Bearing damage and failure analysis

Contents

SKF – the knowledge engineering company

From one simple but inspired solution to a misalignment problem in a textile mill in Sweden, and fifteen employees in 1907, SKF has grown to become a global industrial knowledge leader. Over the years, we have built on our expertise in bearings, extending it to seals, mechatronics, services and lubrication systems. Our knowledge network includes 46 000 employees, 15 000 distributor partners, offices in more than 130 countries, and a growing number of SKF Solution Factory sites around the world.

Research and development

We have hands-on experience in over forty industries based on our employees' knowledge of real life conditions. In addition, our world-leading experts and university partners pioneer advanced theoretical research and development in areas including tribology, condition monitoring, asset management and bearing life theory. Our ongoing commitment to research and development helps us keep our customers at the forefront of their industries.

Meeting the toughest challenges

Our network of knowledge and experience, along with our understanding of how our core technologies can be combined, helps us create innovative solutions that meet the toughest of challenges. We work closely with our customers throughout the asset life cycle, helping them to profitably and responsibly grow their businesses.

Working for a sustainable future

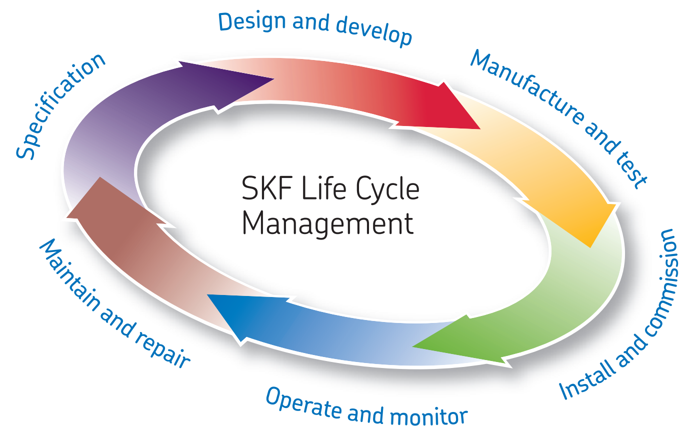
Since 2005, SKF has worked to reduce the negative environmental impact from our operations and those of our suppliers. Our continuing technology development resulted in the introduction of the SKF BeyondZero portfolio of products and services which improve efficiency and reduce energy losses, as well as enable new technologies harnessing wind, solar and ocean power. This combined approach helps reduce the environmental impact both in our operations and our customers' operations.

SKF Solution Factory makes SKF knowledge and manufacturing expertise available locally to provide unique solutions and services to our customers.

Working with SKF IT and logistics systems and application experts, SKF Authorized Distributors deliver a valuable mix of product and application knowledge to customers worldwide.

Our knowledge – your success

SKF Life Cycle Management is how we combine our technology platforms and advanced services, and apply them at each stage of the asset life cycle, to help our customers to be more successful, sustainable and profitable.



Working closely with you

Our objective is to help our customers improve productivity, minimize maintenance, achieve higher energy and resource efficiency, and optimize designs for long service life and reliability.

Innovative solutions

Whether the application is linear or rotary or a combination, SKF engineers can work with you at each stage of the asset life cycle to improve machine performance by looking at the entire application. This approach doesn't just focus on individual components like bearings or seals. It looks at the whole application to see how each component interacts with each other.

Design optimization and verification

SKF can work with you to optimize current or new designs with proprietary 3-D modelling software that can also be used as a virtual test rig to confirm the integrity of the design.

Bearings
SKF is the world leader in the design, development and manufacture of high performance rolling bearings, plain bearings, bearing units and housings.

Machinery maintenance
Condition monitoring technologies and maintenance services from SKF can help minimize unplanned downtime, improve operational efficiency and reduce maintenance costs.

Sealing solutions
SKF offers standard seals and custom engineered sealing solutions to increase uptime, improve machine reliability, reduce friction and power losses, and extend lubricant life.

Mechatronics
SKF fly-by-wire systems for aircraft and drive-by-wire systems for off-road, agricultural and forklift applications replace heavy, grease or oil consuming mechanical and hydraulic systems.

Lubrication solutions
From specialized lubricants to state-of-the-art lubrication systems and lubrication management services, lubrication solutions from SKF can help to reduce lubrication related downtime and lubricant consumption.

Actuation and motion control
With a wide assortment of products – from actuators and ball screws to profile rail guides – SKF can work with you to solve your most pressing linear system challenges.

Introduction

Rolling bearings are among the most important components in the vast majority of machines. Exacting demands are made on their load carrying capability, running accuracy, noise levels, friction and frictional heat, life and reliability. Therefore, it is quite natural that rolling bearings should have come to play such a prominent part and that over the years they have been the subject of extensive research and continuous improvements.

Rolling bearing technology has developed into a particular branch of science. SKF has been in the forefront right from the start and has been one of the leaders in this field. Among the benefits resulting from this research has been the ability to manufacture bearings of the highest quality, and to calculate the rating life of a bearing with considerable accuracy, together with detailed application knowledge, making it possible to maximize the bearing service life of the machine involved.

Despite careful design and manufacture as well as testing the bearing in the application, it sometimes happens that a bearing does not attain its required service life. Failures will generally cause economic losses due to loss of production, consequential damage of adjacent parts, and the cost of repairs.

Premature bearing failure can occur for a variety of reasons. Each failure leaves its own special imprint on the bearing.

Consequently, by examining a failed or damaged bearing, it is possible in the majority of cases to establish the root cause and define corrective actions to prevent a recurrence. This publication is intended to provide a basic understanding of bearing failures and failure analysis.

With the knowledge presented in this publication, it is possible to assess simple failure situations and start the right analysis. However, the information is not sufficient to do in-depth bearing failure analysis and does not compensate for experience necessary in this domain.

About this publication

This publication is made up of different chapters:

1. **Bearing life and bearing failures**
   Most bearings outlive the equipment in which they are installed. Only some fail.
2. **Inspection and troubleshooting**
   When a problem occurs, inspection during operation or standstill and immediate troubleshooting can give hints about what is happening. The very important subject of condition monitoring (finding damage in time) is not covered here. More information about condition monitoring is provided in the *SKF bearing maintenance handbook* or specialized publications.
3. **Path patterns**
   Once damage has occurred, the bearing needs to be examined and analyzed. Analysis requires a good understanding of path patterns.
4. **ISO failure modes classification**
   Terminology and the ISO classification system helps to communicate the type of damage and its possible causes.
5. **Damage and actions**
   A number of cases are described together with corrective actions. In this chapter, only non-destructive analysis is covered.
6. **Other investigations**
   For complex cases, there are several advanced and destructive methods for failure analysis available at SKF's laboratories. This chapter provides a brief summary.
7. **Case studies**
   Bearing damage analysis can be quite complex. This is demonstrated with a few case studies.
8. **Appendices**
   Appendices A to E contain key charts for quick overviews, hints about how to collect bearing damage information, and a glossary for easy reference.

1 Bearing life and bearing failures

Every year an estimated 10 billion bearings are manufactured around the world. Only a small fraction of all bearings in use actually fail (→ **diagram 1**). Most of them (some 90%) outlive the equipment in which they are installed. A number of bearings (9,5%) are replaced prior to failure for security (preventive) reasons. Approximately 0,5% of bearings are replaced because they are damaged or fail. This means that some 50 000 000 bearings are replaced every year due to damage and failure.

There are several reasons why bearings can be damaged or fail. Generally speaking,:

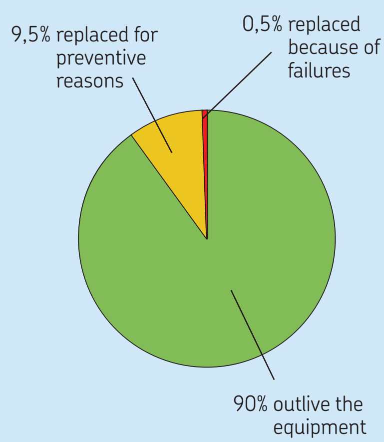
- 1/3 fail due to fatigue
- 1/3 fail due to lubrication problems (wrong lubricant, wrong quantity, wrong lubrication interval)
- 1/6 fail due to contamination (ineffective seals)
- 1/6 fail for other reasons (improper handling and mounting, heavier or different loading than anticipated, wrong or inadequate fits)

The figures vary depending on the industry or application. In the pulp and paper industry, for example, a major cause of bearing failure is contamination and inadequate lubrication, not fatigue.

Each of these events produces a unique damage imprint, called a pattern (path pattern when referring to raceways, → *Path patterns*, **page 32**). Consequently, by examining a damaged bearing carefully, it is possible, in the majority of cases, to find the root cause of the damage. Based on the findings, corrective actions can be taken to prevent a recurrence of the problem.

Diagram 1

Bearing life and failure



For example, take an application with ineffective seals. When contaminants in the form of particles get into the bearing through the seals, they can be over-rolled by the rolling elements. The over-rolling creates indentations in the raceways (→ **fig. 1**). Hard particles may cause indentations with sharp edges. When the area around the indentation is then subject to cyclic stress due to normal over-rolling by the rolling elements, surface fatigue is initiated and the metal will start to break away from the raceway. This is called spalling. Once spalling has occurred, damage will progress until the bearing becomes unserviceable.

Factors influencing bearing service life

Generally speaking, the rating life of a bearing in an application can be calculated based on the SKF rating life formula:

$$L_{nm} = a_1\, a_{SKF} \left(\frac{C}{P}\right)^p$$

where

L_{nm} = SKF rating life (at 100 – n[1] % reliability) [millions of revolutions]
a_1 = life adjustment factor for reliability
a_{SKF} = SKF life modification factor
C = basic dynamic load rating [kN]
P = equivalent dynamic bearing load [kN]
p = exponent of the life equation

[1] The factor n represents the failure probability, which is the difference between the requisite reliability and 100%.

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This method not only takes loads into consideration, but includes other important factors like reliability, lubrication conditions, contamination and the fatigue load limit.

Whether or not the service life of a bearing reaches or exceeds that calculated rating life depends on a number of factors:

- **Bearing quality**
  Only bearings manufactured to the highest quality standards can provide long service life.
- **Storage**
  Stocking bearings correctly is an important aspect of proper storage. Avoid overstocking. Using the "first in, first out" approach will help make sure that "fresh" bearings are on the shelf. This is particularly important for bearings containing seals or shields as they are lubricated at the factory and the grease has a limited shelf life. Also, keep in mind that with rapid changes in manufacturing technology, bearings made today have a much longer built-in life than bearings made 10 or 15 years ago.
- **Application**
  The application utilizes the appropriate bearings.
- **Mounting**
  Bearings will only function properly if mounted correctly (→ *SKF bearing maintenance handbook*). Improper mounting techniques can easily damage bearings, causing premature failure.
- **Lubrication**
  Different operating conditions require different lubricants, relubrication intervals and lubricant change intervals. Therefore, it is important to not only apply the right lubricant, but to also apply the right amount, at the right time, using the right method.
- **Sealing solution**
  The purpose of a seal is to keep lubricants in and contaminants out of the bearing. Premature bearing failure could result if the application is not sealed effectively.

