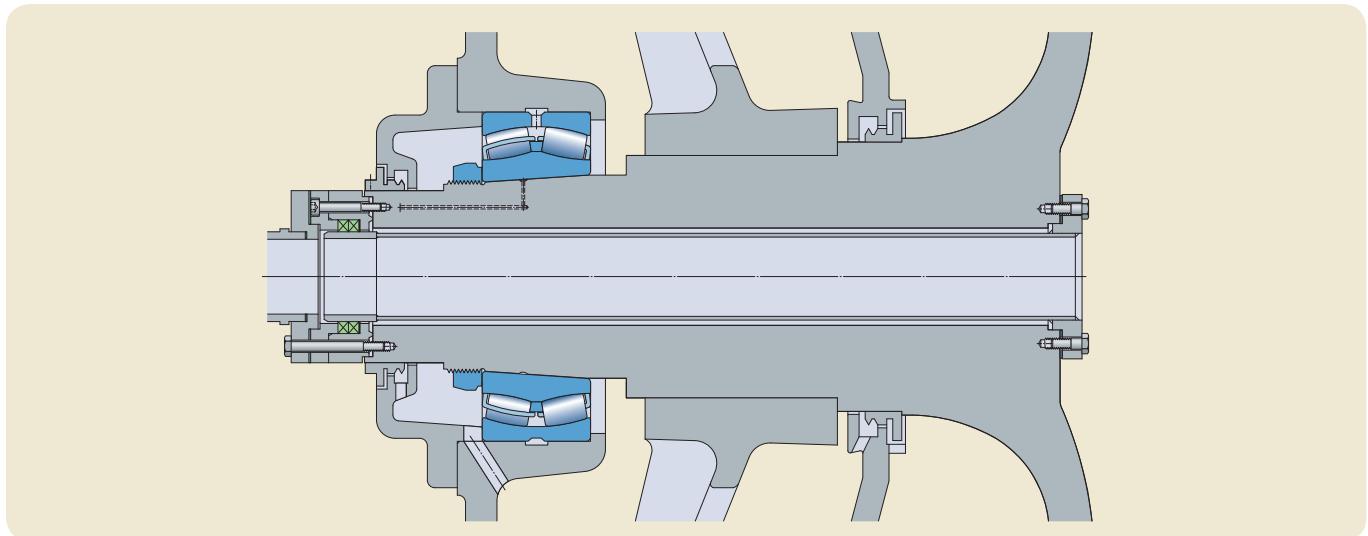
**Fig. 2** Temperature distribution 15 to 30 minutes after start up without journal insulation.



**Fig. 3** Temperature distribution during normal operation without journal insulation.



**Fig. 4** Air gap insulation on the drive side of a drying cylinder.



# Main issues

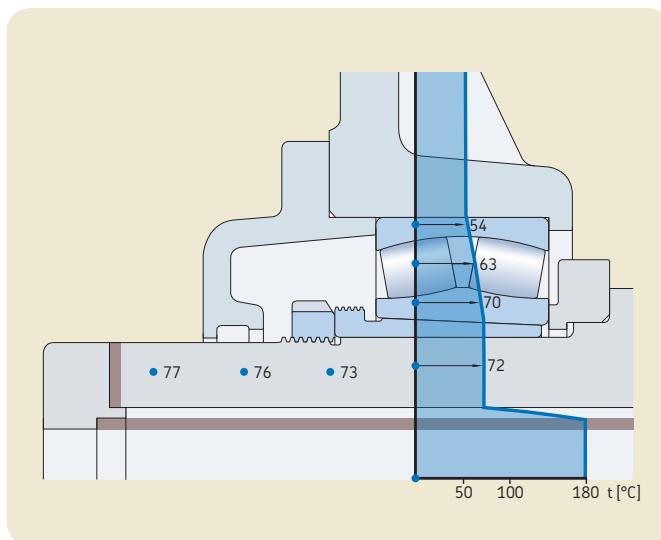
There are a number of issues that can cause problems in drying and Yankee cylinder applications:

