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Fig. 1: Spalling on CARB bearing outer ring raceway due to subsurface fatigue, caused by high load. Standstill corrosion marks generated on raceway during the transportation to failure analysis because of poor corrosion protection.

Are premature failures caused by wrong bearing sizing?

When a bearing fails prematurely, the question "was the bearing size selection wrong?" will often be asked.

In most cases, bearing dimensioning is performed correctly using the information provided and proven rating life calculation methods. However, rating life calculations cannot consider all possible parameters and their variables, which in reality, affect the bearing service life of a given application. Rating life methods differ in the number of parameters they consider: one only considers the load, another also considers lubrication and contamination conditions, while others also consider bearing internal load distribution, deflections, contact stress and so on.

This all goes back to the "basic rating life", which was developed in 1947 by SKF and is still used today to select bearing size based on a statistical survival reliability of 90%. However, this method only considers the bearing load. If you have experience with the operating conditions related to lubrication and contamination, and know that the conditions in your application do not have a dramatic effect on the life of your bearings, the basic rating life can still be used. Over the years, a lot of research has been conducted, resulting in the "SKF rating life method", which takes into account lubrication and contamination conditions in order to estimate the expected bearing life. Other additional parameters, such as detailed bearing geometry, deformations of bearing, bearing housing and shaft, require the resolving of complex hyperstatic models and powerful analysis tools, such as SKF SimPro tools. In many of the premature failure cases, bearing dimensioning has been performed correctly with given inputs; however, if the actual acting load is much higher (such as, for example, bearing excessive preload because of lack of clearance), operational life will be shortened (see P&P Practice 2). In this issue, I will discuss a few more possible reasons why operational life is sometimes shorter than expected.

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Are premature failures caused by wrong bearing sizing?

Premature failures typically occur at 5% or less of their calculated rating life, although there are cases where the bearing lifetime has been longer than 5% of the calculated life, but customers have felt that the bearing life has not been long enough compared to calculated rating life. Some mills believe that premature bearing failure could be due to inadequate bearing size selection. In such instances, they often either ask the bearing manufacturer to perform new calculations or attempt to perform the calculations themselves based on the bearing rating life calculations described in the SKF rolling bearings catalogue.

Using the bearing catalogue or any other life calculation methods, while forgetting some induced or unexpected loads, could lead to wrong conclusions.

This article has been created to highlight the need for advanced life calculation methods, and to discuss some typical examples of unexpected load-affecting bearing life, especially in highly loaded press rolls.

Before reading this article, I recommend that you re-read Pulp & Paper Practices, issue 9, which gives information about what the calculated bearing rating life is and why this isn't the same as the bearing service life.

Most of the bearing type and size selection in the pulp and paper industry is based on bearing catalogue rating life calculation methods. TAPPI, the Technical Association for the Pulp & Paper Industry, provides recommended rating lives based on the "standard catalogue" life calculation method instead of the advanced one, which considers housing and shaft deformations. The bearing catalogue rating life calculation methods suppose that the bearing housing is sufficiently stiff and well supported, that the bearing clearance in operation is close to zero, and so on. But what happens if the housing isn't sufficiently stiff or is badly supported?

In some cases, the housing and shaft deformation have a positive influence on bearing life by increasing the number of bearing rollers supporting the load and/or reducing the load on the roller with the highest load. Unfortunately, this isn't always the case and the deformations can have a negative influence. In such instances, a mill faced with repetitive premature bearings failures could, based on the standard bearing rating life calculations, start to search for the root causes in the wrong place. Taking into account housing, shaft and bearing deformation requires the use of complex computer programs, such as SKF SimPro Expert. In these programs, the bearings, shafts and housings are considered to be flexible components of a system. However, one issue is that, for such advanced calculations, a 3D model of the housing is needed.

When is there a need for bearing dimensioning with flexible housings? Generally, always where there is insufficient stiffness of the housing, shaft or the base, or when there are major changes in stiffness in the bearing load zone. The question of how this is to be analyzed is much more difficult. Normally, if the bearing load is towards the housing base and the frame is stiff (base plate or normal paper machine frame), it can be assumed as rigid. But, if the bearing load is such that it is directed towards bearing housing areas where the stiffness changes, and especially if the wall-thickness of the housing is low (→ **fig 2**), the bearing load distribution can be disturbed, causing high contact pressure peaks. Increasing maximum roller load and contact pressure in the bearing will decrease bearing life (→ **fig 3**). In many of these cases, housing deflection also widens the bearing load distribution, which increases bearing heat generation. Increased heat generation causes higher bearing temperature => worse lubrication conditions => shorter bearing service life.