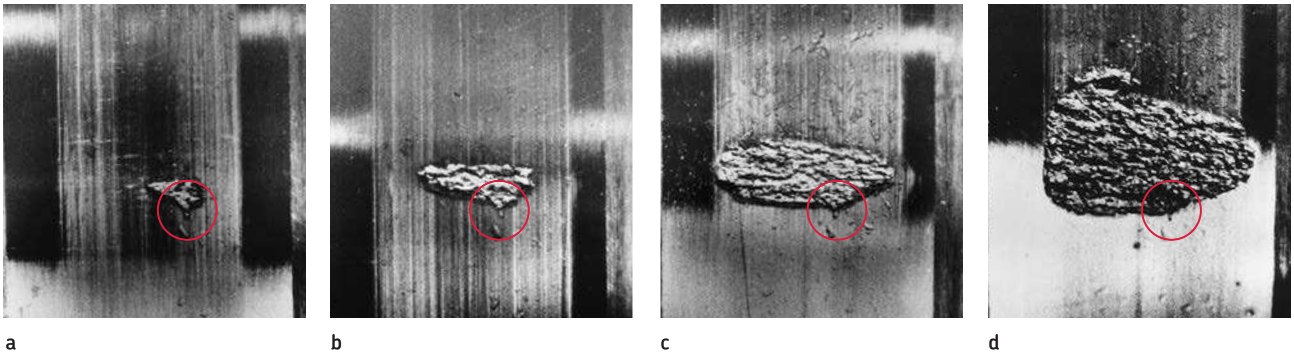
When to replace a bearing?

The amount of time from the first (initial) damage until the bearing becomes unserviceable can vary considerably. At higher speeds, it can take a few seconds. In large, slow rotating machines, it can take months. The question, "When should I replace the bearing?", is best answered by monitoring the condition of the bearing (→ *Inspection and troubleshooting*, **page 10**).

If a damaged bearing goes undiagnosed, and is not replaced before it fails catastrophically, secondary damage to the machine and its components can result. Also, when a bearing fails catastrophically, it can be difficult, even impossible, to determine the root cause of the failure.

Damage progression
*A hard contaminant was over-rolled and made an indentation in the inner ring raceway of a cylindrical roller bearing (**a**). The surface initiated fatigue resulting in a spall started just behind the indentation. Over a period of time, spalling became more and more pronounced (**b**, **c**). If the machine was not stopped in time, secondary damage to machine components could have occurred. The initial indentation is no longer recognizable (**d**).*

Fig. 1



2 Inspection and troubleshooting

Inspection during operation

Early indications of bearing damage enable a user to replace bearings during regularly scheduled maintenance, avoiding otherwise costly unscheduled machine downtime due to bearing failure. Important parameters for monitoring machine condition include noise, temperature and vibration.

Bearings that are worn or damaged usually exhibit identifiable symptoms. Many possible causes could be responsible and need to be investigated (→ *Troubleshooting*, **page 12**).

For practical reasons, not all machines or machine functions can be monitored using advanced systems. In these cases, trouble can be detected by looking at or listening to

Diagram 1

The advantage of advanced condition monitoring

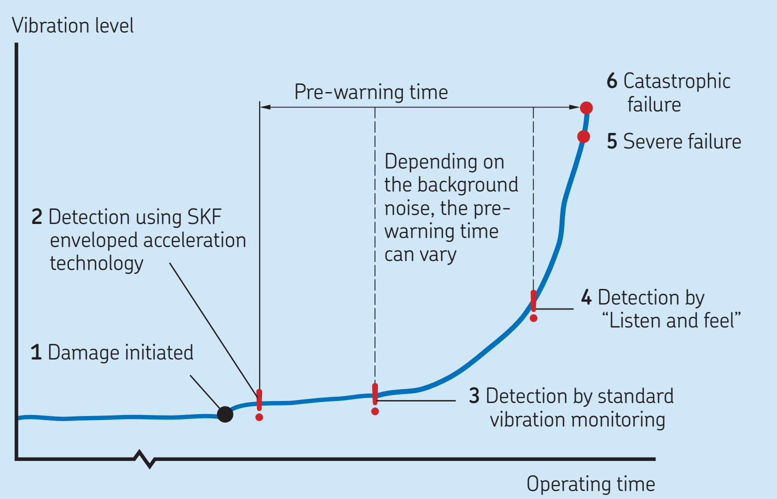


Fig. 1

the machine. Using the human senses to detect machinery problems, however, has limited benefit. By the time sufficient deterioration has occurred for the change to be noticeable, the damage may already be extensive. The advantage of employing objective technologies, such as advanced vibration analysis, is that damage is detected at an early stage of development, before it becomes problematic (→ **diagram 1**). By using professional condition monitoring instruments and the SKF enveloped acceleration technology, the pre-warning time can be maximized.

Fig. 1 shows the progress of damage as illustrated in **diagram 1**:

1 Bearing exhibits incipient abrasive wear.
2 First spall, detected by SKF enveloped acceleration technology.
3 Spalling has developed to an extent that the damage can be detected by standard vibration monitoring.
4 Advanced spalling causes high vibration and noise levels and an increase in operating temperature.
5 Severe damage occurs: fatigue fracture of the bearing inner ring.
6 Catastrophic failure occurs with secondary damage to other components.

Monitoring noise and vibration

A common method used to try to identify deterioration or damage in a bearing is by listening. Bearings that are in good condition produce a soft purring noise. Grinding, squeaking and other irregular sounds usually indicate that the bearings are in poor condition, or that something is wrong.

The need for vibration monitoring comes from three fundamental facts:

- All machines vibrate.
- The onset of a mechanical problem is generally accompanied by an increase in vibration levels.
- The nature of the fault can be determined from the vibration characteristics.

Monitoring temperature

It is important to monitor the operating temperature at bearing positions. If the operating conditions have not been altered, an increase in temperature is often an indication of imminent bearing damage. However, keep in mind that a natural temperature rise lasting one or two days normally occurs immediately after first machine start up and after each relubrication when using grease.

Monitoring lubrication conditions

Bearings can only achieve maximum performance levels with adequate lubrication. The lubrication conditions of a bearing should therefore be monitored closely. The condition of the lubricant itself should also be assessed periodically, preferably by taking samples and having them analyzed.

SKF recommends the following general guidelines for lubrication-related inspection activities:

- Check for lubricant leaks in the areas surrounding the bearing positions.
- Keep protective collars and labyrinth seals filled with grease for maximum protection.
- Check that automatic lubricating systems are functioning properly and providing the appropriate amount of lubricant to the bearings.
- Check the lubricant level in sumps and reservoirs, and replenish as necessary.
- Where manual grease lubrication is employed, relubricate according to schedule.
- Where oil lubrication is used, change oil according to schedule.
- Always make sure that the specified lubricant is used.

Inspection during a machine shutdown

When a machine is not operating, it is an opportunity to assess the condition of bearings, seals, seal counterfaces, housings and lubricant. A general inspection can often be done by removing a housing cover or cap. If a bearing appears to be damaged, it should be dismounted and thoroughly inspected.

Shaft and belt alignment as well as a thorough inspection of the machine foundation and exterior can also be done during a machine shutdown.

Any condition, whether it is a missing shim or a deteriorating foundation, can negatively affect machine performance. The sooner any problem is identified, the sooner corrective action can begin. It is far less costly to replace bearings and associated components during a regularly scheduled shutdown as opposed to unscheduled downtime, which unexpectedly takes the machine out of service.

Inspecting bearings

Bearings are not always easily accessible. However, when bearings are partially exposed, visual checks can be made. The most practical time to inspect bearings is during routine maintenance.

When inspecting a mounted bearing, SKF recommends following these general guidelines:

Preparation

- Clean the external surface of the machine.
- Remove the housing cover, or the housing cap, to expose the bearing.
- Take lubricant samples for analysis. For oil lubrication, take samples from sump/reservoir. For grease lubricated open bearings, take samples from various positions within the bearing. Visually inspect the condition of the lubricant. Often impurities can be detected by spreading a thin layer on a sheet of paper and examining it under a light.
- Clean the exposed external surfaces of the bearing with a lint-free cloth.

Inspection

- Inspect the exposed external surfaces of the bearing for fretting corrosion. Inspect the bearing rings for cracks.
- For sealed bearings, inspect the seals for wear or damage.
- Where possible, rotate the shaft very slowly and feel for uneven resistance in the bearing. An undamaged bearing turns smoothly.

Grease lubricated open bearings in dedicated bearing housings, e.g. split plummer blocks, can be subject to a more detailed in-situ inspection as follows:

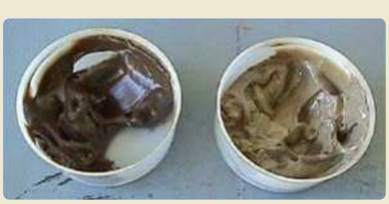
- Remove all grease around the bearing.
- Remove as much grease from the bearing as possible using a non-metallic scraper.

- Clean the bearing with a petroleum based solvent by spraying the solvent into the bearing. Rotate the shaft very slowly while cleaning it and continue to spray until the solvent ceases to collect dirt and grease. For large bearings that contain a build-up of severely oxidized lubricant, clean them with a strong alkaline solution containing up to 10% caustic soda and 1% wetting agent.
- Dry the bearing with a lint-free cloth or clean, moisture-free compressed air (but do not rotate or spin the bearing).
- Inspect the bearing raceways, cage(s) and rolling elements for spalls, marks, scratches, streaks, discolouration and mirror-like areas. Where applicable, measure the radial internal clearance of the bearing (to determine if wear has taken place) and confirm that it is within specification.
- If the condition of the bearing is satisfactory, apply the appropriate grease to the bearing immediately and close the housing. If bearing damage is evident, dismount the bearing and protect it from corrosion. Then, conduct a full analysis.

General recommendations

- Take photographs throughout the inspection process to help document the condition of the bearing, lubricant and machine in general.
- Check the condition of the grease at different places and compare with fresh grease (→ **fig. 2**). Keep a representative sample of the grease for further analysis.
- Certain large and medium-size bearings are suitable for reconditioning. For additional information, refer to the *SKF bearing maintenance handbook* and publication *SKF Remanufacturing Services*.