- 1 Premature oxidation of the lubricating oil into a black, sticky sludge or even carbon. I call this "the black death" (→ fig. 7 and 8). It can be caused by using unsuitable oil, too low oil flows, too high temperatures, contamination that accelerates oxidation etc.
- 2 Paper mills reducing oil flow due to leakages which often occur because return pipes are dirty and create high flow resistance.
- 3 The use of unsuitable oil. Many of the products sold as paper machine oils for the dryer section do not pass SKF tests. These tests were developed by SKF in the late 1980s to test and approve new oils and additive packages for the operating conditions found in paper machines. Inadequate oils age quickly and become aggressive to bearing steel.
- 4 Liquid contamination due to condensation, high pressure cleaning, steam joint/stationary siphon leakage. One issue here is that most in-line oil/water separators are not efficient enough to evacuate all the water coming from a steam joint/stationary siphon leakage. This results in a bad balance i.e. more water entering the system than can be removed from it.
- 5 Bearing inner ring cracking issues. This happens most often during start up when the journal is much hotter than the bearing inner ring. The crack typically starts at a position where there is already damage like a dent, subsurface fatigue micro crack, a spall or corrosion. It starts from damage on the raceway or from the bore. Some bearing steel heat treatments are more sensitive than others. Don't believe that case hardened bearings are the only solution. Many customers have used SKF through hardened bearings for many years without problems. That said, some types of heat treatment shouldn't be used for drying cylinder bearings.

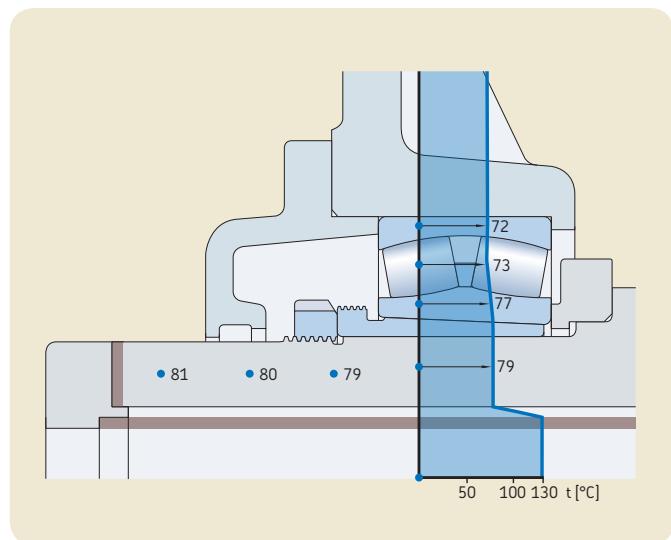
6 Too high temperatures. This is usually due to old machines, without drying cylinder journal insulation, being speeded up to produce more paper. Instead of adding more drying cylinders and/or having increasing water removal in the press section, steam temperature is increased without adding journal insulation.

- 7 Axial overloading because the outer ring of the axially free spherical roller bearing - traditionally on the front side - cannot slide in its housing. Most often this is due to too high fretting corrosion in the housing bore and/or on the bearing outer diameter. There have also been cases where the temperature difference between the housing and the bearing outer ring was so high that it resulted in an interference fit between the outer ring and its seat.
- 8 Excessive misalignment. This concerns designs that use a cylindrical roller bearing as the axially free bearing. Everything is aligned properly when the machine is built, but, over time, machine frame deformation will occur. Visually, this is hard to see, but it is enough to reduce cylindrical roller bearing life as they are very sensitive to misalignment. Mostly, bearings are replaced and the alignment isn't checked. Placing the housing back in position with the help of marks and/or position pins only is not enough. The first CARB mounted in France on a drying cylinder was at International Paper Saillat sur Vienne. This was in 1996 with CARB replacing a cylindrical roller bearing that was running with too high misalignment since the frame may have moved. In 1997, I replaced 43 cylindrical roller bearings N 3040 K/C4VA701 with CARB C 3040 K/HA3C4 on a 22 year old machine because of repetitive failures. Inspecting these bearings revealed that 15 had a load zone pattern typical of bearings running with too high misalignment and that two of them had already developed spalls.

