



## Don't judge too quickly



*The inner ring of the bearing used to check shaft geometry on the cover photograph of SKF Pulp & Paper Practices 11. You can tell it's not an SKF bearing because it has a central flange. SKF spherical roller bearings have floating guide rings.*

*You may recall the cover photograph on the previous issue of SKF Pulp & Paper Practices which showed a former colleague of mine checking journal geometry with Prussian blue and a spherical roller bearing inner ring. A number of readers contacted me to say that this was not a precise enough method. In reality, the photograph did not show the complete picture. The load zone on the inner ring raceway wasn't constant. This isn't normal for a bearing inner ring mounted on a drying cylinder journal. Was it an inner ring quality issue? A shaft quality problem? Something else entirely? I'll show you how we determined the real problem using Prussian blue in the next issue.*

Coming back to this issue of SKF Pulp & Paper Practices, we're going to examine paper machine speed increases from a bearing perspective. SKF engineers often get asked questions about this as many

mills need to run their machines at more than their original design speeds. As such, I'll set out some guidelines for what to look at and how to work with a bearing manufacturer on a machine speed increase project in the rest of this issue.

Regards,  
Philippe Gachet  
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SKF Pulp & Paper global segment



# Paper machine speed increases

*Paper machines, as you know, are created with specific design speeds in mind and these have increased significantly over the years. In 1964 when we published the first SKF Rolling bearings in paper machines handbook, most machines were running below 500 m/min. A few tissue machines and newsprint machines were designed for 900 m/min or more, but no machines had broken the 1 000 m/min barrier. Today, 50 years later, speeds have doubled with some machines designed to operate at over 2 000 m/min and older machines often need to run at well above their original design speeds.*

Several times a year I'm asked to give advice on machine speed increases. These days, it's mainly helping SKF colleagues handle requests from their paper mill customers. In the past, it wasn't unusual to be shown an old paper machine and asked whether it could run at higher speeds. On one memorable occasion, I was given the machine speed and a list of bearings (without the roll diameter dimensions) and asked to comment on the machine speed increase within a week.

After nearly a quarter of a century of working with application engineering for the paper industry, I've come to the conclusion that:

- People tend to focus on the bearing rotational speed only. They seem to have potential problems with additional centrifugal forces creating more mechanical stress on the bearing components in mind. They ask questions like "Can this solid press roll bearing that's now running at 250 r/min cope with 280 r/min?"
- There are so many different paper machines with different configurations and different upgrades that it isn't possible to give meaningful advice on speed increases without some work. The operating conditions of each bearing need to be checked. A study, in three phases, needs to be undertaken:
  - 1 Technical information is gathered and the amount of engineering man hours is estimated.
  - 2 Answers are found on whether the machine can be speeded up without modification or not. The amount of time needed for this phase can vary enormously. Some machines might take as little as eight hours. Others can need more than 300 man hours.
  - 3 A detailed study on the modifications needed to bearing housings, lubrication systems etc. is undertaken.

I'll provide more details and explanations about all this in the rest of the newsletter.

# 1. Bearing operating condition changes due to machine speed increases

When paper machine speed is increased other things change too. Wire and felt tension, for instance, are also increased. In extreme cases, especially in the forming section, the tension increases so much that the rolls bend and roll failure by fatigue fracture can occur. Note, however, that increasing wire and felt tension does not always increase the loads on the bearings. It can also decrease the load (→ figure 1)

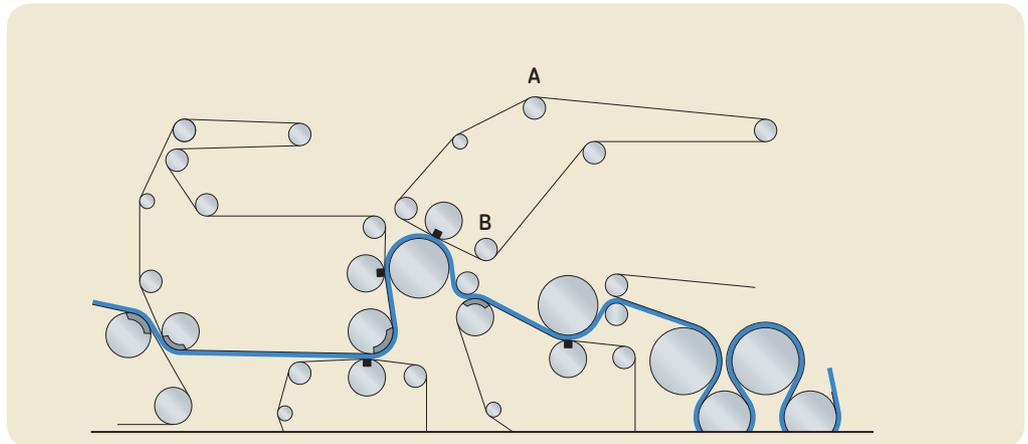
This can also happen with press rolls (→ figure 2). With increasing speed, the paper spends less time in the nip and the easiest way to maintain dewatering without changing the press is to increase the nip load. The nip load will be in the opposite direction to the top roll

(roll C) weight so increasing nip load will reduce the load on the bearings supporting the top roll if its weight is larger than the nip load.

