SKF Pulp & Paper Practices

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Fig. 1: Bearing damage that doesn't require laboratory analysis.

Visual inspection of bearing can establish probable cause of damage

When I first started to take care of customers from the paper industry as an SKF application engineer, some end users (but also SKF distributors) would complain that the bearing damage report didn't contain thorough laboratory investigations. These were often included in the reports from some of our competitors, although only for selected customers.

My colleague, the bearing damage expert who wrote the report, would then ask to see the competitor's report, and it was quite often the case that the final conclusions were the same. Sometimes, the laboratory report wasn't of any help at all, mainly because the conclusion was that the bearing was within specification and, as the lab had no information about operating conditions, they weren't able to correlate all of the potential causes with operating conditions. On the other hand, visual inspections with a good understanding of operating conditions would lead to more effective conclusions. I must admit that a report containing microscope images of steel structure analysis is more appealing, but this entails both an additional cost and a longer delivery time.

Laboratory investigations, without a knowledge and understanding of the operating conditions, can be misleading. I've seen many cases where a metallurgic analysis found that the steel was slightly out of specification or had an inclusion (that could be within bearing manufacturer specification), from which the customer immediately concludes that the cause of damage is a quality issue. This isn't always the case – sometimes it may be but, in the majority of cases, it is not.

I seldom request laboratory investigations. The cases for which I do request such an investigation (following a visual one) are when:

- I am unable to identify the most probable cause of damage, even if there is good information about the operating conditions and the bearing isn't too damaged, and there is a possibility that steel quality could be an issue, or
- there is a need for a microscope with a high magnification ratio. This is typically the case when one can visually identify surface distress (micro spalling due to inadequate lubrication) but all the information about lubrication tends to exclude this as the cause of damage. The microscope analysis can then identify whether it is surface distress or a type of current leakage erosion, which can sometimes appear quite similar to the naked eye.

This Pulp & Paper Practice concerns a case of the visual inspection of bearing damage that doesn't require laboratory analysis. The mill had a known issue of water content in oil, and thorough, competent investigations were performed by the mill in order to understand the cause of the water content. I learnt a lot about what was happening in the dryer section, under the hood, with this case. The bearing visual analysis confirmed with a high degree of probability that the low bearing service life was due to the excessive water content, excluding many other possible causes of damage.

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Drying cylinder bearing damage: case 1

Advice: It is recommended that you first read the SKF publication "Bearing damage and failure analysis", reference 14219 EN.

I have received several requests to write about bearing damage or failure cases, including solutions. Over the course of many years, I have seen quite a number of such cases, and the question was which one I should choose.

I remembered the case of a damaged bearing 23148 CCK/HA3C4W33, of which I had taken photos – not only of the damage but also of how I had disassembled it without causing more damage. What made the case even more interesting is that the damage provided a good clue about the possible causes.

The bearing was a spherical roller bearing mounted on the drive side of a drying cylinder, similar to the one shown in (→ **fig 1**). The main difference is that there is a CARB™ on the front side.

The paper mill was experiencing several recurring cases of bearing damage in this application. The machine was quite a recent model, less than five years old. The calculated rating life, taking into consideration the loads, viscosity ratio κ (lubrication condition) and filter rating (contamination factor), was more than one hundred years – yes, years, not thousands of hours.

I met the end user and the OEM at the mill, and several potential causes were discussed. However, there was no dismounted damaged bearing to look at, so it was difficult to confirm one cause or another, even if we were able to construct a cause hierarchy, from the most to the least probable.

Fig. 2: Complete bearing in quite good condition, ready for investigation.

One year later, the mill sent me a damaged bearing, treating it like a new bearing to avoid causing additional damage that could be misleading. This provided the chance to receive a complete bearing that seemed to be in quite good condition (→ **fig 2**).

However, as there were no indications or markings that could reveal in which position the outer ring had been mounted on the machine, and because, following dismounting, the customer could have swivelled the inner ring and rollers to check the raceways, I could not be sure which roller row rotated on which side on the outer ring. In general, deterioration of rollers or inner ring raceways can help in identifying this, but this is not always the case. Some have a rule when mounting the bearing: always have the bearing designation, which is on one of the outer ring faces, facing outwards of the machine, but this isn't universal, and it is sometimes not possible with other bearings, such as the CARB™ toroidal bearing, depending on how they are mounted (direct tapered seat, adapter or withdrawal sleeve).