**Fig. 5 Temperature distribution 15 to 30 minutes after start up with journal insulation.**



**Fig. 6 Temperature distribution during normal operation with journal insulation.**



Many of the problems listed above can be linked together. Take the example of an old paper machine without journal insulation. It has been speeded up and the steam temperature has been increased. The lubricating oil, while previously adequate, will age prematurely with the increased operating temperature. The oil will oxidize quickly resulting in inadequate bearing lubrication and contaminating return oil pipes with deposits. These deposits cause resistance to oil flow so the mill reduces the flow rate to minimise leakage. Without adequate lubrication, bearing raceways get damaged which increases the risk of inner ring cracks in future.

Generally, when there is a bearing failure paper mills first question the bearing type and its carrying capacity. In fact, the root causes are mainly related to the oil used, the flow rate, inadequate journal insulation and water content in the oil.

When there is no journal insulation and steam temperatures are high, bearings with case hardened inner rings are often selected. For me, this is only a stop-gap solution since the bearing will have a short service life anyway due to inadequate lubrication. Even very high oil flows will not reduce temperature enough for an adequate oil film to form since excess oil passes too quickly to reduce it. The real solution is to insulate the journals.

## Bearing types

There are many different bearings types and bearing arrangements used in drying and Yankee cylinder applications. Let's look at the most common ones.

Today, nearly all drying cylinders have spherical rollers bearings on the drive side. There are still some plain bearings used on very old machines as evidenced by the occasional requests I get to work on a conversion to rolling element bearings. In addition, split bearings are sometimes used. At first glance, these seem like a good solution where bearings have short service lives and need to be replaced quickly and easily. However, the weak point is the gap between the two parts of the inner ring. In addition, the tight fit of the inner ring cannot be adjusted with sufficient precision. As such, while SKF can supply split roller bearings, we don't recommend them for paper machine applications.

**Fig. 7 Oil transformed into carbon.**



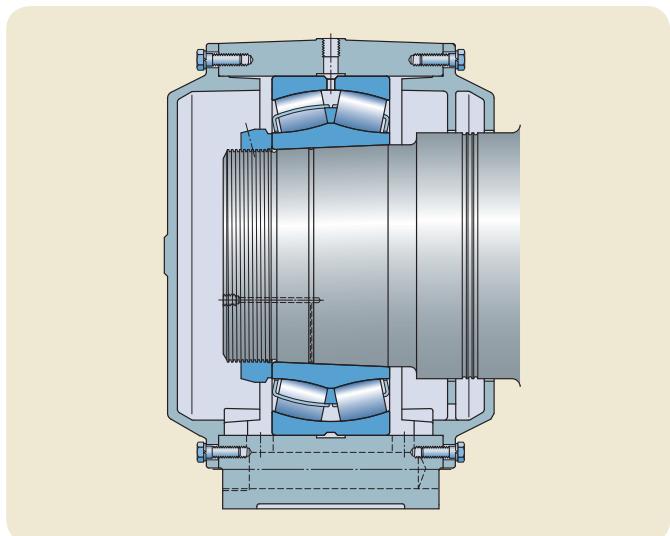
My experience is that more bearing types are used on the front side of machines - fewer and fewer plain bearings, lots of spherical roller bearings, some cylindrical roller bearings and, increasingly, CARB. Such diversity is understandable given the axial displacement and misalignment involved and the number of engineers who have tried to solve the resulting problems. Some of these solutions have worked well and others not so well. As such, let's look at the pros and cons of each bearing type.

Firstly, let's consider spherical roller bearings. With such bearings, there are two assembly options: bolting the bearing housing to the machine frame and accommodating axial displacement by the axial displacement of the bearing in the housing (**→ fig. 9**); or mounting the bearing housing on rockers with the bearing axially located in the housing.

**Fig. 8 The black death.**



**Fig. 9 Bearing housing bolted to the frame with axial displacement accommodated by the bearing which is axially free in the housing.**



The first option can be found on many old machines and narrow machines that don't run particularly fast and/or don't have high steam temperatures. In such cases, a standard bearing can be used providing it is made from suitably hardened steel like SKF uses. However, two main issues with such arrangements led engineers to search for other solutions.