Fig. 2



Fresh grease: brown colour

Used grease: colour turned greyish

Inspecting seal counterfaces

To be effective, a seal lip must run on a smooth counterface. If the counterface is worn or damaged, the seal lip will cease to function properly.

When inspecting the seal counterface, also check for corrosion. If corrosion is evident but not severe, use a fine wet/dry abrasive paper to remove it.

CAUTION: When working with solvents or alkaline solutions, apply relevant safety rules and equipment.

Troubleshooting

Bearings that are not operating properly usually exhibit identifiable symptoms. The best way to identify these symptoms, and take corrective action at an early stage, is to establish a plantwide condition monitoring programme. In cases where condition monitoring equipment is not available or practical, the following section presents some useful hints to help identify the most common symptoms, their causes, and whenever possible, some practical solutions. Depending on the degree of bearing damage, some symptoms may be misleading and, in many cases, are the result of secondary damage. To effectively troubleshoot bearing problems, it is necessary to analyze the symptoms according to those first observed in the application. This is dealt with in more detail under *ISO failure modes classification*, **page 42**.

Common symptoms of bearing trouble

Symptoms of bearing trouble can usually be reduced to a few common ones that are listed here. Each symptom is broken down into categories of conditions that can lead to those symptoms (→ **table 1**). Each condition has a numerical code that references practical solutions for that specific condition (→ **table 2**, **page 16**).

Troubleshooting information presented in this section should be used as a guideline only.

Table 1

Common symptoms of bearing trouble

A	Excessive heat → **table 1a**
B	Excessive noise levels → **table 1b**
C	Excessive vibration levels → **table 1c**, **page 14**
D	Excessive shaft movement → **table 1d**, **page 14**
E	Excessive frictional moment to rotate the shaft → **table 1e**, **page 15**

Table 1a

Symptom A: Excessive heat

Possible cause	Solution code
Lubrication problem	
• Insufficient lubricant – too little grease, or too low oil level	1
• Excessive lubricant – too much grease without the ability to purge or oil level too high	2
• Wrong type of lubricant – wrong consistency, wrong viscosity, wrong additives	3
• Wrong lubrication system	4
Sealing conditions	
• Housing seals too tight, or other components foul the seals	5
• Multiple seals in a bearing (housing) arrangement	6
• Misalignment of the external (housing) seals	7
• Operating speed too high for the contact seals in a bearing	8
• Seals not properly lubricated	9
• Seals oriented in the wrong direction	10
Insufficient clearance in operation	
• Wrong choice of initial bearing internal clearance	11
• Shaft material expanding more than bearing steel (e.g. stainless steel)	12
• Large temperature difference between the shaft and housing (housing much cooler than the shaft)	13
• Excessive drive-up on a tapered seat	14
• Excessive out-of-round condition of the shaft or housing – bearing pinched in an oval housing	15
• Excessive shaft interference fit or oversized shaft seat diameter	16
• Excessive housing interference fit or undersized housing seat diameter	17
Improper bearing loading	
• Too heavily loaded bearings as a result of changing application parameters	18
• Offset misalignment of two units	19
• Angular misalignment of two units	20
• Bearing installed backwards	21
• Out-of-balance condition	22
• Wrong bearing located	23
• Excessive thrust loads induced	24
• Insufficient load	25
• Excessive preload	26

Table 1b

Symptom B: Excessive noise levels

Possible cause	Solution code
Metal-to-metal contact	
• Insufficient lubricant	1
• Oil film too thin for the operating conditions	3
• Rolling elements sliding (skidding)	25
Contamination	
• Dents in raceways and/or rolling elements due to ingress and over-rolling of solid contaminants	27
• Solid particles left in the housing from manufacturing or previous bearing failures	28
• Liquid contaminants reducing the lubricant viscosity	29
Too loose fits	
• Inner ring creeping (turning) on the shaft	30
• Outer ring creeping (turning) in the housing	31
• Bearing lock nut loose on the shaft or on the bearing sleeve	32
• Bearing not clamped securely against mating components	33
• Excessive radial/axial internal clearance in the bearing	34
Surface damage	
• Abrasive wear from ineffective lubrication	1, 2, 3, 4
• Smearing damage due to sliding rolling elements	25
• Dents in raceways and/or rolling elements due to over-rolling of solid contaminants	27
• Dents in raceways and/or rolling elements from impact or shock loading	35
• False brinelling marks on raceways and/or rolling elements due to static vibration	36
• Spalls in raceways and/or rolling elements due to material fatigue	37
• Spalls in raceways and/or rolling elements due to surface initiated damage	38
• Static etching on raceways and/or rolling elements due to chemical/liquid contaminants	39
• (Micro) Spalls on raceways and/or rolling elements due to moisture or damaging electric current	40
• Fluting in raceways and/or rolling elements due to passage of damaging electric current	41
Rubbing	
• Housing seals installed incorrectly	7
• Adapter or withdrawal sleeve not properly mounted	32
• Spacer rings not properly clamped	33
• Lock washer tabs bent	42

Table 1c

Symptom C: Excessive vibration levels

Possible cause	Solution code
Metal-to-metal contact	
• Rolling elements sliding (skidding)	**25**
Contamination	
• Dented raceways and/or rolling elements due to ingress and over-rolling of solid contaminants	**27**
• Solid particles left in the housing from manufacturing or previous bearing failures	**28**
Too loose fits	
• Inner ring creeping (turning) on the shaft	**30**
• Outer ring creeping (turning) in the housing	**31**
Surface damage	
• Wear from ineffective lubrication	**1, 2, 3, 4**
• Smearing damage due to sliding rolling elements	**25**
• Dents in raceways and/or rolling elements due to over-rolling of solid contaminants	**27**
• Dents in raceways and/or rolling elements from impact or shock loading	**35**
• False brinelling marks on raceways and/or rolling elements due to static vibration	**36**
• Spalls in raceways and/or rolling elements due to material fatigue	**37**
• Spalls in raceways and/or rolling elements due to surface initiated damage	**38**
• Static etching on raceways and/or rolling elements due to chemical/liquid contaminants	**39**
• (Micro) Spalls on raceways and/or rolling elements due to moisture or damaging electric current	**40**
• Fluting in raceways and/or rolling elements due to passage of damaging electric current	**41**

Table 1d

Symptom D: Excessive shaft movement

Possible cause	Solution code
Looseness	
• Inner ring loose on the shaft	**30**
• Outer ring excessively loose in the housing	**31**
• Bearing not properly clamped on the shaft or in the housing	**32**
Surface damage	
• Wear from ineffective lubrication	**1, 2, 3, 4**
• Spalls in raceways and/or rolling elements due to fatigue	**37**
• Spalls in raceways and/or rolling elements due to surface initiated damage	**38**
Incorrect internal bearing clearance	
• Bearing with wrong clearance installed	**11**
• Bearing not properly clamped on the shaft or in the housing, excessive endplay	**33**

Table 1e

Symptom E: Excessive frictional moment to rotate the shaft	
Possible cause	**Solution code**
Preloaded bearing	
• Wrong clearance selected for the replacement bearing	11
• Shaft material expanding more than bearing steel (e.g. stainless steel)	12
• Large temperature difference between the shaft and housing	13
• Excessive drive-up on a tapered seat	14
• Excessive out-of-round condition of the shaft or housing – pinched bearing	15
• Excessive shaft and/or housing interference fits	16, 17
• Excessive preload – incorrect assembly (preload)	26
Sealing drag	
• Housing seals too tight, or other components foul the seals	5
• Multiple seals in a bearing (housing) arrangement	6
• Misalignment of external (housing) seals	7
• Seals not properly lubricated	9
Surface damage	
• Spalls in raceways and/or rolling elements due to fatigue	37
• Spalls in raceways and/or rolling elements due to surface initiated damage	38
• Fluting in raceways and/or rolling elements due to passage of damaging electric current	41
Design	
• Shaft and/or housing shoulders out-of-square with the bearing seat	43
• Shaft shoulder is too large, fouling the seals/shields	44

Trouble conditions and their solutions

Practical solutions to common symptoms of bearing trouble are provided in **table 2**, **page 16**.

WARNING!
To reduce the risk of serious injuries, perform the required lockout/tag out procedures prior to starting any work.

CAUTION: Direct contact with petroleum products may cause allergic reactions! Read the material safety data sheets and any instructions and warnings before handling lubricants. Use protective gloves at all times.

Table 2

Trouble conditions and their solutions

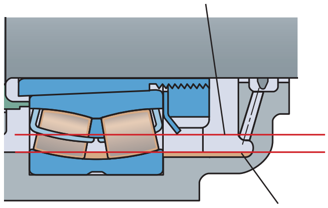
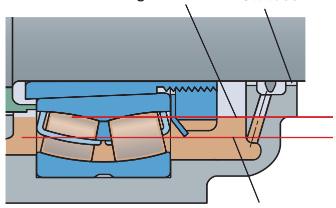
Solution code	Condition / Practical solution
1 	**Insufficient lubricant** Grease lubrication Considerations during first-fill or start-up: • The grease should fill 100% of the bearing and up to the bottom of the shaft in the housing (1/3 to 1/2). • If the housing cavity alongside the bearing is small, the grease quantity may need to be reduced slightly to avoid overheating from churning. Actions during operation: • Check the seals for wear, damage and leaks. Actions during relubrication: • Make sure the relubrication interval is correct (not too long). • Make sure fresh grease gets into the bearing. Oil bath lubrication Consideration during first fill, refill or standstill: • The oil bath level should be at the middle of the lowest rolling element during standstill. Actions during operation: • Make sure the housing is vented properly to avoid back pressure, which can cause automatic lubricators to malfunction. • Check the seals for wear, damage and leaks. • Check the housing split for leaks and apply a thin layer of gasket cement if necessary.
2 	**Excessive lubricant** Too much lubricant can cause excessive churning and elevated temperatures. Grease lubrication Considerations during first fill or start-up: • The grease should fill 100% of the bearing and up to the bottom of the shaft in the housing (1/3 to 1/2). • If the housing cavity alongside the bearing is small, the grease quantity may need to be reduced slightly to avoid overheating from churning. Actions during operation: • Check if grease purging is possible, either through the seals or a drain plug. A grease escape valve might avoid applying excessive grease. • Check the seals for proper orientation, which will enable excess lubricant to purge while keeping contaminants out. • Make sure the relubrication interval is not too short. • Make sure to apply the right quantity when relubricating. Oil bath lubrication Actions: • Make sure the oil bath level is set to the middle of the lowest rolling element during standstill. • Inspect oil return holes for blockages. • Installing a sight glass on all housings is a quick, easy way to check whether the oil level in the housings is correct.