Time to disassemble the bearing without causing additional damage

Warning: the method shown is only for the spherical roller bearing of the "CC" type. Such a method would damage cages of the "E-type" and be impossible with the solid brass cage. **Fig 3** shows the main SKF spherical roller bearing executions used in a paper or pulp mill, according to bearing size and series.

Fig. 1: Drying cylinder similar to the one on which the damaged bearing was mounted.

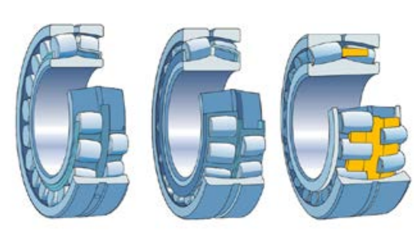

Fig. 3: The main SKF spherical roller bearing types used in a paper or pulp mill.

To disassemble the bearing, you need to pull out some rollers radially. For this bearing size, locking pliers are used in order to grab one of the rollers (→ **fig 4**).

Fig. 4: Locking pliers are used to grab one of the rollers.

Put a tool and a rag under the locking pliers (→ **fig 5**) and level out the roller using the locking pliers as leverage. The roller should come out without having to force it with a small tap, as long as the pliers do not slip on the roller end faces (→ **fig 6**).

Fig. 5: Using the locking pliers as leverage.

Fig. 6: The roller is easily removed.

Then use a flat screwdriver without any sharp edges to remove the roller next to the empty space (→ **fig 7**). Gently insert the flat end of the screwdriver under the roller, lifting the roller slightly against the cage. Then carefully twist the screwdriver, and the roller will come out easily.

Fig. 7: Removing roller with a screwdriver.

Repeat the roller removal on the other row (→ **fig 8**). Do not mix rollers from the two rows; mark them to keep them separate. Removing just one roller from each row allows you to check the inner ring condition by rotating the inner ring and looking at the inner ring raceway through the empty cage pocket, without needing to disassemble the bearing. This is often done for large heavy spherical roller bearings, when the question is whether to remount or not.

Fig. 8: Rollers of each row removed.

To disassemble the bearing in this case, it is necessary to remove eight adjacent rollers – four from each row. Place the cage section with empty cage pockets on top, and roll the inner ring with rollers and cage out of the outer ring (→ **fig 9**).

Fig. 9: Rolling out the inner ring with rollers and cages.

An alternative (and "official") practice is to remove two rollers per row (four) from both the top and the bottom (→ **fig 10**). Note that, for some wider bearings (240 and 241 series), it is necessary to position the inner ring horizontally and remove all rollers from the top row. But that is another story.

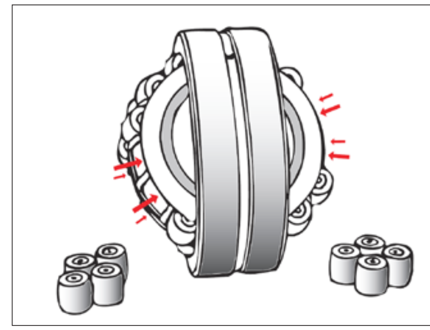

Fig. 1: Best practice is to remove four rollers on each side.

The bearing is then easily disassembled. Keep the half cages with their rollers apart (→ **fig 11**). It is normally recommended to mark the parts so it is easy to know which half cage, which rollers and which raceways have been in contact.

Fig. 11: When disassembling, keep rollers from each row together with their half cage.

Now it is time for visual inspection

A spall zone could be noticed on the outer ring raceway. This can be seen in **Fig 4** to **8**. This is the most important damage on the bearing, but focusing on this – as many do – is not the best practice in damage analysis. In addition, the most obvious damage, such as spall or fractures, is often additional (secondary) damage that hides the primary damage, which could have given a good clue to the failure cause. All bearing parts should be examined. The best tool for visual inspection is a magnifier with magnification of between 8 to 10 times (→ **fig 12**). Binoculars with higher magnification, microscopes and metallurgic analysis should only be used when necessary.

Fig. 12: The must-have tool: an 8 to 10 times magnifier.

Visual inspection: the guide ring

With the exception of the outer diameter (→ **fig 13**), where some slight wear is visible on one side and on the contact between the guide ring and half cage, the guide ring is in very good condition (→ **fig 14**). There is no smearing, and only very slight abrasive wear.