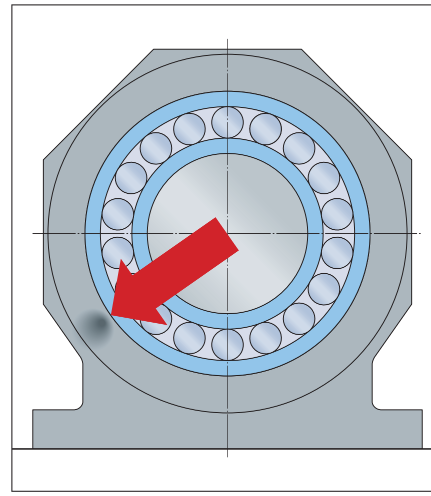

***Fig. 2:** In many cases, the bearing load is exerted on the housing base, but in some cases the bearing load is exerted in a direction where the housing stiffness is changing rapidly.*

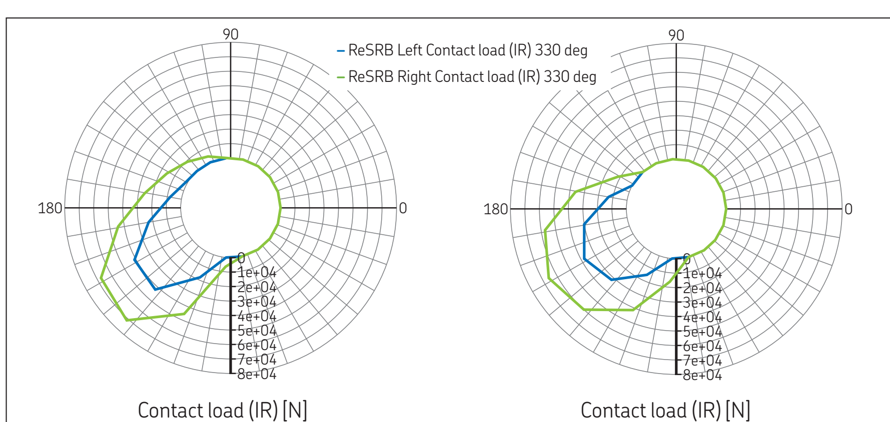

***Fig. 3:** Bearing roller load distribution is wider and maximum load is higher with flexible housing (left) than when calculated with rigid parts (right). SKF Advanced life is 126,000 h with flexible housing, whilst SKF Advanced life with rigid housing is 166,000 h.*