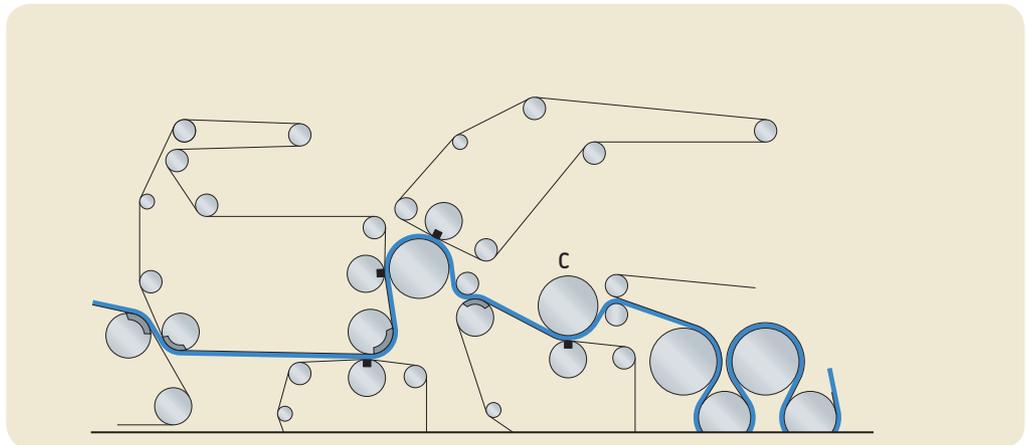
There can be an issue with suction rolls too. As with the press rolls, dwell time is reduced so suction is often increased to remove the same amount of water. Increased suction also affects the suction roll cylinder of course and the position of the suction box will dictate whether the load on the supporting bearings increases or decreases (→ figure 3). In the case of suction press rolls, both nip load and suction have to be taken into account.

Increasing machine speed also means that the paper is in the dryer section for a shorter time. Rather than extending the section by adding more drying cylinders, mills often simply increase steam temperature. This can lead to problems.

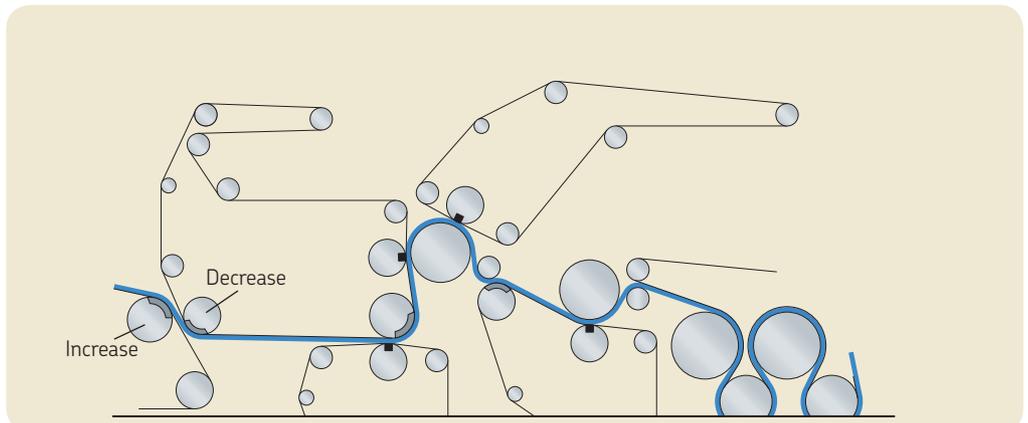
**Fig. 1 Higher felt tension increases the loads on roll A bearings, but can decrease the loads on roll B bearings.**



**Fig. 2 If roll C's weight is larger than the nip load, increasing the nip load will reduce the load on the bearings.**



**Fig. 3 The load on the suction roll bearings can either increase or decrease depending on the position of the suction box.**



I remember a case with an old Beloit kraft machine. It had uninsulated dryer cylinder journals, C3 clearance class bearings and must have been designed for steam temperatures no higher than 130 °C. The mill asked me if they could keep the same oil flow if the steam temperature was increased to 170 °C following a speed increase project. I told them that they could do this if they insulated the journals and mounted C4 clearance class bearings. It simply wasn't possible to meet SKF lubrication recommendations (see *SKF Pulp & Paper Practices 7*) without journal insulation. Not even by upgrading the oil from ISO VG 220 to ISO VG 460 and increasing the oil flow. Besides which, the mill was unable to increase flow without changing the circulating oil system and the design of the bearing housings used. Eventually, after much discussion, the maintenance manager convinced his colleagues to add a second hand dryer section from another mill. More often, mills just increase steam temperature and dryer cylinder bearing life decreases.

Paper machine cylinders and rolls are generally balanced for maximum speed as designed. Speeding them up beyond their original design speed can lead to vibrations so they should be rebalanced for the increased speed. If this is not done, there can be issues especially in dryer sections with bearing housings mounted on rockers (see *SKF Pulp & Paper Practices 7*). The problem is that front side bearing housings on rockers do not damp vibrations (→ **figure 4**). Usually, the first problem that is noticed will be increased rocker wear. Reworking the housing to a fixed housing (→ **figure 5**) and substituting a CARB toroidal roller bearing can be enough to solve the problem, but we recommend balancing the cylinders anyway.