Visual inspection: half cages

The very first action is to check whether the half cages have signs of wear – in the drying cylinder application, this would point to a lubrication issue. Visual inspection shows very slight abrasive wear in the cage pockets where there is contact with the rollers (→ **fig 15, 16 and 17**). I cannot feel any sharp edges with my thumb (→ **fig 17**), and there is only slight abrasive wear on one half cage – at the contact with the guide ring (→ **fig 16**), and, on the other guide ring, at the contact with the inner ring (→ **fig 15**). Note that sharp edges and/or burrs are created by a lack of lubrication between the roller and the cage. Of course, there is a risk that you could cut yourself, so you must be as careful as when checking the sharpness of a knife with your finger. Unfortunately, the touch-test is often more effective than the visual inspection. There is no adhesive wear (smearing).

The second action is to look for deformations and/or cracks. None of these are visible.

The condition of the half cages is very good after 6 years' service in a drying cylinder.

Fig. 15: Half cage with slight abrasive wear at its contact with the inner ring.

Fig. 16: Half cage with slight abrasive wear at the contact with the guide ring.

Fig. 13: Outer diameter of guide ring: slight wear.

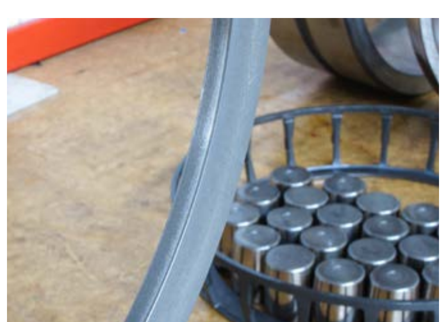

Fig. 14: Face and bore of guide ring: in good condition.

Fig. 17: Feeling for sharp edges or/and burrs with the thumb.

Visual inspection: rollers

Each roller is visually inspected, revealing that they are in more or less similar condition, with some slight abrasive wear and indentations due to solid hard particles. The rollers on one row have more indentations. Apart from the presence of indentations and some slight circumferential grooves, the rollers are in good condition (→ **fig 18**).

Fig. 18: : Rollers with slight abrasive wear (shiny appearance) and numerous indentations.

Visual inspection: inner ring

The inner ring bore (→ **fig 19**) shows some slight fretting corrosion. The shape suggests a slight lack of a tight fit, and perhaps conicity and straightness deviation in the contact, but nothing serious. Small axial smearing marks suggest that the bearing mounting has been performed without oil or with too thin a coating of oil, or that perhaps some small hard particles became trapped between the inner ring and shaft. A reminder about best practices for bearing mounting should be sent to the mill, even if this slight damage has no influence on the bearing service life.

The condition of the inner ring raceways (→ **fig 20**) is like the roller's condition. What is written above, concerning the rollers, is valid for the raceways and will then not be repeated.

The inner ring faces are in good condition – as good as new for the face on the large bore diameter (→ **fig 21**), with slight fretting corrosion on the face in contact with the locking washer and locking nut (→ **fig 22**).

Fig. 19: Inner ring bore. Slight fretting corrosion and small axial smearing marks.

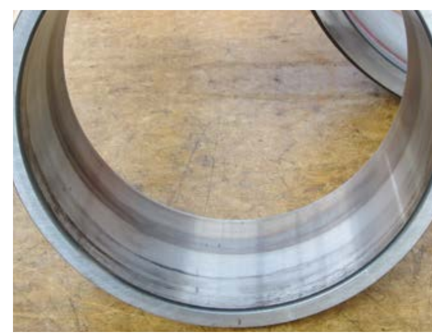

Fig. 21: The condition of the large bore diameter side inner ring face is as good as new.

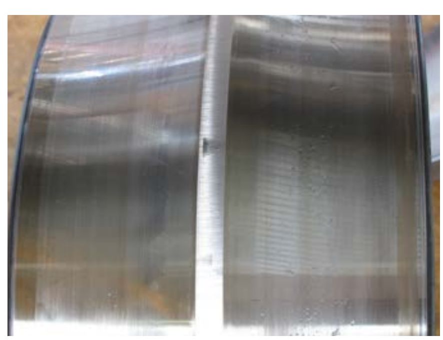

Fig. 20: The condition of the inner ring raceways is like the roller's condition.

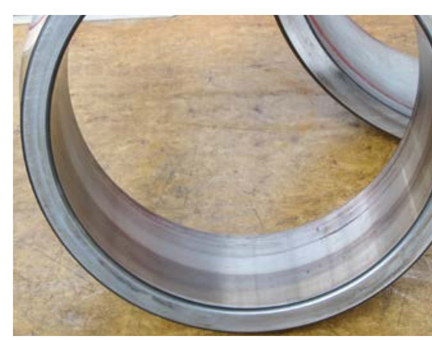

Fig. 22: Small bore diameter side: slight fretting corrosion.