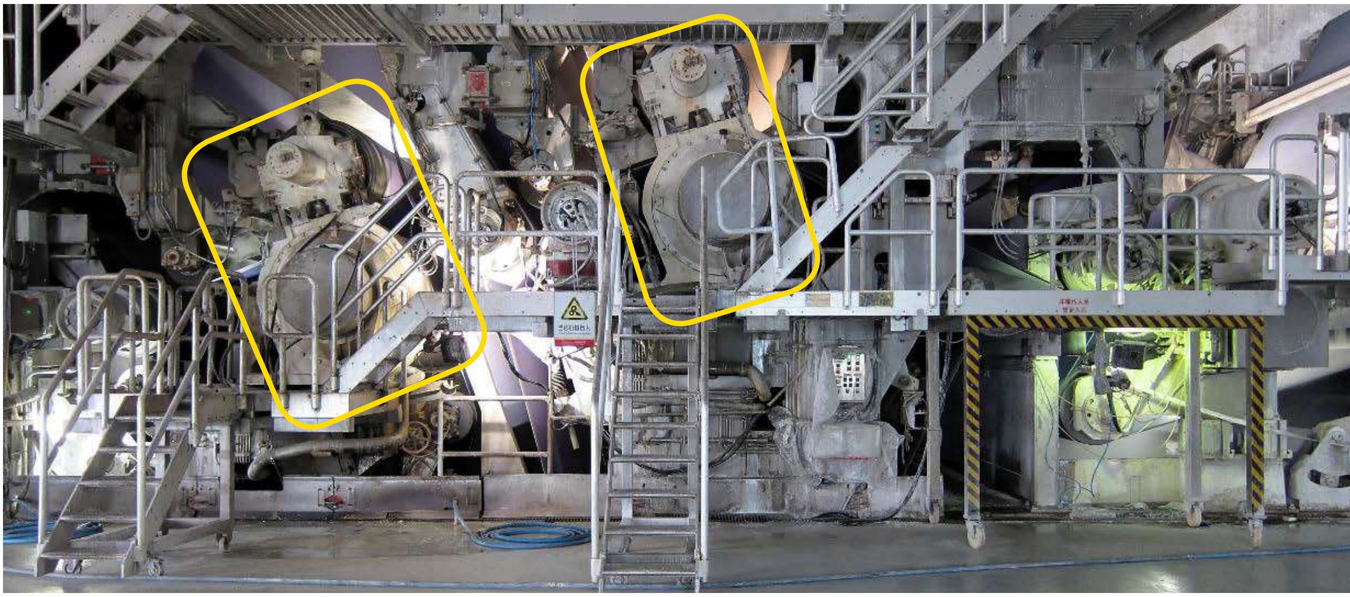

Fig. 4: Press section shoe nip, where bearing loads are going through the bearing housing to the counter roll.

In some pulp & paper applications, bearing forces are guided through the bearing housing to the counter roll. The most common application is press section shoe nip, where rolls are connected to each other by using tension bars or a different type of clamps (→ **fig 4**). The benefit of this construction is that nip loads are kept inside the rolls and the housings, and forces are not passing through the machine frame. Many of these roll housing deflections are so substantial that standard catalogue calculations do not give an adequate estimation of the bearing life, and calculations with flexible housings are needed. Some of these nips are equipped with deflection-compensated rolls (typically bigger machines), and these are not causing the problems because high nip load is not passing through the roll's bearings, but smaller machines, which are equipped with plain press rolls and rolling bearings, where high nip load is passing through the bearings, are the difficult ones.

In these high loaded plain press rolls, there is a definite need for advanced calculations. In some cases, the housing shape is not optimal, and when high bearing loads are going through the housing, housing deformation will disturb the bearing load distribution. In the worst case scenario, there can be two loaded zones (→ **fig 5**) or unexpected load peaks, and, based on field experience, this it is not good for the bearing life and is not recommended – especially if the bearing load is high. The calculated SKF Advanced fatigue life of the bearing in the example in → **fig 5** was 105,000 h. With correctly designed housing, the bearing load distribution can be optimized to increase bearing life. **Fig 6** shows the optimized bearing housing geometry and roller load distribution, and the calculated SKF Advanced fatigue life time is 125 000 h. In this case, there was an improvement of 20,000 h, but I have also seen bigger differences – it all depends on the housing design before and after optimization.

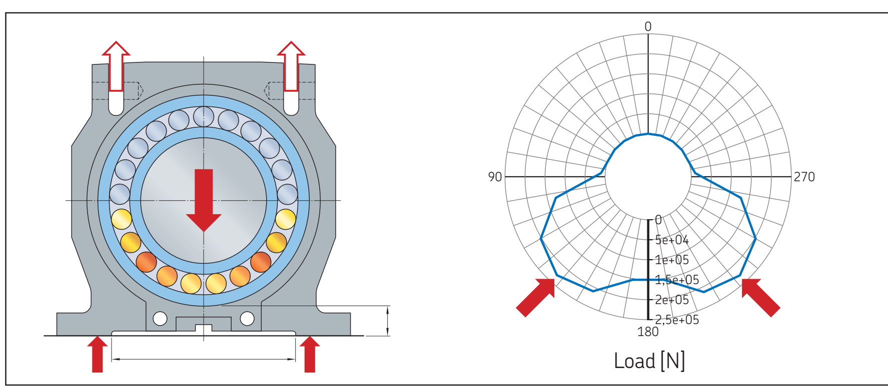

Fig. 5: Non-optimized bearing housing design can create two loading zones per bearing.