*Fig. 4 A rocker housing on an old paper machine.*



*Fig. 5 The housing base is machined to remove the rockers and to accept customized feet. The oil inlet and outlet are also modified.*

## 2. Bearing speed limits (for spherical roller bearings and CARB toroidal roller bearings without seals)

The questions that are normally asked relate to what speeds bearings can operate at and whether the existing bearings can tolerate increased machine speeds. Some people would just open a catalogue and conclude that bearings can operate up to the indicated limiting speed. This is wrong.

Limiting speed isn't the maximum speed limit. Consider the example of a 232/500 CAK/C084W33 press roll bearing. It has a 500 mm bore, it weighs nearly a ton and it has a limiting speed of 500 r/min. However, such bearings have run on our test rigs at 960 r/min and could have run even faster.

Some installed bearings on modern deflection compensating press rolls run close to or above the limiting speed as the outer ring rotates. In such cases, the roller sets run faster than they would do if the inner ring was rotating.

Limiting speeds consider cage strength, smearing risk, vibration and field experience. The limiting speed values in product tables are practical recommendations for general applications and they are rather conservative to give a safety margin.

If you are going to run your bearings close to or above the limiting speed, I recommend a direct seat on the shaft, narrower run-out tolerances and circulating oil lubrication. Don't try it with bearings on adapter sleeves or with grease lubrication.

What then is the real operating speed limit? This depends, in fact, on how the heat created by internal bearing friction can be dissipated and the overall run-out values of the bearing and surrounding components e.g. housing, shaft, sleeve etc.

At first glance, the equations seem easy:

- Power loss (W) =  $0,105 \times$  total internal bearing friction (Nm)  $\times$  rotational speed (r/min)
- Bearing temperature increase (°C) = Power loss (W) / Cooling factor (W/°C)

The difficult part is calculating the cooling factor. This depends on housing, shaft, foundation geometry and material, the ambient air temperature and the lubrication method.

The SKF rolling bearing catalogue will help you to determine whether you're on the safe side or not.

There is another speed indicated in the bearing catalogue – the reference speed. This is a thermal speed limit where equilibrium is reached between heat created by a bearing and heat dissipated under certain conditions of temperature, load and lubrication (see *norm ISO 15312:2003*) e.g. bearing temperature increase of 50 °C above 20 °C ambient temperature. The reference speed and limiting can be quite different e.g. a 231/750 spherical roller bearing, weigh-

ing 1,7 tons, has a limiting speed of 430 r/min and a reference speed of 220 r/min.

Real bearing operating conditions, of course, do not always correspond to the ISO norm so there are adjustment factors for load and lubricant viscosity. The reference speed multiplied by the adjustment factors gives an adjusted reference speed. This is quite important as it gives an SKF engineer an indication that, without undertaking cooling factor calculations, below this speed there is enough cooling to dissipate heat without the need for circulating oil or other cooling systems. Of course, if he needs to do a bearing temperature calculation, he would need to calculate the cooling factors.

The aforementioned 231/750 mounted in a press roll, lubricated with an ISO VG 150 oil with a 2,8 MN radial load would have an adjusted reference speed of 66 r/min during start up (when the oil and bearing were still cold) and 94 r/min during steady state operating conditions.

Is the adjusted reference speed a limit? No, it's not. In the real application the bearing rotates at 280 r/min. This is possible because a circulating oil lubrication system dissipates the heat created by the bearing. If there was oil bath lubrication instead, it would be very risky to run at twice or more the adjusted reference speed as the bearing would create more heat than could be removed. You can find more information on this on **pages 118–128** of the *SKF Rolling bearings catalogue* (publication number 10 000).

If the application is grease lubricated, speed factor A should be calculated. This gives an idea of the peripheral speed of the rollers. For applications with inner ring rotation, use the equation below.

$$A = n \times \frac{d+D}{2}$$

For applications with outer ring rotation, such as old grease-lubricated suction rolls, use the equation below as a rough estimate. For a more precise calculation, internal bearing geometry information such as contact angle and roller diameter would be needed.

$$A = n \times D$$

n: rotational speed in r/min

d: bearing bore diameter in mm

D: bearing outside diameter in mm

Compare this with values given in **table 5** on **page 257** of the *SKF Rolling bearings catalogue*. It gives recommended limits for the A factor with grease lubrication. These are not absolute limits, but my experience leads me to strongly recommend that you follow them. With manual relubrication it's far too easy to over-grease and end up with overheating.

Starting to get a headache? Let's make it simple with a drawing (→ figure 6).

Very low speed isn't an easy situation since bearings don't rotate fast enough to build up an oil film between the rollers and raceways. In such cases, high viscosity oils are needed with anti-wear or EP additives. Note that this situation might occur at higher speeds too if operating temperature is too high and lubricant viscosity is too low. This is sometimes seen on heated cylinders with uninsulated journals.

With grease lubrication and very low speeds, bearings may not heat up to a sufficient temperature that the lubricant bleeds enough oil. Be careful when lubricating felt rolls at the bottom of the dryer section with high temperature grease as there may not be enough oil bleeding with the operating temperatures there.