The first issue is that the outer ring is hotter than the housing. During start up it can expand enough radially to remove any clearance between the outer ring and the housing bore. This leads to the outer ring getting stuck and the bearing becoming axially overloaded leading to premature failure. To avoid this, the bearing is mounted with a very loose housing bore fit – typically F7, sometimes E7 instead of the typical G7. However, during normal machine operation, the housing reaches a temperature where the fit is too loose and this increases the risk of fretting corrosion.

Secondly, with high axial displacement, fretting corrosion in the outer ring to housing contact zone is quite common. This is exacerbated by water content in the oil – caused by condensation, the humid environment and high pressure cleaning – and oil ageing. When the bearing moves axially due to thermal expansion of the drying cylinder, the outer ring doesn't move smoothly. Instead, it moves with a stick-slip movement. This is due to the fact that there is adhesion friction (coefficient  $\mu_{ad}$ ) and sliding friction (coefficient  $\mu_{sl}$ ). In a contact surface, sliding friction is always lower than adhesion friction.

In good conditions  $\mu_{ad} = 0,15$  to  $0,25$  and  $\mu_{sl} = 0,08$  to  $0,15$ . If we take, for example,  $\mu_{sl} = 0,12$  and  $\mu_{ad} = 0,20$  on a drying cylinder weighing 15 tons, it would mean that the bearing on the front side will not move until the axial load created by the thermal expansion reaches  $(15/2 \times 0,20) = 1,5$  tons. Then the bearing moves axially, but stops as soon as the axial load gets below  $(15/2 \times 0,12) = 0,90$  tons. If thermal expansion continues, the axial load will increase again. There can be several stick-slip movements and at the end the bearings will be loaded with an axial residual load between 0,90 and 1,2 tons. While this is the case where surfaces are in good condition, in reality, fretting corrosion and oil ageing lead to higher sliding and adhesion friction coefficient which can even be above 0,40.

Quite often, when calculating the nominal life of a drying cylinder bearing most people consider zero axial loads. However, as shown above, an axial load exists and because the spherical roller bearing isn't a thrust bearing, it will have a strong influence on bearing life. For a 23052 CCK/C4W33, an axial load equal to 15% of the radial load reduces the calculated basic rating life by 70%. If the axial load is equal to 40% of the radial load, the calculated basic rating life is reduced by 96%. This is one of the reasons why paper machine manufacturers' design departments used to, and sometimes still do, request a basic rating life over  $L_{10h} = 200\,000$  hours.

SKF doesn't recommend this bearing assembly solution for the front side of drying cylinders on machines with wire widths above 4 500 mm. Personally, I don't recommend it for any drying cylinder, but for cost reasons on older machines, I can understand using it.

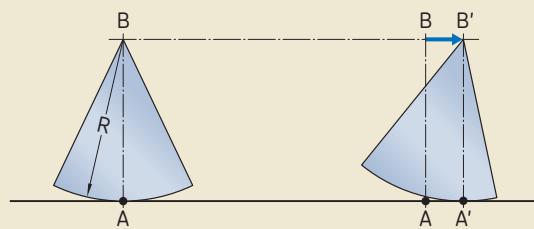
With a bearing housing on three rockers and the bearing axially located in the housing, axial displacement is accommodated by the axial displacement of the housing on the rockers. The shape of the rockers allows the housing to always be at the same height (→ fig. 10 and 11)

For Yankee cylinders there can be the need to have additional rockers on the side since the press and/or suction press roll push the Yankee cylinder radially. Side rockers are necessary if the resultant

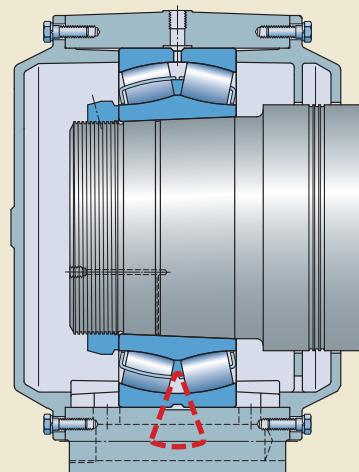
radial load on the cylinder diverges more than  $30^\circ$  from the vertical downward position (→ fig. 12)