Visual inspection: the outer ring

The condition of the outer ring faces (→ **fig 23 and 24**) is as good as new.

Fig. 23: Outer ring face, designation side, is in good condition.

Fig. 24: Outer ring face, opposite designation side, is in good condition.

The outer diameter has some fretting corrosion in the loaded zone – this is only slight on one side, but more pronounced on the side that has its raceway with the spall (→ **fig 25**). In the unloaded zone area (→ **fig 26**), the outer diameter is in quite good condition. With a loose fit, fretting corrosion cannot be avoided (read Pulp & Paper Practices, issue 16). The intensity of the fretting corrosion depends on many parameters, including load and raceway condition. Is the greater fretting corrosion on one side due to axial load (one row with greater load than the other) and the spall, which increases the fretting corrosion damage? This is possible, but it cannot be confirmed by the spall alone. It is too early to conclude that it is the high axial load, and that the spall is premature fatigue due to the excessive axial load. Such hasty conclusions should be avoided.

Staying with the outer diameter, it is noticed that one of the lubrication holes in the outer ring has some mayonnaise-like substance (→ **fig 27**), whilst the others are clean.

Fig. 25:

Fig. 26

Fig. 27:

Fig. 28:

With the exception of the spall and the indentations, the outer ring raceways (→ **fig 28**) look to be in good condition. The grinding pattern from manufacturing can still be seen even in the most loaded zone, and the lubrication is fine. The length of load zone on each raceway is checked to confirm or eliminate the possibility of a heavy axial load. But, as the lubrication is good, it is difficult to be 100% sure where the load zone starts and ends on the raceway which doesn't have the spall. Depending on the light, it appears that the load zone, which doesn't have the spall, is smaller, confirming a higher load on the raceway which has the spall, meaning that this last raceway takes some axial load in addition to the radial load.

Let's now look at the main damage, keeping in mind what we have seen on the other bearing parts and other outer ring surfaces.

Considering the generally good surface condition of the raceways, inadequate lubrication is, in this case, not likely to be the cause.

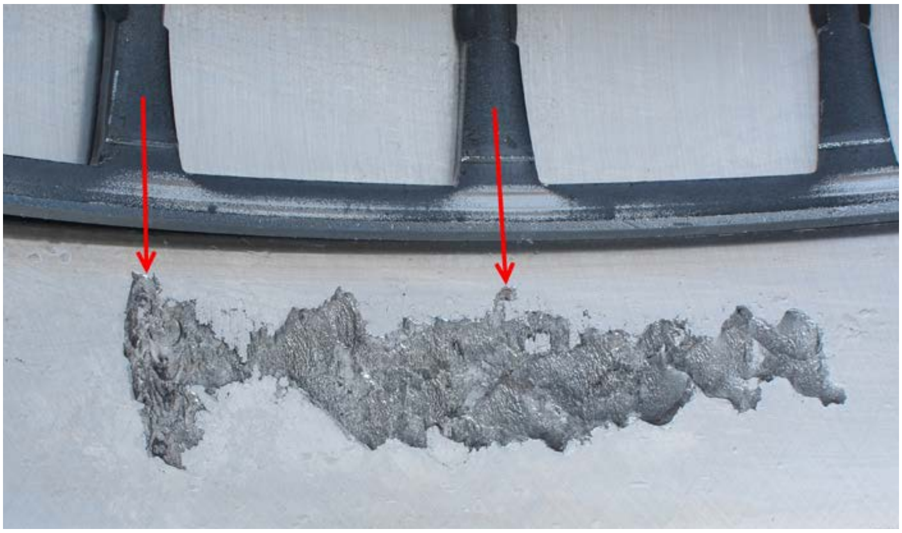

Fig. 29: Spall on the outer ring raceway (cage) can help to discover evidence about damage sustained during standstill.

Fig. 30: Primary propagation of the fatigue is in the axial direction, and then in the rolling direction.

By placing the cage close to the raceway damage (→ **fig 29**), I can look for clues indicating possible standstill damage, with the main damage being separated by the distance between two rollers. The red arrows show two areas where the primary damage, before the spall, could have occurred.