Speeds below the adjusted reference speed are quite easy for application engineers as the indications given in the *SKF Rolling bearings catalogue* can often be used. I remember being asked by a customer whether his felt roll bearings could still be lubricated with grease after a speed increase project as he was reluctant to spend more money on converting to an oil lubrication system. After finding out the grease he was using and the load on the bearings, the manual calculation using the catalogue took less than five minutes. It turned out that the increased speed would still be under the adjusted refer-

ence speed and the A factor was below the recommended limit. As such, I told him he could stick with grease lubrication, but that we'd need to look at the minimum load. I'll explain why later on.

Above the adjusted reference speed things start to become complicated. You need to think carefully about heat exchange. If the bearing is manually relubricated with grease and if the speed is above the adjusted reference speed, a centralized grease system or circulating oil system might be necessary. Above a certain speed, oil lubrication is the only option. In addition, the bearing clearance class might need to be increased. As the *SKF Rolling bearings catalogue* does not contain all the information needed to make this decision, you need to get an SKF engineer with access to specialist software to advise you.

Near the reference speed and above, you not only have to consider clearance class, lubrication and heat evacuation, you also need to look at run-out tolerances of the bearings and other rotating components e.g. the shaft or cylinder. The bearings should be mounted directly on cylindrical or tapered seats rather than on adapter or withdrawal sleeves. The bearing seat should be manufactured with tighter tolerances as well. For circularity and straightness reasons, two IT grades better than the specified dimensional tolerances are recommended. Bearings with reduced run-out tolerances should be mounted. Even though standard SKF bearings have lower

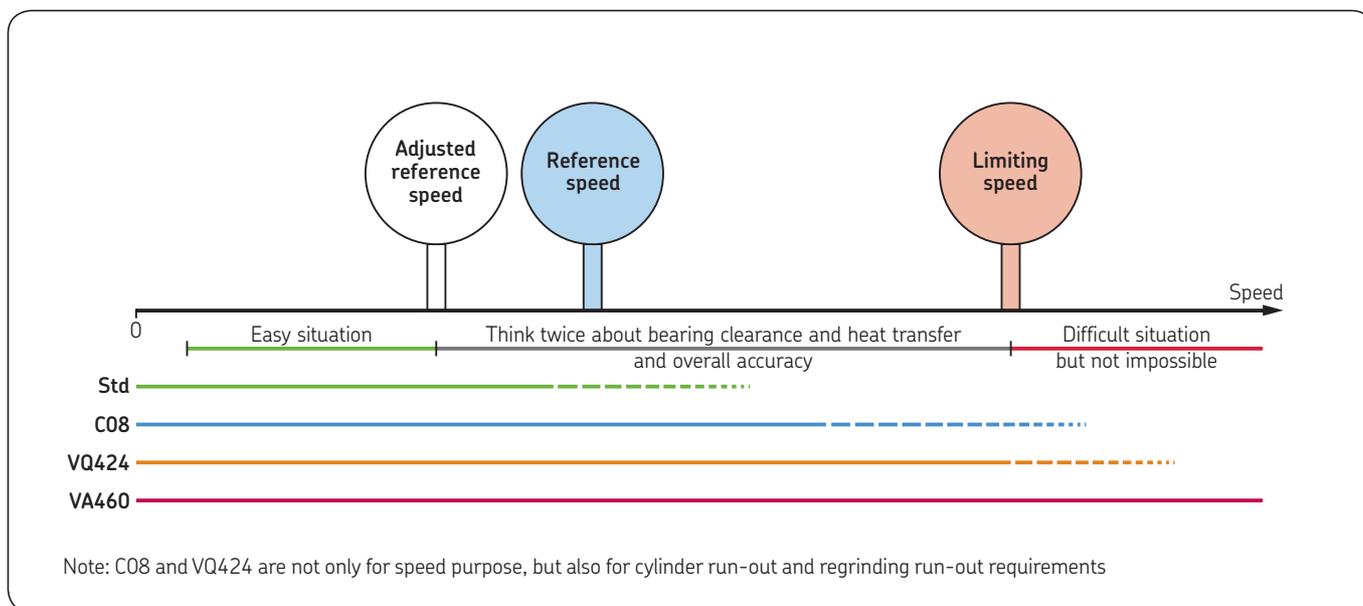


Fig. 6 Recommended bearing variants by speed.



*Fig. 7 A roll grinding machine with the roll rotating on its main bearings.*

run-out than ISO Normal, I often recommend bearings with a C08, a VQ424 or a VA460 suffix (→ **table 1**). My recommendation is based on the specific application and speed, so sometimes I will suggest standard SKF bearings. Note that for grease-lubricated bearings mounted on withdrawal or adapter sleeves, it can be necessary to change to an oil-lubricated bearing with a special suffix mounted on a new direct tapered seat.

At the limiting speed, because bearings will not run in laboratory conditions, I recommend VQ424 or VA460 bearings and contacting a local SKF application engineer.

In conclusion, the operating speed limit doesn't depend on the mechanical stress due to centrifugal forces, but mainly on how the heat created by internal friction is dissipated. That said, the internal bearing clearance class and run-out tolerances are also important.