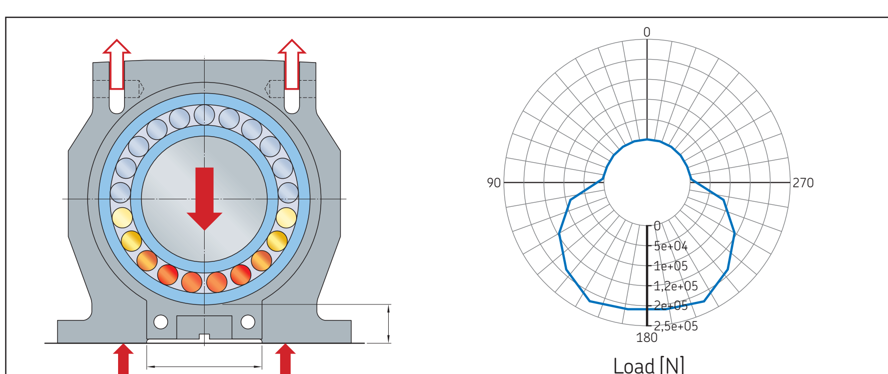

Fig. 6: Optimized bearing housing design (optimized gap width, housing thickness and key size).

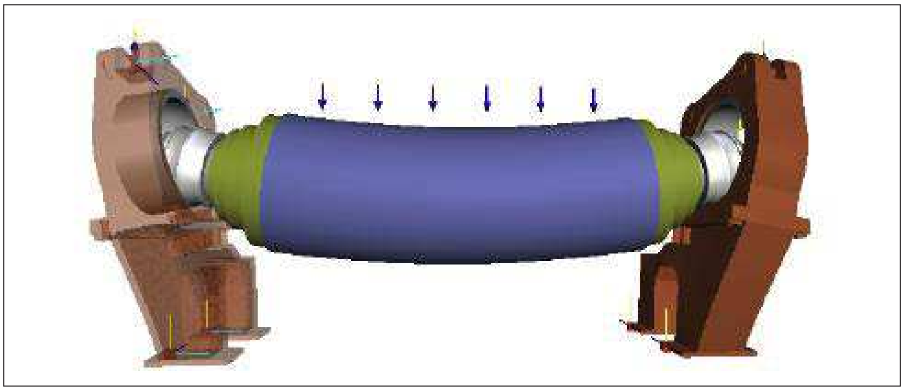

Fig. 7: Advanced bearing calculations made for a high loaded plain press roll with two spherical roller bearings. Internal axial loads are causing the frames to bend.

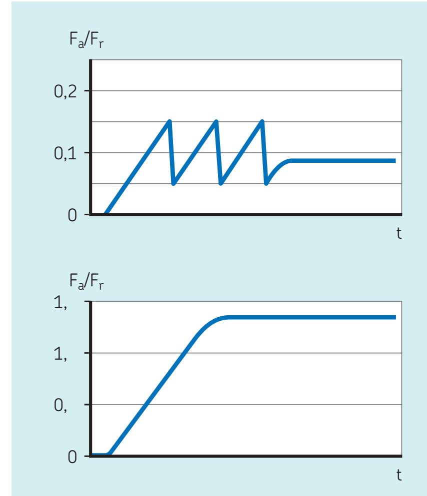

Fig. 9: The upper diagram shows internal axial loads to overcome friction. If axially free bearing movement is prevented by housing deformation, fretting corrosion, dirt, wear particles, etc., the internal axial load can be much bigger than expected (lower diagram).

But do we have some other issues to consider? Older rolls have been manufactured to this press section shoe nip position with two spherical roller bearings, and, when there are high deflections on the housing, this will hinder axially free bearing movement (→ **fig 7**). In a bearing arrangement with two spherical roller bearings, at least one bearing needs to be non-locating, i.e. axially free to move in the housing (bearing outer ring sliding axially in housing bore), if there is no other solution which allows axial movement (for example, between the housing and the frame). Axial movement is needed to accommodate dimensional changes to the roll and frame caused by temperature differences (heat expansion).

If the housing deflection is substantial, the housing will act like a rubber band around the bearing, preventing free bearing axial movement, which will generate a high internal axial load to bearing arrangement (Figure 8). This phenomenon can be eliminated by using a CARB-bearing as the non-locating bearing (→ **fig 8**).