The bearing used can be a standard SKF bearing due to our heat treatment, but the housing is quite expensive. The bearing has to withstand very low axial loads which are neglected in life calculations. In addition, there's no need for a very loose fit between bearing outer ring and housing. Since the bearing outer ring doesn't axially displace in the housing, fretting corrosion is less pronounced and has less influence on bearing life. This was previously the best solution and accordingly recommended by SKF for paper machines with a wire width above 4500 mm. However, this housing arrangement is rather unstable and does not damp vibration as well as solid housings. This may be a problem when upgrading to higher speeds. This arrangement is also sensitive to tilting forces from rope sheaves and steam joints fastened on housings, for instance.

**Fig. 10** Rockers ensure that a drying cylinder housing is always at the same height.



**Fig. 11** Spherical roller bearing in a drying cylinder housing supported by rockers.



Rockers do wear out and will need to be changed after some time. When a rocker wears, the housing stands lower. I've seen housings as much as 3 mm lower than their original position due to rocker wear. On the rocker contact surface with the base, wear creates a flat zone and there is a need for more axial load to make them tilt to let the housing move axially. In addition, some rocker housing designs don't have any features to stop the housing from jumping off the rockers. I've seen a case where a paper jam lifted the housing on the front side and the drying cylinder fell damaging the drive side, felt and felt rolls.

Many customers modify their housings to upgrade to CARB by converting rocker housings to fixed housings ( $\rightarrow$  fig. 13 and 14).

Moving on to cylindrical roller bearings, the idea to use them is a good one since there will be no axial residual load due to thermal expansion of the drying cylinder. Also, with the bearing outer ring located in the housing, without a too loose fit, fretting corrosion is small. Furthermore, rocker housings aren't needed, of course. However, standard cylindrical roller bearings do not have adequate heat

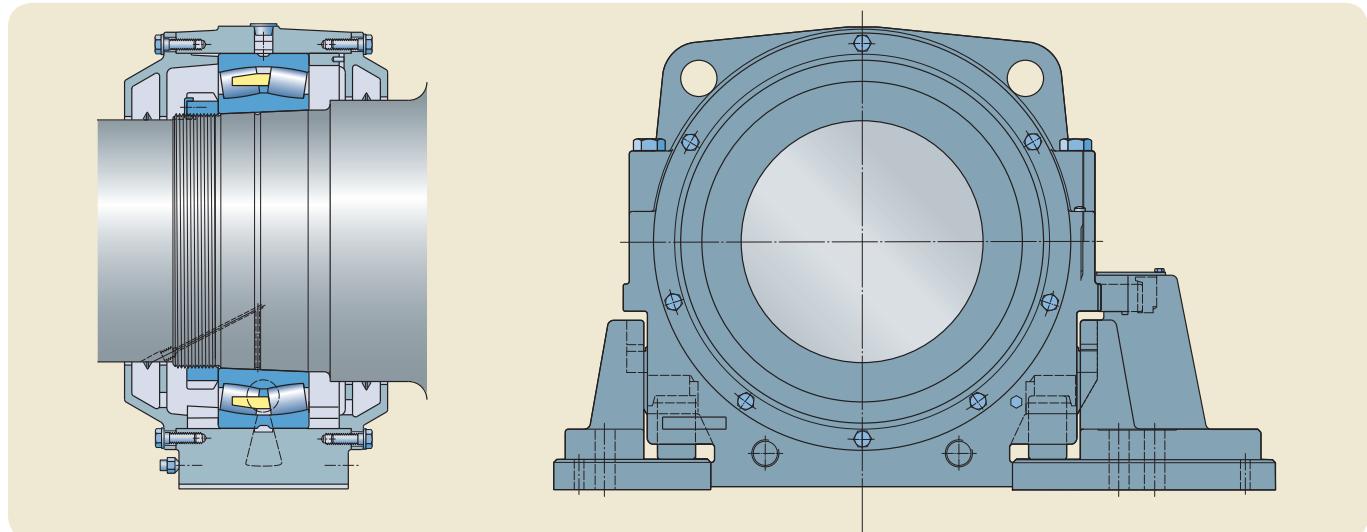
treatment and wouldn't withstand the misalignment that could easily be found in the drying cylinder application. As such, a special cylindrical roller bearing was created. The SKF version, old suffix 342460 or VA701, had a case hardened inner ring and a special roller profile to withstand up to 7 minutes misalignment. An example of an arrangement using such a bearing is shown in fig. 15. The bearing designation could, for example, be N 3040 K/C4VA701.