Table 2 cont.

Trouble conditions and their solutions

Solution code | **Condition / Practical solution**

3

The wrong lubricant

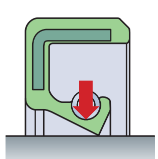
Actions:
- Review the application to determine the correct base oil viscosity (grease, oil) and consistency (grease) required for the specific operating conditions.
- Metal-to-metal contact can lead to excessive heat and premature wear, ultimately leading to higher noise levels.
- Check the miscibility if the grease or oil has been changed from one type to another.
- Check the grease consistency.
- Check the operating viscosity.

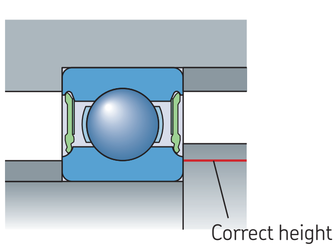
4

The wrong lubrication system

Actions:
- Review the operational speed and measure the operating temperature.
- Determine whether a suitable lubrication system is used.
- Switching from grease to oil can be a simple solution.
- Switching from oil bath lubrication to circulating oil can be a solution.
- Adding an auxiliary cooler to an existing oil lubrication system can also avoid many heat related problems.
- Consult with SKF or the equipment manufacturer for specific requirements.
- Reference the speed rating values provided in the manufacturer's product guide. SKF values for reference and limiting speeds are available online at www.skf.com/bearings.

5





Housing seals are too tight

Actions:
- Replace the seal with one that has the right tension. Alternatively, machine the shaft to obtain the correct tension for the present spring-type seal.
- Make sure the seals are lubricated properly.
- Check seal lips for wear.
- Felt seals should be soaked in hot oil prior to installation.

Other components foul the bearing seals

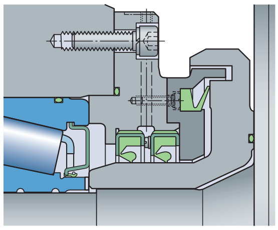
Action:
- Check components adjacent to the seals:
  - abutment heights (→ www.skf.com/bearings)
  - possibility to accommodate axial displacement if shaft elongation occurs

Table 2 cont.

Trouble conditions and their solutions

Solution code	Condition / Practical solution

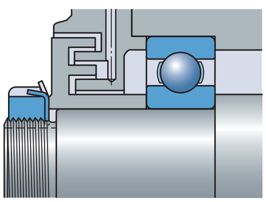
6



Multiple seals in a bearing (housing) arrangement

Considerations:
- If multiple contact seals are used to help keep contaminants out, friction and heat will increase.
- Before adding additional seals to an application, consider the thermal effects on the bearing and lubricant.
- In addition, consider the extra power required to rotate the equipment.

7

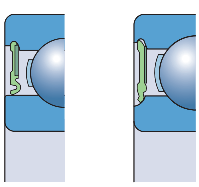


Misalignment of external (housing) seals

Considerations during assembly:
- Any misalignment of the shaft relative to the housing or the housing seal can cause a non-contact or gap type seal to rub. This condition can elevate temperatures, increase noise levels and accelerate wear during the initial running-in period. It also compromises sealing integrity.

Actions:
- Check the alignment and correct accordingly.
- If misalignment cannot be avoided, there might be a need to increase the clearance or gaps between the external seals.

8

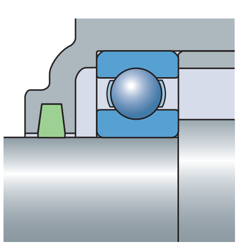


Contact seals

Operating speed too high for contact seals in the bearing

Considerations:
- Seal lips have a limiting speed. If operating speeds exceed these limits, seal lip damage and grease leakage will result.
- If the operating speed has been increased or if a bearing with a different seal is used, check that the bearing seal can accommodate the speed.
- Contact seals will generate more heat than low-friction seals, shields or open bearings.

9



Seals not properly lubricated

Considerations:
- Dry running contact seals can add significant amounts of heat to the system.

Action during assembly:
- Make sure that seals are properly lubricated at start-up of new or rebuilt equipment.
  (Felt seals should be soaked in hot oil, prior to installation.)

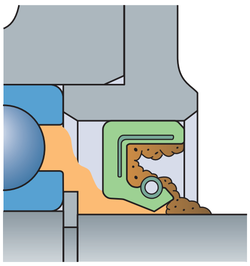
Actions during operation:
- Normally the lubricant in the housing will get thrown outward towards the seals and automatically lubricate them.
- Properly lubricated seals will run cooler and will create an effective seal since any gaps between the contacts will be filled with a lubricant barrier.
- Proper lubrication will also reduce premature seal wear.
- Check seals for wear or damage.

Table 2 cont.

Trouble conditions and their solutions

Solution code | **Condition / Practical solution**

10



Seals oriented in the wrong direction and not allowing grease purge

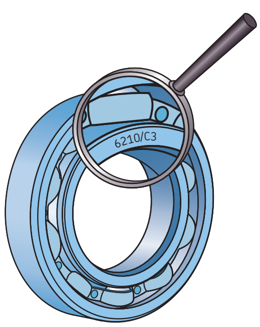
Consideration during assembly:
- Depending on the application, contact seals may need to be oriented in a specific direction to either allow the lubricant to purge or to prevent oil leakage.

Action:
- Check the application drawings or contact the equipment manufacturer to determine the proper orientation of the seals for the equipment.

Consideration during operation:
- Seal lips that face outward will usually allow purging of excess lubricant and prevent the ingress of contaminants.

Action:
- Seals must be oriented correctly to keep grease in and contaminants out of the bearing.

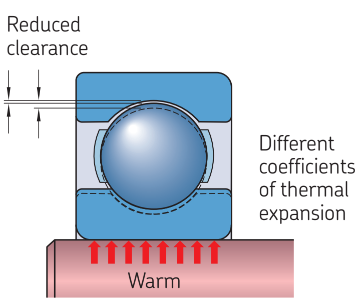
11



Wrong choice of initial bearing internal clearance

Action:
- Check the package to make sure that the internal clearance of the new bearing is in accordance with the original design specification.
- If a bearing is overheating after it has been replaced, and if larger clearance is required for the application, contact the SKF application engineering service for the effects of additional clearance on the equipment, as well as the bearing.
- Check all dimensions, as component wear can influence bearing clearance.

12



Shaft (and housing) material expands more than bearing steel

Considerations during redesign or remanufacturing:
- In some cases, shaft and housing materials might be changed, e.g. stainless steel shaft to comply with food regulations or an aluminium housing to reduce equipment weight.
- When the shaft material has a higher coefficient of thermal expansion than bearing steel, the radial internal clearance is further reduced. Therefore, for certain stainless steel shaft materials (300 series), either a slightly looser shaft fit is required or a bearing with increased radial internal clearance is required, e.g. CN to C3, C3 to C4, etc.
- If a housing made from a material with a higher coefficient of thermal expansion than bearing steel, e.g. aluminium, is used, a slightly tighter fit may be required to prevent the outer ring from turning in the housing seat.

Action:
- In both cases, it might be necessary to calculate the effect of the new shaft or housing material on internal bearing clearance and replace the bearing.

Table 2 cont.

Trouble conditions and their solutions

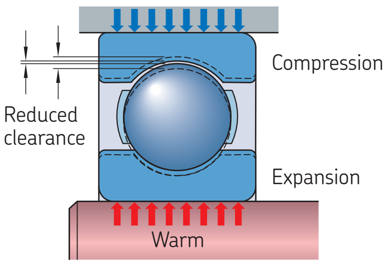
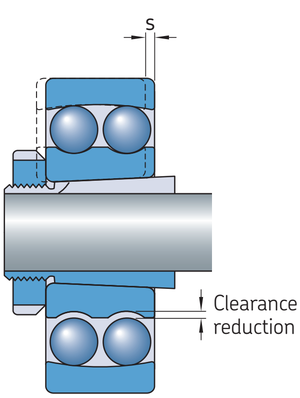
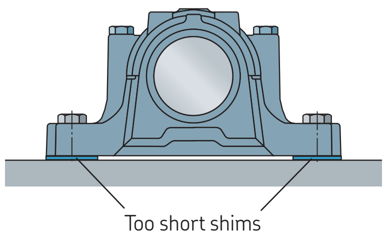
Solution code	Condition / Practical solution
13 	**Large temperature difference between the shaft and housing** Considerations during design: • Due to their design, bearing arrangements often have an inner ring temperature that is higher than the outer ring temperature. For example, the shaft in an electric motor is relatively warm, causing the inner ring to expand. The motor covers that contain the bearing outer rings have a rather large surface area that promotes heat dissipation, making the temperature difference quite substantial. Considerations during operation: • A large temperature difference between the shaft and housing reduces bearing internal clearance, which can result in too little clearance or even preload, causing high operating temperatures. Actions: • Check the shaft and housing temperatures closest to the bearing. • If justified, select a bearing with increased internal clearance to prevent preloading, e.g. CN to C3, C3 to C4, etc.
14 	**Excessive drive-up on a tapered seat** Considerations during mounting: • Mounting a bearing with a tapered bore on a tapered seat (shaft or sleeve) reduces the radial internal clearance within the bearing. Considerations during operation: • Too much drive-up “s” may result in too little internal clearance or even preload. This causes higher operating temperatures. • Excessive drive-up “s” may result in too high hoop stresses in the bearing, resulting in inner ring cracking. Actions: • Self-aligning ball bearings: After mounting on the shaft, check whether the outer ring can be swivelled easily. If not, dismount the bearing, and start the mounting procedure from the beginning. • Spherical roller and CARB toroidal roller bearings: Compare the resulting clearance after mounting with the initial bearing clearance (→ SKF catalogue *Rolling bearings* or *SKF bearing maintenance handbook*) for maximum values for clearance reduction. If there is insufficient clearance, dismount the bearing and start the mounting procedure from the beginning. • When mounting, use the SKF Drive-up Method or tightening angle method for self-aligning ball bearings, the SKF Drive-up Method or clearance reduction method for spherical roller and CARB toroidal roller bearings. The well-proven SKF Drive-up Method is an easy way to achieve the correct operating clearance without using feeler gauges. Use SensorMount for very large bearings.

Table 2 cont.