Due to friction between the bearing outer ring and the housing, axial forces are created when thermal expansion pushes the bearing in the axial direction. These need to be estimated. In → **fig 9**, Diagram 1 shows normal friction behaviour where axial load (F_a) in relation to radial load (F_r) is increasing until static friction is exceeded and the bearing moves axially, friction starts to increase, moving axially, until a steady state position is found. Diagram 2 shows the axial/radial load ratio if a bearing's axial movement is prevented, although similar situations can arise if bearing housing deformation is substantial enough. If we assume that all components are sufficiently rigid and in good condition, axial movement occurs when axial load due to thermal expansion and friction exceeds ($F_{friction}=\mu\times F_r$, → **fig 10**). Typically, the steel-steel friction coefficient is 0.12-0.15, which will cause F_a=0.12-0.15×F_r. This is a simplified assumption of the axial load caused by friction – a more detailed description begins on page 6 of Pulp & Paper Practice 6, which describes the stick slip phenomenon in greater detail. In the main applications (such as felt rolls, suction rolls, drying cylinders, etc.), this is correct and provides a good estimation of the force needed to move the bearing outer ring axially. If, however, we have an application where housing deflection is substantial, especially in high loaded press rolls, where forces are going through the

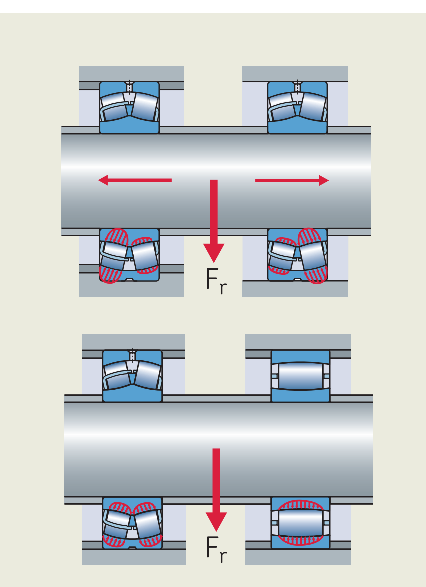

Fig. 8: A traditional plain press roll bearing arrangement with two spherical roller bearings will generate internal axial loads because of the friction and housing deformations. This phenomenon can be eliminated by using CARB as the non-locating bearing.

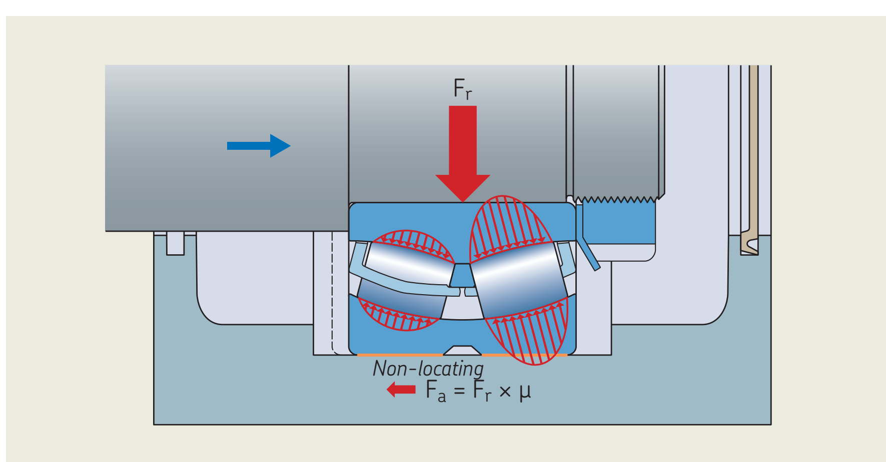

Fig. 10: Axial load generation to spherical roller bearing in an axially free bearing.