Mounting such a bearing is a special and time consuming procedure using a dial gauge and a special dial gauge support to check misalignment ( $\rightarrow$  fig. 16). Then, depending on dimension  $D_0$  and the dial gauge reading  $S$ , the misalignment was found with the help of a diagram.

Unfortunately, misalignment was rarely checked after the initial mounting and most of the bearings suffered from too high misalignment due to frame deformation or the foundations settling over time. Given this, and because these bearings can be replaced – without any modification – by CARB, SKF has stopped making them. Nevertheless, there are still a few machines running with such bearings.

Self-aligning double row cylindrical roller bearings are also sometimes used. The idea is to keep the advantages of the cylindrical roll-

**Fig. 12 Yankee cylinder bearing housing with side rockers, front side**



**Fig. 13 Rocker housing before modification.**



**Fig. 14 Rocker housing converted to a fixed housing by SKF.**



er bearing, but without the misalignment issue. The misalignment is taken by the outer ring which is, in fact, a spherical plain bearing (→ fig. 17)

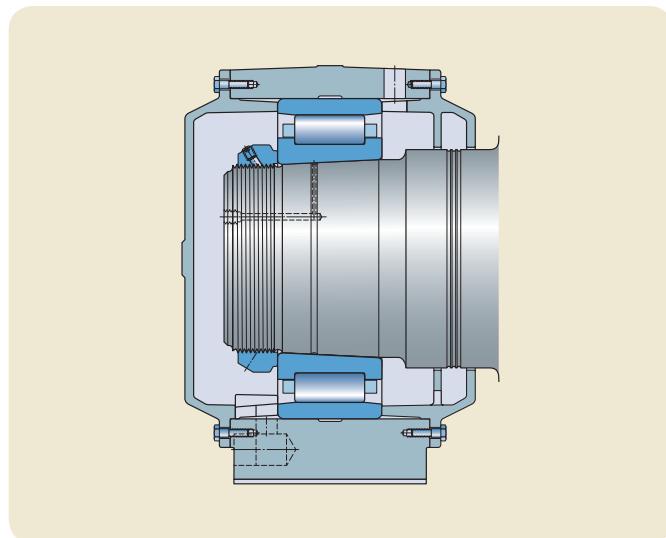
To be able to have a spherical plain bearing and a cylindrical roller bearing with ISO bearing dimensions, the rollers need to have a small diameter. As such, load carrying capacity is much lower than a spherical roller bearing with the same dimensions. Compared with a spherical roller bearing that slides in its housing, thus having to withstand axial load, the lower load capacity of the self-aligning double row cylindrical bearing isn't an issue, since the bearing has only radial load. That's the theory. In reality, the bearing has radial load and some moment load due to misalignment. Furthermore, there is always some friction in the spherical plain bearing part. The bearing will then misalign when loaded with a stick-slip movement. Thus, the cylindrical roller part will always have to withstand some misalignment. The internal stress due to misalignment will be low when a new bearing is mounted but, as time passes, the friction in the plain bearing part will increase due to oil ageing and fretting corrosion. The internal stress due to misalignment will increase with time thereby reducing the service life of the cylindrical roller bearing part. SKF has experience with these bearings since we used to make them for the metal working industry. Today, SKF recommends CARB as this has proven to be the most reliable solution.

CARB is the acronym for Compact Aligning Roller Bearing. It's an SKF single row toroidal roller bearing that accommodates up to 0.5° misalignment without much influence on its life and which is able to accept axial displacement like a cylindrical roller bearing (→ fig. 18).

While 0.5° misalignment might sound small, it equates to 8.7 mm deviation at one metre and you can surely align a bearing much better than this, even with the naked eye. Besides which, with such misalignment, there would be machine, seal or paper quality issues long before you had a bearing problem.