**Table 1**

#### **C08, VQ424 and VA460 bearings**

- A C08 suffix denotes a P5 run-out tolerance class. The circular radial run-out is one quarter of the ISO Normal class. Remember that all SKF standard bearings with inner ring bore diameters below 320 mm have P5 run-out even if they do not have a C08 suffix.
- VQ424 has, in addition to the C08 features, special tolerances on ring wall thickness. The ISO Norm covers the allowed maximum running accuracy deviation whereas VQ424 also looks at the level of deviation. It was developed for Valmet in the beginning of the 1990s for faster and more accurate regrinding of rolls supported by the bearings (→ **figure 7**).
- VA460 is essentially a VQ424 bearing modified to withstand the effects of centrifugal forces due to very high speeds.

### 3. Other issues related to higher speed

There are other important things to consider when machine speed is increased. Let's imagine for now that operating conditions, such as the loads on the bearings, don't change.

The higher the speed, the higher the difference between inner and outer ring temperature and the higher the roller temperature. The inner ring is generally hotter than the outer ring. So, higher speed means increased clearance reduction. Above the adjusted reference speed, a higher clearance class is needed (see **page 5** of *SKF Pulp & Paper Practices 2*). When approaching the limiting speed, an additional increase in clearance class might be needed. Furthermore, the relationship between the clearance of an unmounted bearing and the bearing size is not linear. As such, for very large bearings - such as the ones found in press rolls on modern high speed machines - a higher clearance class than would be selected for a medium size bearing might be necessary.

To roll without skidding or sliding, a roller needs to be squeezed between the inner ring and the outer ring. The roller has a certain mass and thus a certain rotational speed dependent inertia that makes it reluctant to accelerate. When exiting the loaded zone of the bearing the roller slows down since there is friction against the cage and in the lubricant in the unloaded zone. When it enters the loaded zone again it is squeezed between the rings and forced to accelerate. If there is a large difference between the speed on the rollers in the unloaded and loaded zones and if there is insufficient load in the loaded zone, it will accelerate more slowly than required and create smearing marks in the entrance to the loaded zone (→ **figures 8 and 9**).

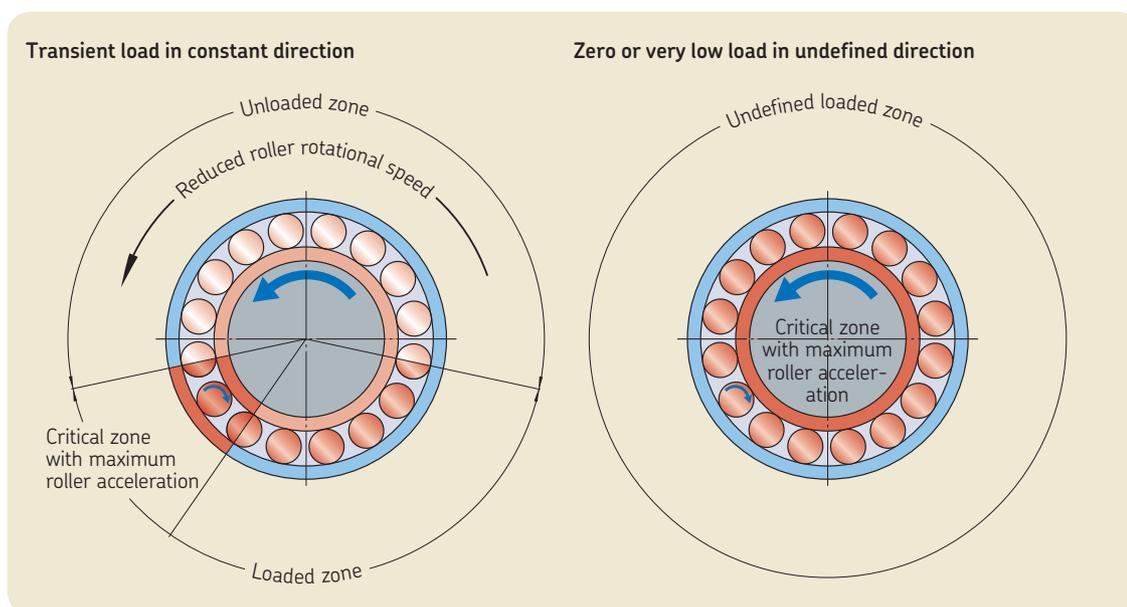
The other case is when the load zone has very light roller loads or when the load zone isn't well defined due to the roll or cylinder weight being supported by the nip load rather than the bearings. This happens in some deflection compensating press rolls as the radial load is carried by both the hydrostatic shoe bearings and the roller bearings. Depending on the oil pressure in the hydrostatic



**Fig. 9 Smearing marks on the entrance to the load zone of a solid press roll bearing.**

shoe bearings, roller bearings could face an undefined load situation with the possibility of zero load. As the load is low there is a risk that that rollers are not always forced to roll at an adequate speed. Rollers slide, accelerate and decelerate in the insufficiently loaded load zone or in the undefined load zone (→ **figures 8 and 10**). Note that this can also be an issue for bearings in some suction rolls, press rolls, calendar and – more rarely – wire and felt rolls.

Increasing machine speed also increases bearing speed and roller inertia leading to a higher risk of smearing due to low load issues.