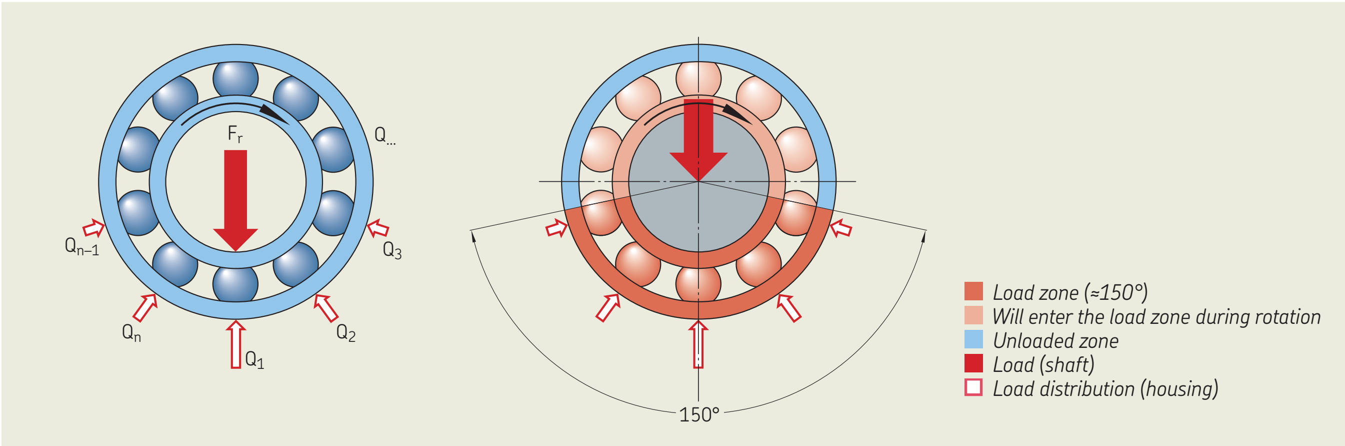

Fig. 11: When the bearing is loaded with external load F_r, bearing load F_r will be transferred from the inner ring to the outer ring via rollers. The external load will be distributed to rollers. Each roller has an individual roller load (Q_n), which is perpendicular to the contact surface. Roller load distribution in the bearing shows how the loads are varied between bearing rollers.

housing to the counter roll, the load distribution between the bearing and housing is, in fact, higher, and the axial induced load due to friction is higher than expected. The reason for this is that the external bearing load (F_r) will be transferred from the inner ring to the outer ring via rollers, and all rollers have an individual load (Q_n in → **fig 11**). From the outer ring, the load will be transferred to the housing bore. When component deflections are added in flexible calculations, the theoretical load (which generates the load between the bearing outer ring and the housing bore) will be changed from the rigid case. The load direction in the roller/raceway contact isn't always the same as the external bearing load direction. This depends on the roller position in the bearing. Load (Q_n, see **fig 11**), between the roller and raceway, is perpendicular to the contact surface and no longer in the same direction as the external bearing load. Load (Q_n) intensity will depend on the roller position and housing and bearing deformation. The sum of all Qn is greater than the external bearing load on the bearing ($_F$r). Because the bearing ring thickness is low, the Qn loads are easily transferred in the bearing ring's contact surface with its seat.

As result, the radial load to be taken into account for axial load estimation due to friction isn't the main radial load due to the external bearing load, but the load between the bearing and its seat due to deformations of the housing. For example, → **fig 12** shows a case where the sum of Q_n is 1.5 times the external load on the bearing. This means that the axial estimated load is 1.5 times that which is to be expected if only the external bearing load (F_r) on the bearing is used in the calculations. In extreme cases, the axial load due to friction can be even greater.

Fig 13 shows this phenomenon on a spherical roller bearing's outer ring that is axially free in its housing. The bearing housing's oil lubrication groove edges are copied to the bearing's outer ring, and the edge of the housing groove on the outer ring is sharp, showing that the bearing has not been moving axially at all. This has generated very high axial forces on both of the bearings, and has led to premature bearing failure.

For high loaded plain press rolls, experience suggests that the most reliable arrangement is spherical roller bearing-CARB, which eliminates induced axial displacement loads from the bearing arrangement.

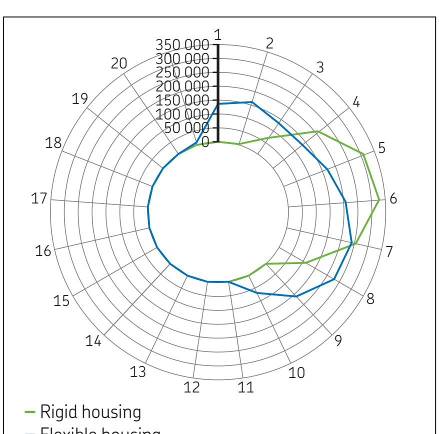

Fig. 12: Sample roller load and load distribution with rigid and flexible calculations.

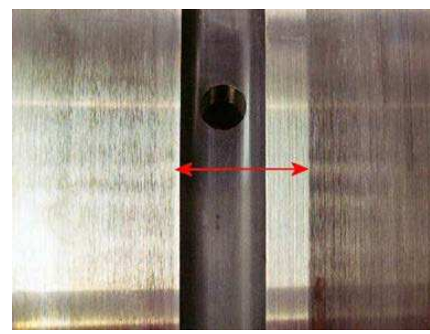

Fig. 13: Spherical roller bearing's outer ring's external surface for non-locating (axially free) bearing. The oil lubrication groove position is sharply marked, which shows that the bearing ring has not been moving axially in the housing bore as it should have been.