Using CARB means that the misalignment problems that can occur with cylindrical roller bearings or self-aligning double row cylinder roller bearings are a thing of the past. When the cylinder expends due to temperature, CARB - like the cylindrical roller bearing – doesn't take any axial load. No stick-slip movement, no residual axial load, just smooth axial thermal expansion. The outer ring is

**Fig. 15 VA701 cylindrical roller bearing used as front side drying cylinder bearing.**



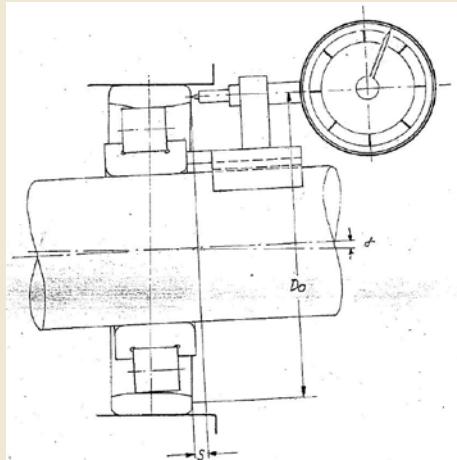
located axially in the housing and the tolerance fit doesn't need to be very loose, just loose enough so that the bearing can be pushed with ease in the housing during mounting.

A typical CARB and SKF housing arrangement is shown in fig. 19. With no rockers and the housing firmly bolted to the machine frame, vibrations are damped. CARB was first mounted on a paper machine in 1994, as a replacement for spherical roller bearings in rocker housings, on PM51 at Holmen Paper's Braviken mill. Vibration in the axial direction was reduced by up to 85%.

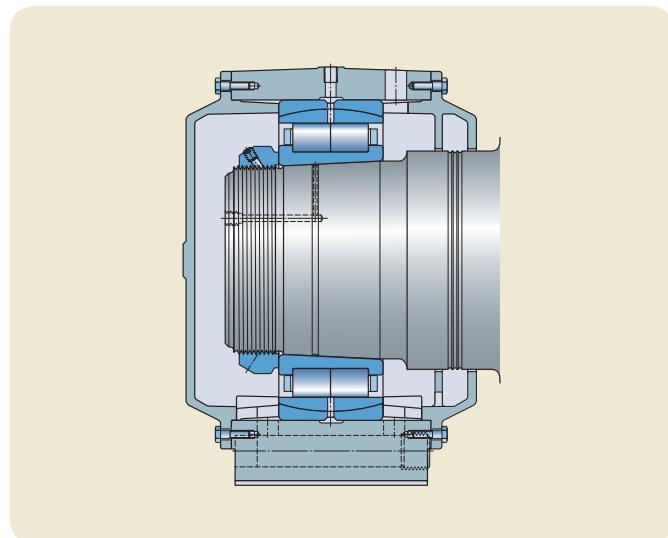
The advantages of CARB on the drying cylinder front side position were so obvious that SKF focused in the beginning on that application. It is now a well accepted solution by the major paper machine OEMs.

Customers must be aware that the internal radial clearance of CARB decreases when the inner ring axially displaces relatively to the outer ring. An axial displacement of 5% of the bearing width gives a very small radial clearance reduction which can be considered as negligible. For example a C 3152 K/C4, the most popular size on modern paper machines, has a width of 144 mm. Bearing