**Fig. 8 Roller slip and the risk of smearing.**

For each speed there is a minimum load that needs to be applied to the bearing. Increasing machine speed without changing the load can lead to premature failure if it was already close to the minimum required for the original speed.

In addition, increasing machine speed might also make it run at one of its natural frequencies. High vibration amplitude may occur. I have never seen paper machines breaking, but I have seen rocker housings falling off the rockers, rockers having premature wear, facets on cylinders or rolls and increased rejected paper. But in other applications, in other industries, I have seen premature bearing failures because grease got softer with the vibration and concrete supporting the machine fractured.

Note that in one case, after a paper machine upgrade, without machine speed increase, the new NIP load in conjunction with the change of a roll diameter made the press roll operate close to its natural frequency. I was contacted since the customer thought that the root cause was the roller bearings.

#### 4. The influence of load change on bearings

As mentioned in section one, machine speed increases also lead to load changes. Loads can increase or decrease on rolls depending on their position in the machine.

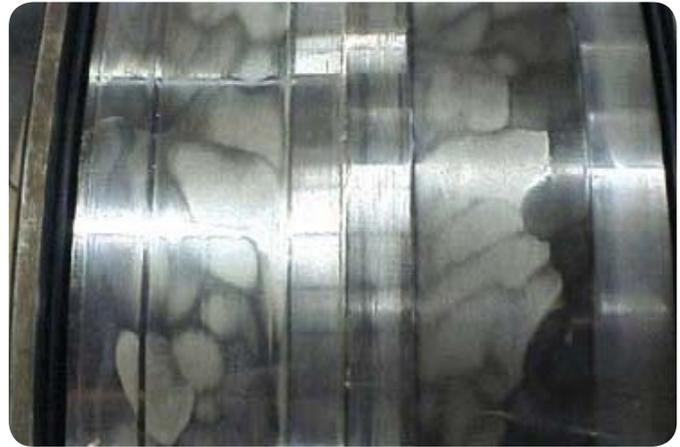
When the load is reduced there can be the risk of low load issues as explained in section three. These can often be resolved using NoWear coated bearings to avoid smearing or by reducing the number of rollers so that contact pressure per roller is increased.

When the load increases there are several things to consider.

A 10% load increase reduces calculated basic rating life L10h by 30%. If the speed increases too, the basic rating life is further reduced. Thankfully, bearing basic dynamic load ratings have increased over the years. A machine designed in the early 1970s can substitute the original SKF 22314 CK/W33 felt roll bearings with today's SKF 22314 EK ones and increase loading by 57% without reducing the basic rating life. This explains why there aren't more fatigue failures despite wire and felt roll tensions increasing significantly over the years. In some unusual cases, rolls designed many years ago break due to fatigue before experiencing severe fatigue issues with the bearings.

Despite the increases in bearing basic load ratings, you still need a tighter fit if you increase the load. High pressures between rollers and raceways create ring deformation and there can be micro movement between a ring and its seat. This creates fretting corrosion and can also lead to creeping and wear if the ring starts to rotate on its seat.

**Figure 11** shows a dryer section felt roll bearing mounted on an adapter sleeve. The mill had replaced the gear with silent drive so the drying cylinders were driven by some of the felt rolls via the felt. Felt tension had been increased and bearing service life dropped dramatically. It was discovered that the bearings were working loose on their seats and rotating together with their adapter sleeves creating heavy wear. This can lead to catastrophic failures (→ **figure 12**). Another problem can be shaft rotating deformation which creates alternate stress and flexion close to the bearing seat. Increasing the bearing drive-up to more than the general recommendation and using the SKF Drive-up method rather than the feeler gauge method increased the bearing service life.



**Fig. 10** Damage on the inner ring of a suction roll bearing due to undefined load zone after a speed increase and/or a suction vacuum increase.



**Fig. 11** Fretting corrosion in the bore of an adapter sleeve of a dryer section felt roll bearing due to an insufficiently tight fit relative to the load.

If loads on bearings are to be increased, fits and mounting procedures should be reviewed. Be aware that tighter fits are used it might be necessary to use a bearing with a higher internal clearance class.

If the load is increased and the speed isn't, bearing operating temperature will still rise. The temperature difference between bearing inner ring and outer ring will also increase. In such cases, a higher internal radial clearance may be needed.

Increasing the load can deform the bearing housing, the machine frame and the shaft or roll. This can have either a positive or a negative effect depending on how the deformation changes the load distribution in the bearings. Normally, wire and felt roll housings are rigid enough relative to the loads they experience, but this is not the case for some press roll bearing housings. For them, FEM calculations can be worthwhile during a machine speed increase project (→ **figure 13**).

## 5. The three phases of a study

Based on my experience and to avoid the steps that are often forgotten during a machine speed increase, I always recommend a three phase study: pre-study, analysis, execution.

The phase one pre-study is to ascertain how difficult it will be. Will it require advanced calculations or just catalogue ones, for instance. Some quick and basic calculations will certainly be needed in this phase and an estimate of the man hours needed for phase two will be made.



**Fig. 12** Advanced wear with rotation of the adapter sleeve on the shaft of a dryer section felt roll bearing. The related high temperature reduced the bearing clearance resulting in uncontrolled preload and, finally, seizure.