Have you checked whether the bearing housing is being used as part of the machine frame? If so, how could this affect bearing life, especially in a high loaded application? If you are lucky, this could increase your bearing life. These external loads can deform the housing so that the bearing load zone becomes wider (more rollers are carrying the load), which will reduce the load of the most loaded roller => lower stress on the bearing will increase the bearing life. Unfortunately, however, almost all cases have a negative effect on bearing life. The bearing housing can sometimes be connected to the frame with an intermediate piece (which is needed for felt change). There may be cases where the thickness of the intermediate piece is too low or too high (see → **fig 14** and → **fig 15**). If the intermediate piece is too thick, it may be necessary to use a hydraulic jack in felt change to remove and assemble the piece. If you need to use a hydraulic jack with a capacity of 30-50 tonnes to remove the intermediate piece, it is likely that the same force will also be applied to the bearing housing when the piece is in position. Alternatively, if the thickness of the piece is too low, a gap may arise between the housing and the intermediate piece (I have seen cases where the gap has been as much as 2-3 mm), which will be tightened with large bolts (for example, 3-4 x M36). The preload of the bolts will be very high and, if the gap has been removed by tensioning of the bolt, there will also be substantial forced displacement on the bearing housing (→ **fig 16**).

When the housing and the frame are connected, there will be a difference in the relative movement of frame and housing between shut-down, start up and steady state. Of course, other components will also be subjected to part of the deflections, so the bearing housing will not have to withstand everything. However, all of these undesired changes will have an effect (typically negative) on bearing life. In some cases, problems may also be caused by machine frames becoming somewhat deformed over the years, even though everything was correct when the machine was first built.

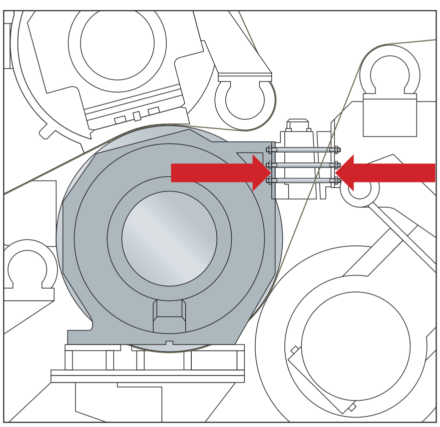

Fig. 14: Bearing housing as part of the machine frame. Intermediate piece tightened with large bolts (and high preload force).

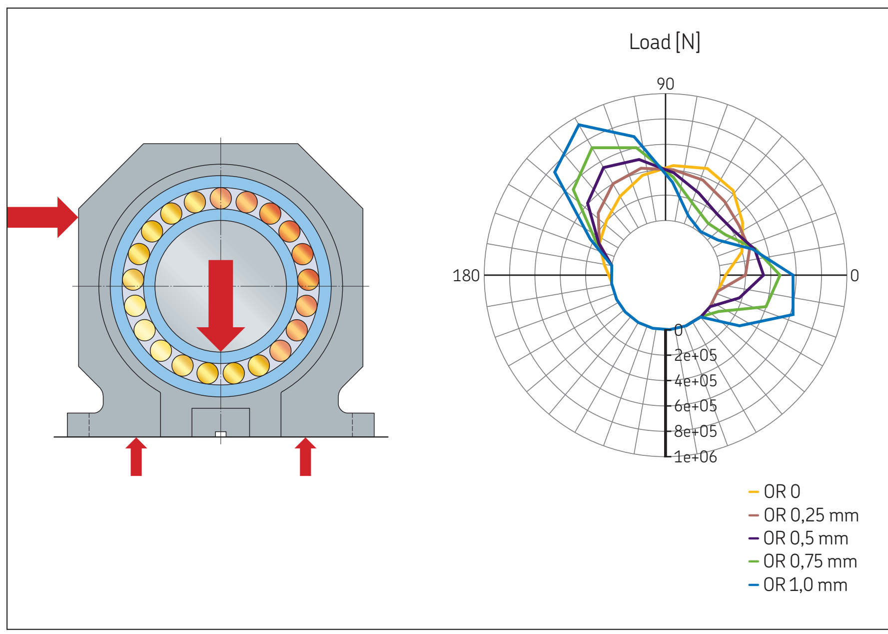

Fig. 16: Bearing roller load distribution with different loads caused by an intermediate piece that is too large. SKF Advanced fatigue life with 0 displacement 330,000 h; 0.5 mm 111,000 h; 1 mm 46,000 h.