Trouble conditions and their solutions

Solution code | **Condition / Practical solution**

15



Bearing seat is out-of-round

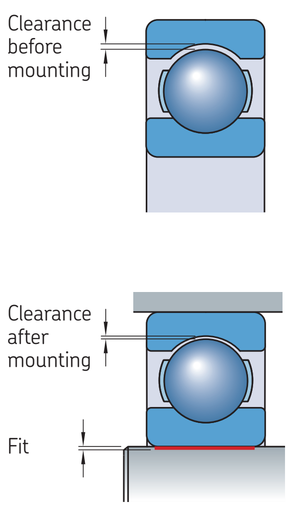
Considerations during operation:

- A bearing outer ring in an out-of-round or distorted housing (oval clamping/pinching) leads to reduced clearance or preload and an increase in operating temperature.
- This is often characterized by two load zones in the outer ring that are 180° apart.
- Oval clamping (pinching) can also restrict axial movement of the non-locating bearing and induce heavy axial loads.

Actions:

- Check that the support surface is flat to avoid soft foot. Any shims should cover the entire area of the housing base.
- Make sure the housing support surface is rigid enough to avoid flexing.
- Check the shaft and housing seats for roundness (ovality). Repair if necessary.

16



Excessive shaft interference fit or oversized shaft seat diameter

Considerations during design:

- An interference fit between the bearing inner ring and shaft seat is often required, but will expand the inner ring and reduce the bearing internal clearance.
- If the fit is too tight, it may result in too little operating clearance in the bearing, or even preload. This will lead to a hot running bearing.

Actions:

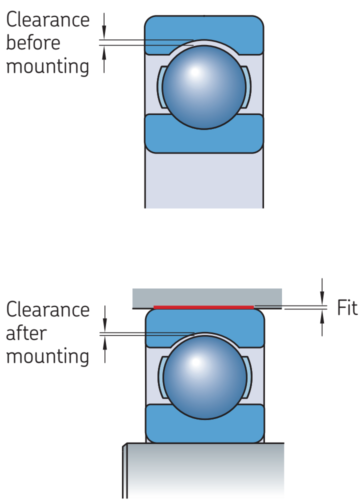
- Check that the installed bearing has the correct internal clearance.
- If the shaft is new or refurbished, carefully check the bearing seat dimensions for both dimensional and form accuracy.
- Prior to taking any corrective action, check the dimensions of the housing bore.
- If all dimensions are to specification, a bearing with a larger internal clearance might be required.
- Note that an interference fit on the shaft and in the housing will probably result in too little operating clearance.

Table 2 cont.

Trouble conditions and their solutions

Solution code | **Condition / Practical solution**

17



Excessive housing interference fit or undersized housing seat diameter

Considerations during design:
- An interference fit between the bearing outer ring and housing seat may be required, but will compress the outer ring and reduce the bearing internal clearance.
- If the fit is too tight, it may result in too little operating clearance in the bearing or even preload. This will lead to a hot running bearing.

Actions:
- Check that the installed bearing has the correct internal clearance.
- If the housing is new or refurbished, carefully check the bearing seat dimensions for both dimensional and form accuracy. Regrind the housing seat to the appropriate fit. If this is not possible, use a bearing with a larger internal clearance.
- Note that an interference fit on the shaft and in the housing will probably result in too little operating clearance .
- Note that for a rotating inner ring load, an interference fit in the housing will cause the “floating” bearing to become fixed, inducing an axial load and excessive heat.

18

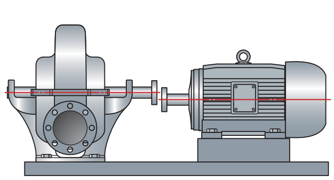
Too heavily loaded bearings as a result of changing application parameters

Considerations during redesign or remanufacturing:
- Increasing the external loads on a bearing will generate more heat within the bearing.
- Heavier loads will reduce bearing service life.
- Therefore, if a design change is made, review the loads to make sure they have not increased.

Examples:
- Going from a coupling to a belt drive.
- Going from a coupling to a sheave.
- Increasing the speed of a piece of equipment.

Action:
- Changes in the performance of a piece of equipment should be reviewed with the original equipment manufacturer.

19



Offset misalignment of two units

Considerations during assembly:
- The two housings are not in a straight line (vertically or horizontally).
- This induces additional loads on the bearings and seals, which increases friction and temperature and reduces service life of the bearings, seals and lubricant.

Action:
- Align the housings using the appropriate equipment using shims to realign vertically.

Table 2 cont.

Trouble conditions and their solutions

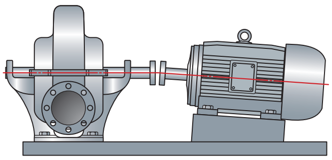
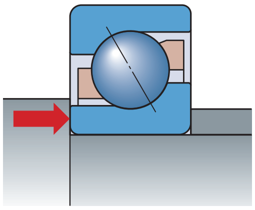
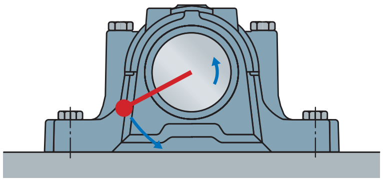
Solution code		Condition / Practical solution
20		**Angular misalignment of two units** Considerations during assembly: • The two support surfaces are not aligned; one is angled relative to the other. • This induces additional loads on the bearings and seals, which increases friction and temperature and reduces service life of the bearings, seals and lubricant. Action: • Align the housings using the appropriate equipment and shims.
21		**Bearing installed backwards causing unloading of angular contact ball bearings** Considerations during assembly: • Directional bearings must be installed in the right direction to function properly. • For example: Single row angular contact ball bearings can only accommodate axial loads in one direction. If installed backwards, the axial load will be taken on the low shoulder of the inner ring, which damages the bearing, increases heat generated by the bearing and leads to premature bearing failure. Action: • During mounting/assembly, make sure the axial load is accommodated by the "high" shoulder.
22		**Out-of-balance condition** Considerations during operation: • An unbalanced load can generate a rotating outer ring load that will significantly increase the heat generated by the bearing while increasing the load on the bearing. Actions: • Inspect the rotor for a build-up of dirt/contaminants. • Rebalance the equipment. • Note that too large a housing seat will also cause vibration and outer ring creep (turning).

Table 2 cont.

Trouble conditions and their solutions

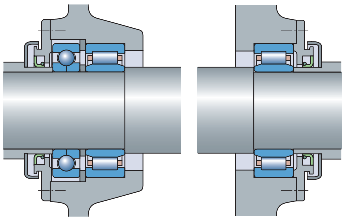
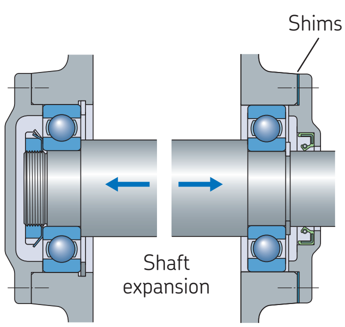
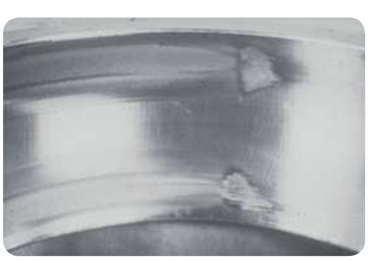
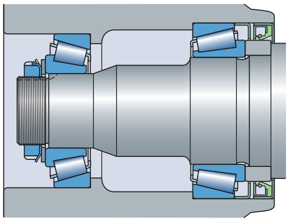
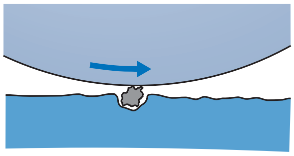
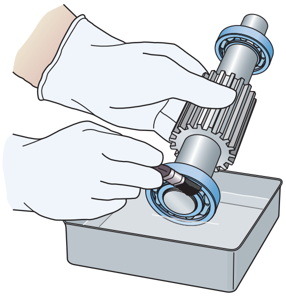
Solution code	Condition / Practical solution
23 	**The wrong bearing is (radially) located** Considerations during design or assembly: • In some applications, the bearing arrangement for the locating position consists of a radial bearing and a thrust bearing. • If the radial bearing is fixed axially, it will be subjected to axial loads, resulting in too heavy combined loads. This can lead to excessive temperatures and possibly premature bearing failure. • If the axial bearing is fixed radially, it will be subjected to radial loads, resulting in heavy or too heavy combined loads. This can lead to excessive temperatures and possibly premature bearing failure. Action: • Make sure that the radial bearing is axially relieved, and the thrust bearing radially relieved. To prevent the outer ring of the thrust bearing from turning, a stop should be provided, e.g. a four-point contact ball bearing generally has locating slots in the outer ring.
24 	**Bearings are cross-located and the shaft can no longer expand** Considerations during design or assembly: • When bearings are cross-located and shaft expansion is too restricted, internal axial loads will be induced in both bearings. • The induced loads can cause excessive operating temperatures and an increased frictional moment. • The induced loads can be heavy and lead to premature fatigue spalling. Actions: • Insert shims between the housing and cover to obtain adequate clearance between the cover and the outer ring side face to avoid axial preloading of the bearings. • Determining the expected shaft thermal elongation should help establish how much clearance is required between the bearing outer ring side face and the housing cover.
25 	**Smearing caused when insufficiently loaded rolling elements slide (skid)** Considerations during design: • In order to provide satisfactory operation and avoid smearing, all ball and roller bearings must always be subjected to a given minimum load (→ www.skf.com/bearings). • If the minimum load requirements are not met, sliding (skidding) can occur. This generates excessive heat and noise. Extremely stiff greases can contribute to this condition, especially in very cold environments. Actions: • Additional external loads can be applied, e.g. external spring devices applied to outer ring side faces. • Alternatively, a bearing with different internal clearance or a different bearing type might be required. • Downsizing the bearing might also be a solution.

Table 2 cont.

Trouble conditions and their solutions

Solution code	Condition / Practical solution
26 	**Bearing adjustment results in excessive preload** Considerations during mounting or assembly: • When adjusting the axial clearance or preload in a bearing arrangement, over-tightening the adjustment device (lock nut) can result in excessive preload and excessive operating temperatures. • Excessive preload will also increase the frictional moment in the bearings. Example: tapered roller bearings or angular contact ball bearings with one bearing on each end of the shaft. Actions: • Check with the equipment manufacturer for the proper mounting procedures to set the endplay (axial clearance) or preload in the equipment. • Use a dial indicator to measure the axial shaft movement (during and) after adjustment.
27 	**Solid contaminants enter the bearing and dent the rolling surfaces** Consideration during operation: • Contaminants can damage the bearing contact surfaces, increasing noise and vibration levels. In some cases, temperatures may also increase. Actions: • Check the sealing arrangement to confirm the following: – The correct seal was used. – The seal was installed correctly. – There is no seal wear, seal damage or lubricant leakage. • The relubrication interval may need to be shortened. Supplying smaller quantities of fresh grease more frequently can help purge contaminated grease from the bearing/housing cavity. • Consider replacing open bearings with sealed bearings.
28 	**Solids from manufacturing or previous bearing failures in the housing** Considerations during cleaning or assembly and about lubricant cleanliness: • Denting of the bearing contact surfaces can occur when solid contaminants are left in the bearing housing from a previous failure, from wear of other components such as gears, or from contaminated lubricant. • This can increase temperature, noise and vibration levels. Actions: • Remove any burrs and make sure that all machined surfaces are smooth. • Thoroughly clean the housing and all components within the housing before fitting a new bearing. • Make sure the applied lubricant is clean and does not contain any contaminants. (Grease containers should be closed and stored properly.)