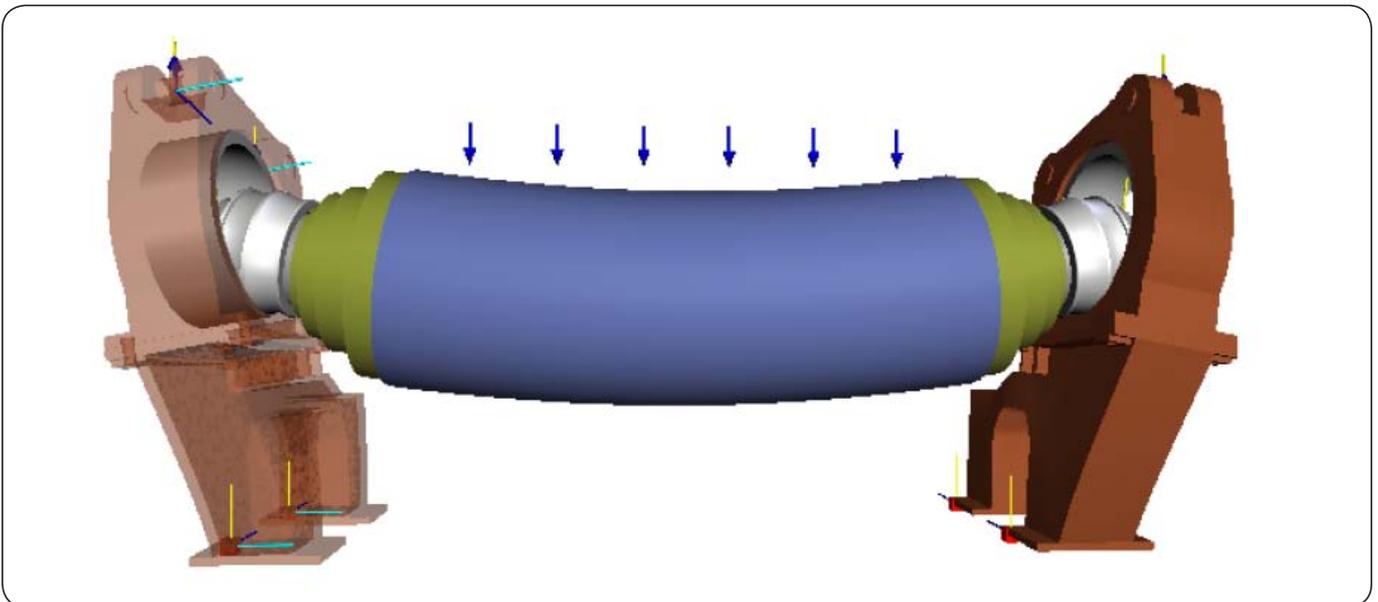
At a minimum, the SKF application engineer will need the following information from his customer:

- A drawing of the bearing assembly including the housing and shaft. Note that a detailed drawing of the housing and shaft are recommended and may be needed for some calculations.
- A drawing of the complete roll or cylinder.
- Minimum and maximum existing and future load for all positions. The direction and position of loads should be marked on drawings.
- Existing and future bearing rotational rather than machine speed for all positions.
- Minimum and maximum ambient temperature for all positions.
- Existing and future heating fluid temperature for drying cylinders, Yankees and calendars together with information on the existing lubricant, lubrication system, relubrication interval, oil flows etc.
- The history of bearing replacement and any repetitive bearing failures for at least the last five years.

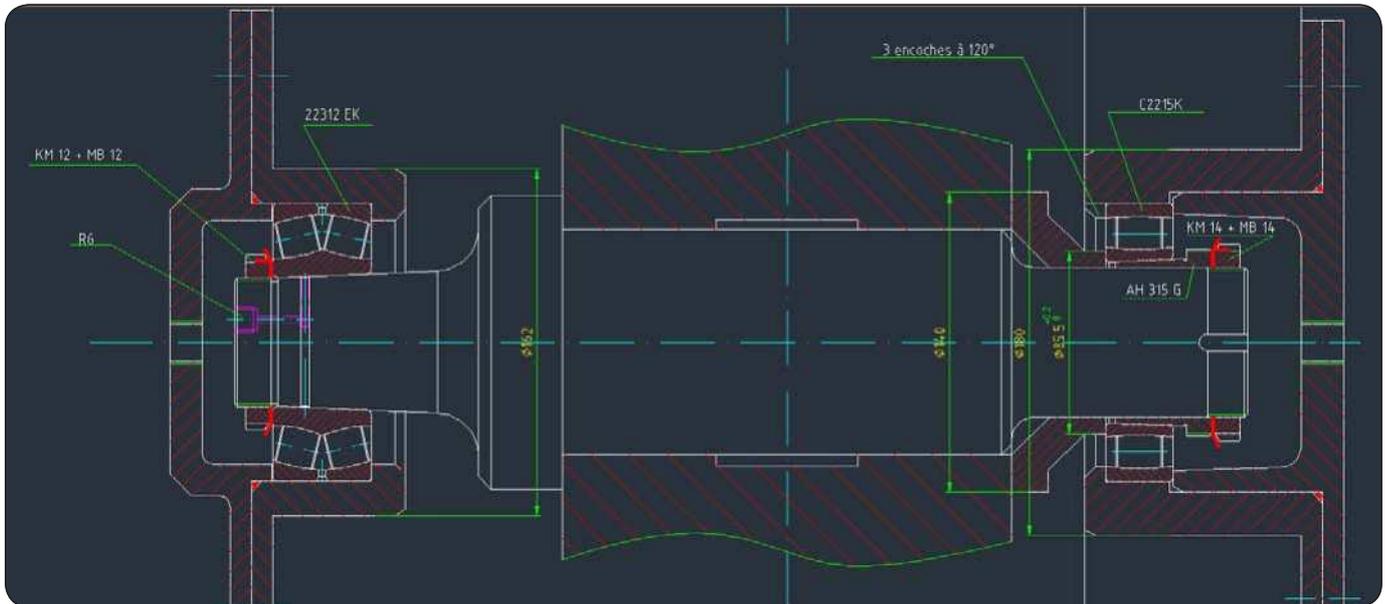
Collecting the above technical information, especially the loads, is what takes the most time. Several weeks or even months may be needed to do it properly. Often, due to missing information, the SKF application engineer has to make assumptions about the operating conditions. These should always be discussed and agreed with the customer.