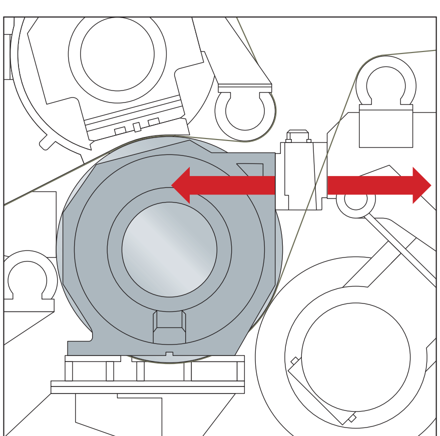

Fig. 15: Bearing housing as part of the machine frame. If the thickness of the intermediate piece thickness is too high, it will generate loads that will deform the bearing housing.

What are the other potential problems when considering bearing housing deflection? How about small parts between the bearing housing and the frame, such as a key that keeps the housing in the correct position? Even though this key is only a small component, it can still damage the bearing if the height of the key is too high (→ **fig 17**). It can prevent designed housing deflection and disturb bearing roller load distribution. By preventing deflection towards the housing frame (no gap between the housing and the key, as in the previous example of optimized bearing housing), this will decrease SKF Advanced fatigue life to 100,000 h, and, if the key is just 0.5 mm higher than fastening surfaces, this will have a much greater effect on calculated life time, which will be just 10,000 h (less than 1/10th of its original value)! The same phenomenon can arise if the designed gap between the housing and the frame is filled with paper, cardboard or pulp (→ **fig 17**). In many cases, all gaps in the press section will be filled with matter during use, and, if this is not removed during roll change, this will create a stiff material layer, which may start to cause problems similar to those caused be the key being too high.

Conclusion

The occurrence of premature failures does not automatically mean that the bearing size selection was wrong. Experience shows that premature failure is often caused by another factor other than the bearing size selection. This could be due to housing deflections, external forces, etc., which have not been taken into account in dimensioning, or that the operating conditions affecting the roller bearing have changed.

It is not normally necessary to use calculation methods that can consider component flexibility for applications such as drying cylinders, felt or wire rolls, fans, and so on. However, for bearings in press rolls with high load and quite flexible housings, and sometimes for flexible shafts (some suction press rolls for example), the differences can be quite important. In case of doubt, please contact your local application engineering service.

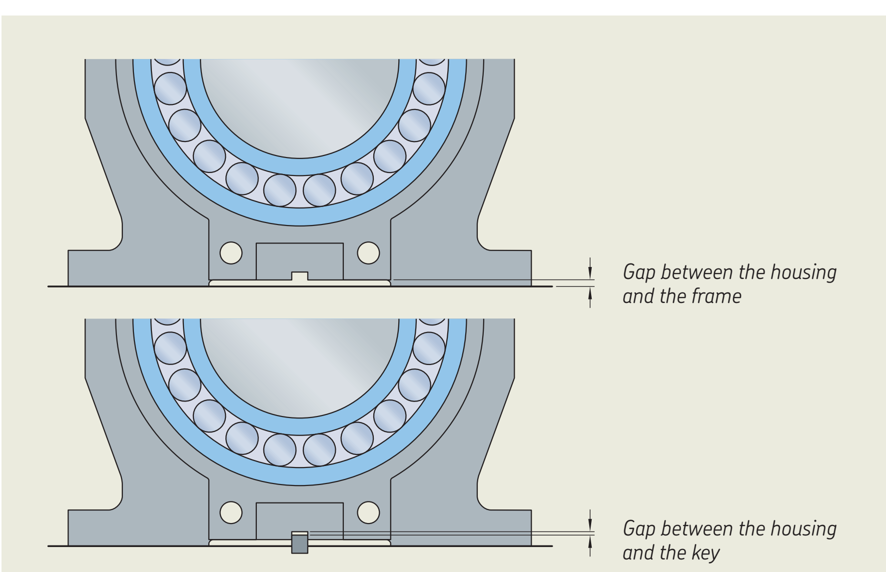

Fig. 17: Bearing housing deflection optimized by the use of a gap between the housing and the frame. The gap beneath the housing must also be maintained during use. There must also be a gap between the housing and the key.

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