2

Table 2 cont.

Trouble conditions and their solutions

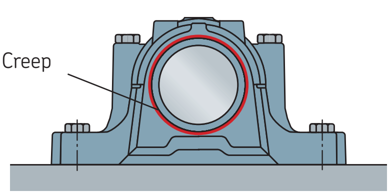
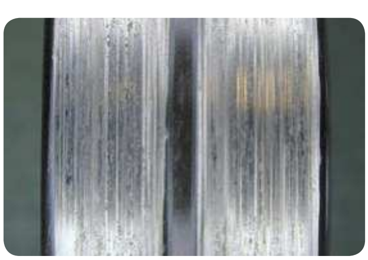
Solution code		Condition / Practical solution
29		**Liquid contaminants reduce the lubricant viscosity** Considerations during assembly or lubrication and about sealing: • Liquid contaminants will reduce the lubricant viscosity, which can lead to metal-to-metal contact. • In addition, it can cause rust to form on the bearing contact surfaces. • These conditions lead to increased temperature, wear, and noise levels. Actions: • Check the housing seals to make sure they can adequately prevent the ingress of liquid contaminants. Alternatively, consider using sealed bearings. • The relubrication interval may need to be shortened. Supplying smaller quantities of fresh grease more frequently can help purge contaminated grease from the bearing/housing cavity.
30		**Inner ring creeps (turns) on the shaft seat** Considerations about fits or creep: • Most applications have a rotating shaft where the load is unidirectional. This is considered a rotating inner ring load and requires a tight fit on the shaft to prevent relative movement. Proper performance of bearings is highly dependent on correct fits. • However, an inner ring can creep or turn on its shaft seat if the seat is undersized or worn. • This leads to increased noise and vibration levels as well as wear. Action: • Metalize and regrind the shaft seat to the appropriate size.
31	 	**Outer ring creeps (turns) in the housing seat** Worn or oversized seat Considerations about fits or creep: • Most applications have a stationary housing where the load is unidirectional. This is considered a stationary outer ring load and, under most conditions, the outer ring can be held in place with a loose fit. • However, an outer ring can creep or turn in its housing seat if the seat is oversized or worn. • This leads to increased noise and vibration levels as well as wear. Actions: • Metalize and regrind the housing seat to the appropriate size. • For large housings, machining the seat to a larger diameter and using a cartridge sleeve might be a solution. Unbalanced load Considerations about fits or creep: • Loads resulting from an unbalanced shaft can cause outer ring creep, even if the fits are correct. Actions: • Eliminate the source of the unbalance. • Rebalance the machine.

Table 2 cont.

Trouble conditions and their solutions

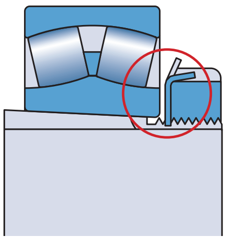
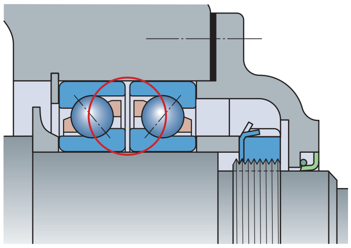
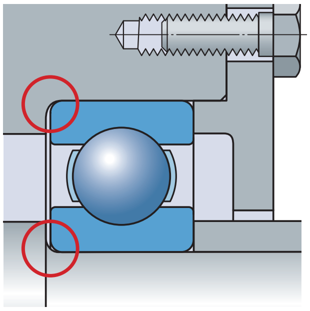
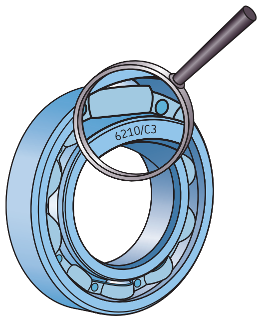
Solution code	Condition / Practical solution
32 	**The bearing lock nut is loose on the shaft or adapter sleeve** Considerations during mounting or assembly: • A loose lock nut can cause the bearing to come loose on its seat. • This can cause the inner ring to creep (turn) on its shaft seat. • This condition can increase noise levels and heat generated by the bearing, but also leads to poor positioning of the bearing. Actions: • Tighten the lock nut to obtain the appropriate position of the inner ring (bearing internal clearance). • Make sure the lock nut is properly locked, with a lock washer tab, for example, when mounting is completed.
33 	**The bearing is not clamped securely against mating components** Considerations during mounting or assembly: • A bearing that is not properly clamped against an adjacent component might not attain the necessary internal clearance or preload. • This condition can increase noise levels and have a negative impact on bearing performance. Examples: • A pair of matchable angular contact ball bearings that are not properly clamped. • This can increase axial clearance in the bearing pair, which can lead to ball sliding damage (smearing), increased noise levels, and lubrication problems. • Not properly clamping the bearing will also affect positioning of the shaft. Action: • Make sure that the locking device positions both bearings against their shaft shoulder or spacer.
	**Fillet (corner radius) too large** Considerations during mounting or assembly: • If the fillet of an adjacent component is too large, the bearing will not be supported properly. • This condition can distort the bearing rings. • The bearing will not achieve the proper internal clearance (preload). Action: • Machine the fillet to obtain the proper support.

Table 2 cont.

Trouble conditions and their solutions

Solution code | **Condition / Practical solution**

34

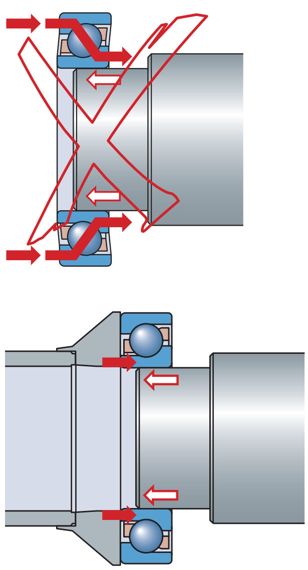


Too large radial or axial internal clearance in a bearing

Considerations during operation:
- Excessive radial or axial internal clearance can increase noise levels because the rolling elements are able to move freely outside the load zone.
- In addition, too much clearance can also have a detrimental effect on bearing performance because of sliding of the rolling elements.

Actions:
- The use of springs or wave washers can provide an adequate axial load to keep the rolling elements loaded at all times (mainly in applications with ball bearings).
- Review the needed initial clearance in the bearing; adjust the clearance selection where appropriate.

35



Rolling surfaces are dented from impact or shock loads (incorrect mounting method)

Considerations during design:
- Most bearings are mounted with an interference fit either on the shaft or in the housing.

Considerations during mounting:
- When mounting the bearing ring with an interference fit, always apply force to the ring that is being mounted. Never allow the mounting force to be transmitted through the rolling elements as this can easily dent the raceways and rolling elements.
- The resulting damage can increase noise and vibration levels and temperature.
- The bearing will probably fail prematurely.

Actions:
- Replace the bearing.
- Never hammer any part of a bearing directly when mounting. Always use a mounting sleeve.
- Review the mounting procedures making sure that no mounting forces are applied through the rolling elements.
- Use a bearing fitting tool. (The SKF Bearing fitting tool kit is an excellent tool for smaller bearings.)

36

Rolling surfaces are false-brinelled due to vibration

Considerations during operation:
- Vibrations from other machines while a piece of equipment is not rotating can lead to false brinelling on the raceways. This damage typically occurs in the loaded zone, and is characterized by depressions in the raceway(s) that match the distance between the rolling elements.
- This common problem leads to noise in standby equipment that is not operational for extended periods.

Actions:
- Periodically rotate the shaft of standby equipment to help minimize the effects of the vibration.
- Isolating the equipment from the vibration would be the real solution but isn't always practical.

Table 2 cont.

Trouble conditions and their solutions

Solution code	Condition / Practical solution
37 	**Rolling surfaces are spalled due to material fatigue** Considerations during operation: • Pure material fatigue in a high quality rolling bearing is becoming rare. • Fatigue spalling, where it does occur, is usually the result of an abnormal operating condition that leads to higher stress in the bearing, such as misalignment, oval clamping (pinching) or the result of material defects such as inclusions or poor quality steel. Actions: • Only use high quality bearings. • Check damaged bearings for misalignment. Realign where necessary. • Check damaged bearings for possible oval clamping (pinching). Repair and machine seats where necessary.
38 	**Rolling surfaces are spalled due to surface initiated fatigue** Considerations during operation: • Inadequate lubrication leads to metal-to-metal contact between the rolling surfaces. • Causes include but are not limited to: viscosity too low at operating temperature, wear particles and the ingress of contaminants. Actions: • Review operating viscosity of the lubricant, taking real operating conditions into consideration. • To discharge wear particles, consider more frequent relubrication. • Check the condition of the sealing arrangement.
	**Rolling surfaces are spalled, initiated from surface damage** Considerations during mounting or operation: • Surface initiated damage includes conditions such as brinelling from impact, false brinelling from vibration, water etching, particle denting, passage of electric current, etc. Actions: • Identify the source of the damage and take appropriate action, e.g. eliminate impact through the rolling elements during mounting, replace seals to prevent ingress of contaminants, ground equipment properly, etc.

Table 2 cont.