At the end of the pre-study, an estimate of the man hours needed for phase two is made. No technical recommendations are made as agreement is needed from the customer to undertake the analysis necessary to make meaningful ones.

Assuming that there is agreement with the customer to proceed, the SKF engineer will undertake further calculations and analysis in phase two. During this phase, any modifications necessary to bearings, housings, mounting and/or lubrication procedures etc. will be uncovered. In some cases, no modifications are necessary.



**Fig. 13** SKF FEM calculations showing the deformation of the solid roll in a shoe press under working load. Note that a high magnification has been applied to clearly visualize the deformations.



**Fig. 14** Modified intermediate gear bearing arrangement with a spherical roller bearing and a CARB toroidal roller bearing. Both have tight fits on their inner and outer rings. The original design had two spherical roller bearings with loose fits on the outer rings. As the gear was driven or driving, there were load direction changes on the outer rings. This led to wear due to micro displacement and creeping of outer rings in their seats.

At the end of phase two, the customer will receive technical information and recommendations on whether FEM calculations, special housing design work and/or new lubrication systems are needed. For example, the SKF engineer could:

- 1 Advise that CARB toroidal roller bearings rather than spherical roller bearings should be used on the non-locating drying cylinders
- 2 Specify the recommend bearing designation and SKF bearing rating life
- 3 Outline the require oil viscosity and oil flow plus the journal insulation requirements
- 4 Propose that the existing housing should be modified to accept CARB or that a new housing should be used
- 5 Indicate any consequences if some recommendations were not adopted e.g. keeping an old oil circulation system with limited oil flow and poor filtration
- 6 Recommend new mounting procedure and/or new fits (if required)

Note that any housing, journal insulation or circulating oil lubrication system design work needed would be undertaken in phase three.

The results of the analysis phase are presented to the customer. Quite often this leads to various “what if?” questions. This is quite normal since he needs to understand and balance the benefits of the proposal against the necessary investment. The phase ends with a decision from the customer on whether to proceed with phase three.

In phase three, the execution phase, any modification design work is undertaken. This can include such things as special housings,

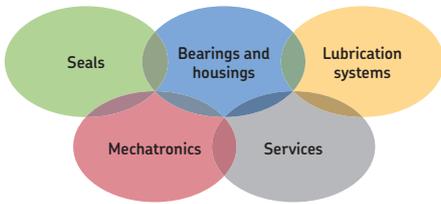
designing in new lubrication systems and modifying existing bearing assemblies (→ **figure 14**). It also included any modifications needed on site. All this work can be undertaken by SKF, the customer themselves, an equipment manufacturer, a sub-contractor or the work can be shared between these various parties.

To sum up, a machine speed increase project is not that simple from a rolling bearing point of view. It isn't just about whether a bearing can tolerate the increased speed. I hope that this issue of SKF Pulp & Paper Practices will help people know what to consider and how to work with SKF on such projects.

As a final note, please remember that the real speed limit for spherical roller bearings and CARB toroidal roller bearings is reached when the heat generated by internal friction cannot be dissipated. In my experience, the mechanical limits due to stresses on the bearing components from centrifugal forces are never reached on SKF bearings in paper machine applications if the arrangement is well engineered.

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### The Power of Knowledge Engineering

Combining products, people, and application-specific knowledge, SKF delivers innovative solutions to equipment manufacturers and production facilities in every major industry worldwide. Having expertise in multiple competence areas supports SKF Life Cycle Management, a proven approach to improving equipment reliability, optimizing operational and energy efficiency and reducing total cost of ownership.

These competence areas include bearings and units, seals, lubrication systems, mechatronics, and a wide range of services, from 3-D computer modelling to cloud-based condition monitoring and asset management services.

SKF's global footprint provides SKF customers with uniform quality standards and worldwide product availability. Our local presence provides direct access to the experience, knowledge and ingenuity of SKF people.

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