It is **Fig 30** that reveals some clues. Normally, on such bearing types, spall created by subsurface fatigue develops in the rolling direction, and not so much in the axial direction. The spall shape shows propagation of the spall from left to right, except for on the far left, where crack propagation is in the axial direction. It is typical in spherical roller bearing failure cases where there has been axial initial raceway damage that the sub-surface microcracks first develop from the damaged area in the axial direction, and subsequently go on to develop in the rolling direction.

Note that the right-hand arrow (→ **fig 29**) points to a sort of hook, where sub-surface crack propagation seems to be axial. Another position of primary damage? Perhaps, or not.

What are the most common causes of 'axial damage'? The list includes:

- False brinelling (vibration during transportation, storage close to a machine in operation, etc.)
- Tilting while bearing is at a standstill and loaded, creating smearing marks when the roller slides axially (lifting one side of the drying cylinder, for example)
- Peak load (bearing housing hitting the machine frame while manipulating the drying cylinder, for example)
- Standstill corrosion (presence of free water in the lubricating oil, condensation during transportation or storage)
- And so on.

Most probable cause of the bearing damage

The main cause of the bearing damage cannot be identified by the visual inspection alone. All we know is that the most probable cause is damage at the roller and raceway contact during standstill – please note that I didn't write "the cause" but "the most probable cause".

Conducting further and more in-depth investigations using an electronic microscope and metallurgic analysis is costly and takes time. In general (there are some exceptions), in-depth laboratory investigations just tend to confirm the results of the visual inspection. So before taking the decision to send the bearing to the lab, further investigations should be performed into the bearing storage, mounting and operating conditions. Such information should be sent to SKF with the damaged bearing. In this case, I had obtained all the information from a meeting with the customer and OEM one year previously. "All" information? Well, all known information. For example, a worker will not report to his hierarchy that he performed a mounting error (bearing receiving high preload during drive up, see previous Pulp & Paper Practices), or that the bearing housing had hit the machine frame or a workshop pillar. I didn't receive any information concerning temperature changes during transportation that could lead to condensation. But the information I had received correlated sufficiently with the most probable cause of bearing damage and, as such, should be treated as a priority.

The information I'd received was that the customer was complaining about excessive water content in the oil. Once every day or every two days, he was able to drain a bucket of water out of the main oil tank. Measurement showed that water content in the oil could reach 2600 ppm. Most oils used in the dryer section cannot dissolve such a large amount of water, even at operating temperature.

But what is the cause of high water content?

Under the hood, the dew point and temperature distribution have an influence on the paper quality and the effectiveness of the heat recovery. Also, the sucking of ambient air into the hood or blowing out hot humid air should be avoided. This is controlled by fans and creates a zero-line under the hood – a level where pressure under the hood is equal to the pressure outside the hood, and so is equal to the ambient pressure. Above this zero-line, pressure is higher, whilst underneath, the pressure is lower.

In drying sections, drying cylinder bearing housings have labyrinth seals instead of friction seals. Air can move through the seals. The housings are connected to the oil reservoir, and are thus connected to ambient air pressure. Below the zero-line, air coming from the main oil tank tends to move into the hood via the bearing housing, sometimes transporting small particles of oil. Above the zero-line, it is hot, humid air that tends to move into the bearing housing and return oil pipes to the oil reservoir.

I will not try to explain how the mill controls the dew point or air distribution, etc., or the creation of the zero-line and the reason for this as it lies outside my area of expertise. But what I can say is that customers with a too high-positioned zero-line sometimes complain about the presence of oil on the frame and/or the hood's internal walls. On the other hand, customers with a zero-line that is positioned too low experience low bearing service life and water content in the oil above recommended limits. Too short bearing service life? If you open the hood service door and find that it is easy to open and you receive a blast of hot air in your face, the cause of the short service life could be excessive water content.

However, the zero-line isn't the only possible cause of excessive water content. Apart from the high pressure cleaning, another reason is the bearing housing oil inlet temperature. If this is below the dew point and the housing is above the zero-line, this can create condensation in the housing, resulting in free water.

Lowering the oil inlet temperature in order to decrease bearing temperature and improve the viscosity ratio (lubrication condition) in the bearing can lead to higher water content in the oil. In fact, the calculated bearing rating life increases (better lubrication condition) but the service life decreases due to increased water content! This is why I now recommend keeping the oil inlet temperature in the dryer section closer to 60°C – although one should never try to lower it below 50°C or try to reach 40°C, as I recommended in the past before I became aware of the zero-line issue.