Trouble conditions and their solutions

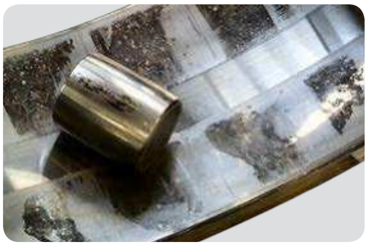
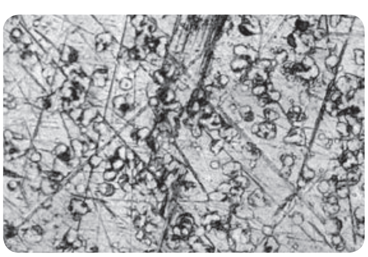
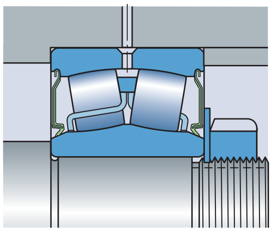
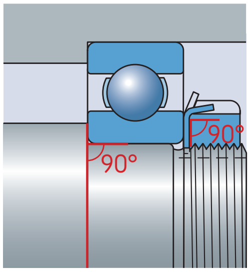
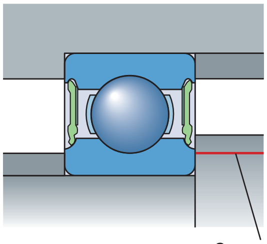
Solution code		Condition / Practical solution
39		**Etching of rolling surfaces from chemical/liquid contaminants (water, acids, gasses, or other corrosives)** During standstill: • Etching (corrosion) occurs when the equipment is idle and is most common in grease lubricated bearings. • Damage from static etching usually occurs at rolling element distance. Actions: • Check the sealing system. • Upgrade the sealing arrangement by installing a protective shield and/or flinger. • Supplying smaller quantities of fresh grease more frequently can help purge contaminated grease from the bearing/housing cavity. • Periodically rotate the shaft to minimize the damaging effects of static etching.
40		**Raceways and/or rolling elements have (micro) spalls** During operation: • Microspalls of the rolling surfaces, sometimes called pitting, is the result of either corrosive contaminants or current leakage (electrical erosion). • Whatever the cause, increased noise and vibration levels will result. Actions: • → Solution codes **39** and **41**.
41		**Raceways and/or rolling elements have craters or fluting** During operation: • Current leakage (electrical erosion) – current passing through the bearing – might result in craters at the surface. As they are very small, they can hardly be seen without magnification. The SKF Electrical discharge detector pen is a non-contact instrument that can help to establish the presence of electrical discharge currents. Actions: • Magnify area from 500 × to 1 000 × to confirm the presence of craters.
		**Fluting of rolling surfaces** During operation: • Fluting of the raceways is secondary damage most commonly attributed to the passage of damaging electric current across the bearing. • In some rare cases, a washboard appearance can be the result of vibration during operation. • Current through the bearing can originate from grounding problems, frequency inverters, cabling, motor design and driven machinery. Actions: • Check that the equipment is grounded properly. • If proper grounding does not correct the problem, alternative solutions include INSOCOAT bearings (with an insulation coating), hybrid bearings (with ceramic rolling elements) or using an insulating sleeve in the housing bore.

Table 2 cont.

Trouble conditions and their solutions

Solution code	Condition / Practical solution
42 	**Lock washer tabs are bent, fouling the cage or bearing seals** Considerations during mounting or assembly: • Some lock washers have bent tabs that can foul the bearing cage or seals, generate noise and accelerate wear and damage. • Used lock washers can also have a damaged locking tab or anti-rotation tab that isn't apparent and may shear off later. Actions: • Never reuse lock washers. • Use a KMFE lock nut, which has a built-in spacer to avoid this kind of damage; alternatively, an intermediate ring can be positioned between the bearing and the lock nut.
43 	**Shaft and/or housing shoulders are out-of-square with the bearing seat** Considerations about machined shoulders during mounting or assembly: • Out-of-square shaft/housing shoulders can distort the bearing rings, which will increase the frictional moment in the bearing and generate heat. • → Solution codes **19** and **20**. Action: • Machine parts to achieve correct perpendicularity.
44 	**Shaft shoulder is too high and is fouling the seals/shields** Considerations about machined shoulders during assembly or operation: • If the shoulder is too high, it can foul the seals/shields. Actions: • Check that the shoulder diameter is in accordance with recommendations, available online at www.skf.com/bearings. • Machine the shaft shoulder to clear the seals/shields.

3 Path patterns

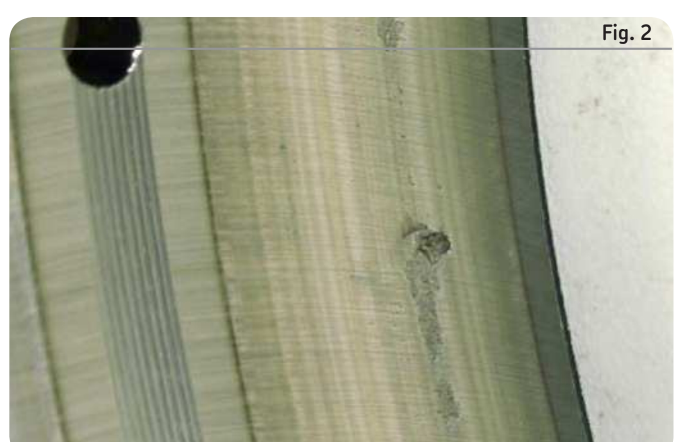
A new bearing looks beautiful, like a piece of art (→ **fig. 1**). Its components have been made to exacting dimensions, often to fractions of a micron. The dimensions of components and the assembled bearing have been checked during the manufacturing process. The areas that have been ground, such as the surfaces of inner and outer rings and rolling elements, look very shiny.

In contrast, when examining a bearing that has run for some time, a number of changes can be observed such as:

- mostly dull areas on the raceways of rings (→ **fig. 2**) and rolling elements; or sometimes also extremely shiny areas
- cage wear
- creep marks on the inner ring bore or outer ring outside surface
- fretting corrosion on the inner ring bore or outer ring outside surface
- spalls on the rolling elements and raceways

Fig. 1

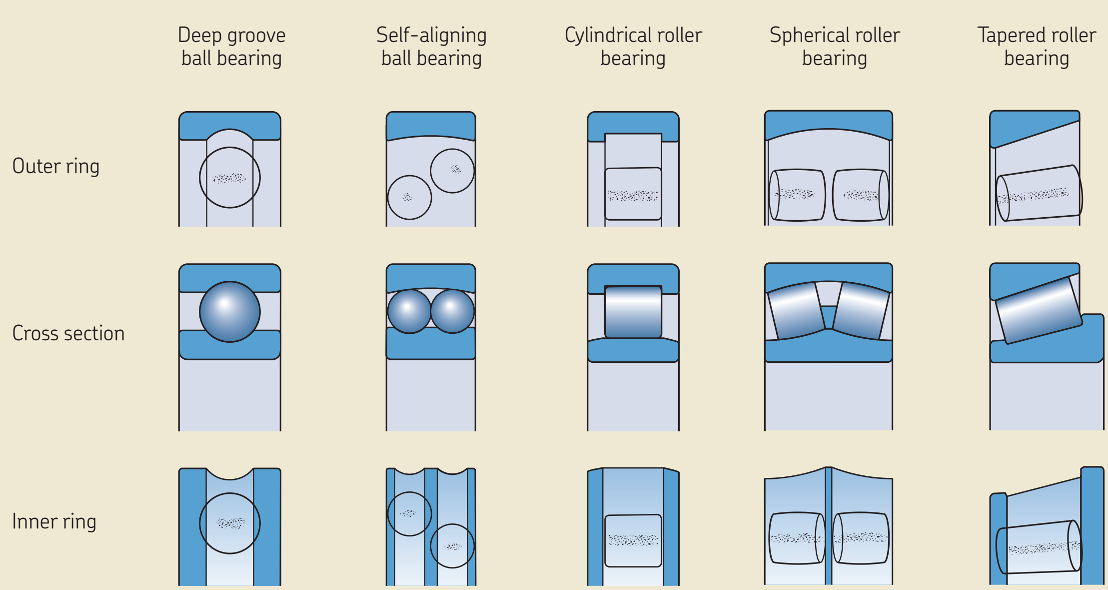
Fig. 2



Whether bearing damage is light or severe, a thorough inspection can provide valuable information about the root cause of the problem. During an inspection, the key is to look for “patterns”, especially path patterns on the raceways. A pattern can be “normal” or it can indicate a problem. The pattern can quite frequently identify the root cause of a problem. A number of typical raceway path patterns are discussed in this chapter.

For simplicity, examples of deep groove ball bearings and thrust ball bearings are shown in this chapter. For other bearing types, the path patterns can vary due to the contact area, which depends on the bearing type, configuration, load, and clearance. Some examples of raceway contact areas are shown in **fig. 3**.

Fig. 3



Normal raceway path patterns

Radial bearings – radial load unidirectional and constant

Fig. 4 shows the load distribution in a radial bearing (inner ring rotation).

The large arrow at the 12 o'clock position represents the applied load on the shaft. The small arrows from 4 o'clock to 8 o'clock represent the load zone in the outer ring and show how the applied load is shared or supported by the rolling elements in the bearing.

Inner ring rotation

Fig. 5 illustrates how an applied unidirectional and constant radial load acting on the rotating inner ring of a bearing is distributed to the stationary outer ring by the rolling elements.

As the inner rotates, every point on the ring enters the load zone. As a result, the entire circumference of the inner ring raceway has a path pattern in its centre that is uniform in width. This is referred to as a rotating inner ring load zone.

The stationary outer ring has a centred path pattern that is limited to the load zone. This is referred to as a stationary outer ring load zone. The load distribution in the outer ring load zone varies. The path pattern is widest in the direction of the load and decreases in either direction from that point. In most applications, bearings operate with radial clearance and the load zone is approximately 150° (→ **fig. 4**).

Outer ring rotation

Fig. 6 illustrates how an applied unidirectional and constant radial load acting on the rotating outer ring of a bearing is distributed to the stationary inner ring by the rolling elements.

As the outer ring rotates, every point on that ring enters the load zone. As a result, the entire circumference of the outer ring raceway has a path pattern in its centre that is uniform in width.

The stationary inner ring has a centred path pattern that is limited to the load zone. The load distribution in the outer ring load zone varies. The path pattern is widest in the direction of the load and decreases in either direction from that point. In most applications, bearings operate with radial clearance and the load zone is approximately 150°.