**Fig. 16 Procedure to check alignment for 342460 or VA701 suffix bearings.**



**Fig. 17 Self-aligning double row cylindrical roller bearing assembly.**

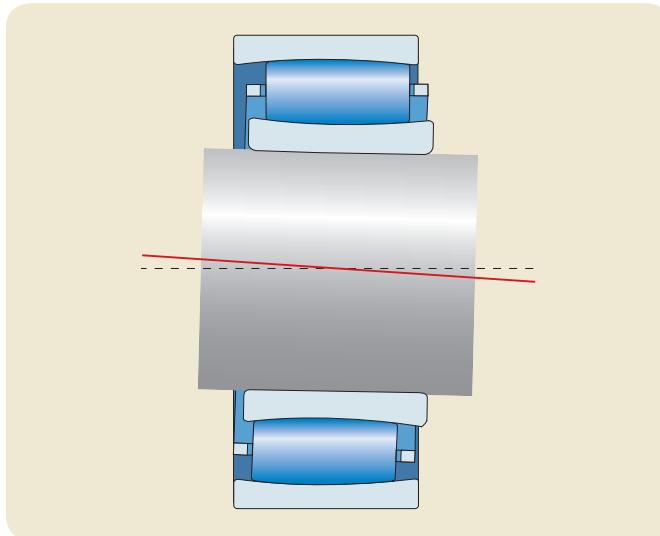


clearance before mounting is between 0,444 and 0,556 mm. An inner ring axial displacement of  $0,05 \times 144 = 5,7$  mm gives a radial clearance reduction of 0,027 mm. Further, axial displacement increases the clearance reduction rapidly. For more information I recommend reading the CARB chapter in the SKF General Catalogue, or on the online catalogue on [www.skf.com](http://www.skf.com), where you will find graphs and formulas.

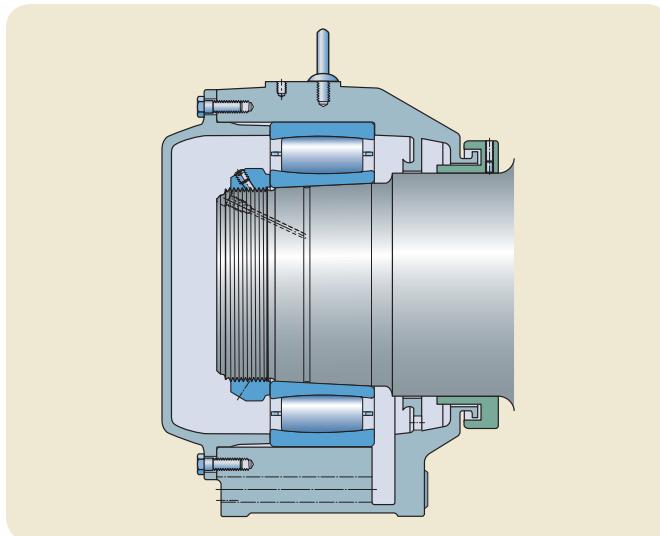
In the majority of applications like fans, gearboxes, felt rolls and press rolls, the inner and outer ring can be aligned by eye and you can just let the CARB do the job. For drying cylinders, I would recommend following the guideline given in **fig. 20**.

This concludes the first part of my coverage of bearings in drying and Yankee cylinder applications, but the next issue of SKF Pulp and Paper Practices will also focus on them. In it, I will cover heat treatment for bearing steel, guidelines for choosing appropriate bearing internal clearance class plus information on selecting suitable paper machine oils and flow rates.

**Fig. 18** CARB accommodates misalignment and axial displacement.



**Fig. 19** CARB in an SKF SBPN drying cylinder housing.

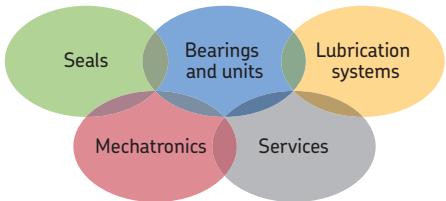


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**Fig. 20** Axial inner ring/outer ring offset when a paper machine is cold.

Cylinder length over m	Cylinder length incl. m	Steam temperature °C	Initial axial displacement mm
0	4	<160	0±1
0	4	160–200	2–4
4	7	<160	2–4
4	7	160–200	4–6
7	11	<160	4–6
7	11	160–200	6–8



### The Power of Knowledge Engineering

Drawing on five areas of competence and application-specific expertise amassed over more than 100 years, SKF brings innovative solutions to OEMs and production facilities in every major industry worldwide. These five competence areas include bearings and units, seals, lubrication systems, mechatronics (combining mechanics and electronics into intelligent systems), and a wide range of services, from 3-D computer modelling to advanced condition monitoring and reliability and asset management systems. A global presence provides SKF customers uniform quality standards and worldwide product availability.

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