Note that Yankees, in tissue machines, do not have bearing housing under the hood. The oil inlet temperature can then be set between 40°C and 45°C.

When the mill conducted measurements, it could clearly be seen that water content in the lubricating oil decreased when the zero-line level was increased and/or the dew point was decreased, and/or the oil inlet temperature was increased.

For the past several years – taking into consideration the dew point, zero-line and oil inlet temperature – I have been able to detect a correlation between repetitive bearing failures and these parameters in the dryer section in many mills.

Naturally, however, this isn't the only reason for the bearing damage in dryer sections. The other main causes are inadequate lubrication, and inadequate inner ring heat treatment, such as martensitic treatments, and so on.

Performing corrective actions, including improved water removal from oil by the lubricating system, in order to reduce water content, will stop repetitive bearing failures due to standstill corrosion. However, this will be the case for new bearings mounted after the corrective actions. But you should expect some more bearing failures for those still in service that have previously had contact with free water.

Standstill corrosion without corrosion marks on the bearing – how can that be?

Some customers do not believe that the bearing damage is due to standstill corrosion, as there are no corrosion marks on the bearing, and sometimes also because the oil analysis doesn't show a water content above the recommended level (200 ppm, but 500 ppm is accepted when the machine is warm and in operation).

The first point is that water content is seldom monitored continuously, and the peak water content can occur between two oil analyses. Also, if the oil sample sent to the lab isn't sealed properly, the water content can change in response to the relative humidity of the ambient air.

Concerning the corrosion marks, it isn't just the presence of free water that causes the bearing to corrode. Corrosion will begin depending on the water content and the capacity of the oil to protect the bearing against corrosion.

Here I shall quote part of what I wrote in the 'Rolling Bearing in Paper Machines' handbook, 5th edition:

"If a non-rotating bearing has free water in the lubricant, this water will accumulate at the bottom of the bearing. The concentration of the water will be highest at a certain distance from the rolling contact (→ **fig 31**). The reason for this is that the free water in the oil, being heavier, will sink until it comes to a suitable gap between the roller and the raceway. Corrosion due to water or any other aggressive liquid at, and, around the contact surface between rollers and raceways is called contact corrosion, standstill corrosion or etching.

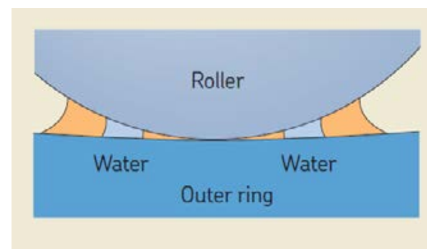

Fig. 31: Water concentration in a stationary bearing.

"**Fig 32** shows corrosion on the inner ring of a spherical roller bearing under static conditions. The corrosion marks are separated by the same distance that separates two adjacent rollers. There is enough water in the lubricant to cause contact corrosion marks, but not enough to significantly corrode the other parts of the raceways that are protected by the lubricant."

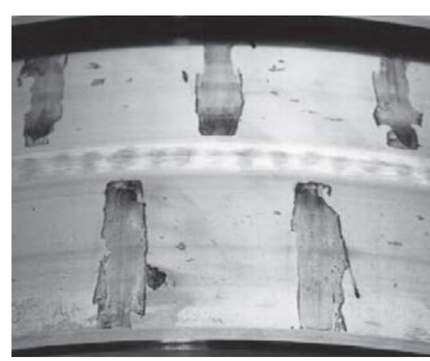

Fig. 32: Standstill corrosion under static conditions.

For the bearing shown in **Fig 32**, the corrosion marks that are only superficial can be easily worn away. Only the deepest corrosion marks will remain as weak spots, and it is from these that fatigue microcracks will develop, resulting in a spall.

Conclusion

I hope that this issue of Pulp & Paper Practices has opened your mind to the fact that a bearing can be damaged by corrosion, even if it bears no visible evidence of corrosion.

In addition, you should keep in mind that a damaged bearing should be treated like a new bearing, in order to avoid causing additional damage that could lead to incorrect investigation results. Also, remember to examine all parts and surfaces of the bearing, not only the damaged ones.

Finally, laboratory investigations with metallurgic analyses are not a 'must-do'. Having a good understanding about the actual operating conditions, mounting conditions, overall machine and maintenance practice, and so on, is much more valuable in the effective and pragmatic determination of the cause(s) and meaningful corrective actions.

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