Fig. 5

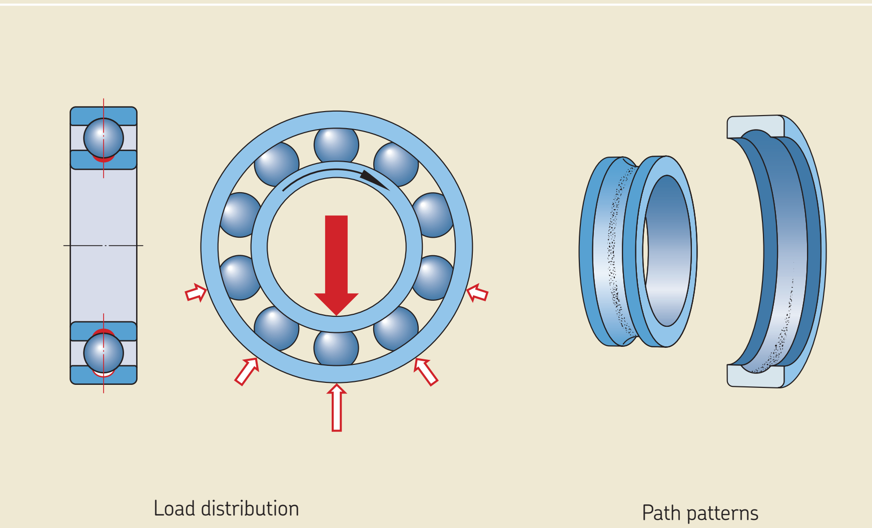


Fig. 4

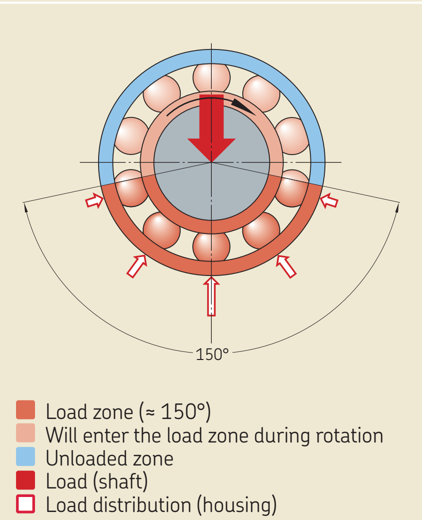
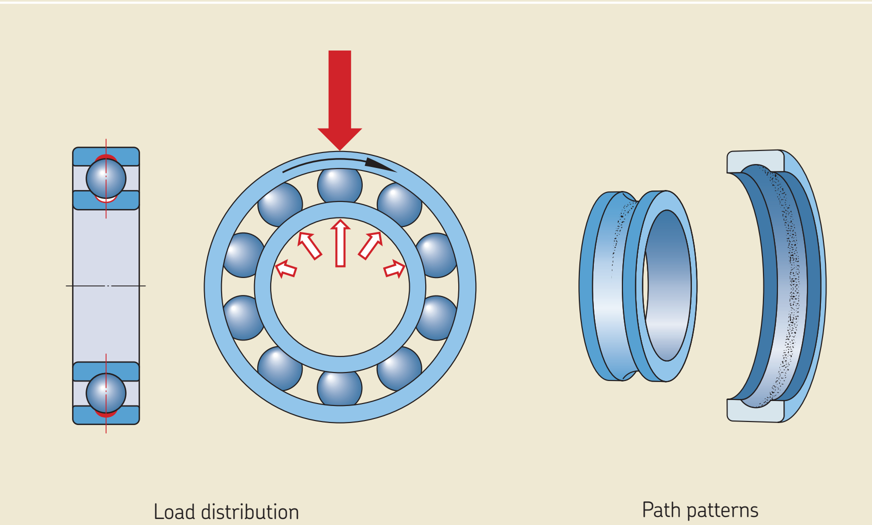


Fig. 6



Radial bearings – radial load rotating in phase and constant

Inner ring rotation

Fig. 7 illustrates how an applied constant radial load rotating in phase with the inner ring of a bearing (i.e. imbalanced or eccentric load) is distributed to the stationary outer ring by the rolling elements.

The outer ring is stationary; but every point on that ring in turn enters the load zone. As a result, the entire circumference of the outer ring raceway has a path pattern in its centre that is uniform in width.

Although the inner ring rotates, the load on the inner ring is stationary. The load distribution on the inner ring varies. The centred path pattern is widest in the direction of the load and decreases in either direction from that point. In most applications, bearings operate with radial clearance and the load zone is approximately 150°.

The path pattern is identical to **fig. 6**.

Outer ring rotation

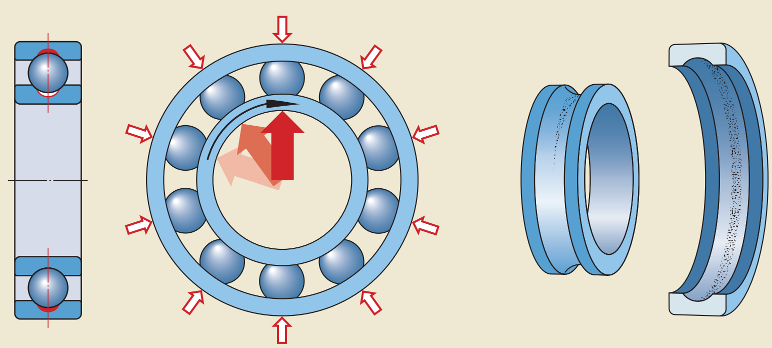
Fig. 8 illustrates how an applied constant radial load rotating in phase with the outer ring of a bearing (i.e. imbalanced or eccentric load) is distributed to the stationary inner ring by the rolling elements.

The inner ring is stationary. Every point on that ring is subjected to the load zone. As a result, the entire circumference of the inner ring raceway has a path pattern in its centre that is uniform in width.

Although the outer ring rotates, the load on the outer ring is stationary. The load distribution on the outer ring varies. The centred path pattern is widest in the direction of the load and decreases in either direction from that point. In most applications, bearings operate with radial clearance and the load zone is approximately 150°.

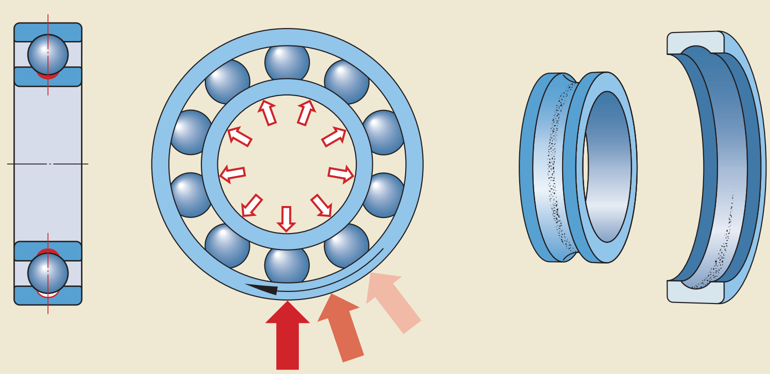
The path pattern is identical to **fig. 5**.

Fig. 7



Load distribution   Path patterns

Fig. 8



Load distribution   Path patterns

Radial bearings – axial load unidirectional and constant

Inner or outer ring rotation

Fig. 9 illustrates how an applied unidirectional and constant axial load on a bearing is distributed to the stationary outer ring by the rolling elements.

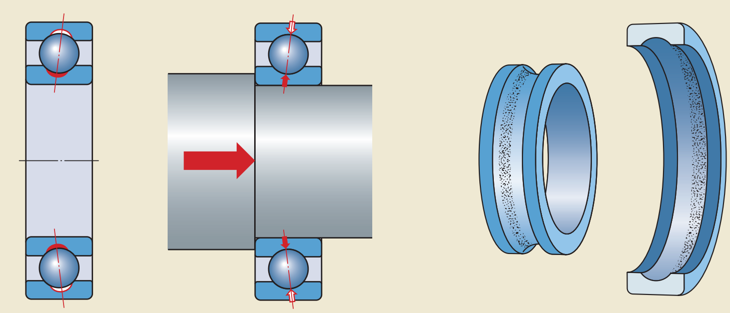
The rotating ring has a laterally displaced path pattern around its entire circumference.

The stationary ring has a laterally displaced path pattern on the opposite side. In the absence of any radial load, the path pattern on the stationary ring will be around its entire circumference.

The contact area between ball and raceway in a deep groove ball bearing is an ellipse (→ **fig. 10**). Under pure radial load, the contact ellipse is centred in the middle of the raceway (→ **fig. 10a**). When the bearing is subjected to an axial load, the bearing operates with a contact angle (α) and the contact area moves along the groove profile towards the ring edge (→ **fig. 10b**).

Under too heavy axial loads or misalignment, the loading conditions of the bearing can be such that part of the contact ellipse is no longer supported by the raceway (→ **fig. 10c**). This phenomenon is called ellipse truncation, which leads to stress concentrations in the contact area. This may be detrimental for both bearing fatigue life and noise levels.

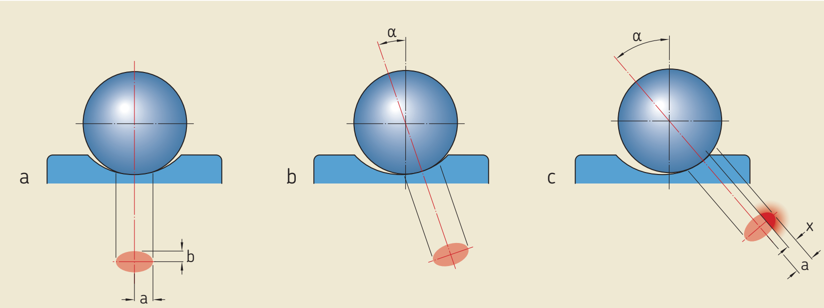
Fig. 9



Load distribution

Path patterns

Fig. 10



Radial load only

Axial or combined load

Too heavy axial loads or misalignment (ellipse truncation)

Radial bearings – combination of radial and axial loads unidirectional and constant

Inner ring rotation

Fig. 11 illustrates how an applied combination of unidirectional and constant radial and axial loads on a bearing is distributed to the stationary outer ring by the rolling elements.

The inner ring has a laterally displaced path pattern around its entire circumference.

The outer ring is stationary and has a laterally displaced path pattern on the opposite side. The load distribution in the outer ring varies. The path pattern is widest in the direction of the radial load and decreases in either direction from that point. The length of the load zone is greater than one that would be produced by just a radial load, but not necessarily 360°.

The path pattern on the outer ring varies, depending on the magnitude of the radial load relative to the axial load as follows:

- Under pure radial load, only a small section (approximately 150°) of the outer ring will have a path pattern in its centre (→ **fig. 5**, **page 34**).
- Under pure axial load, the whole outer ring has a path pattern, which is displaced laterally (→ **fig. 9**).
- Under a combined load, the path pattern is somewhere in between, depending on the magnitude of the radial load relative to the axial load (→ **fig. 12**).

For double row bearings, combined loads will produce load zones of unequal length. The row that carries the axial load has a longer stationary load zone. If the axial load is of sufficient magnitude, one row of rolling elements can become completely unloaded.

Thrust bearings – axial load unidirectional and constant

Rotating shaft washer

Fig. 13 illustrates how an applied unidirectional and constant axial load on a thrust ball bearing is distributed to the stationary housing washer by the rolling elements. Both washers have a path pattern, uniform in width, extended around the entire circumference of the raceways and concentric with the bearing axis.

3

Fig. 11

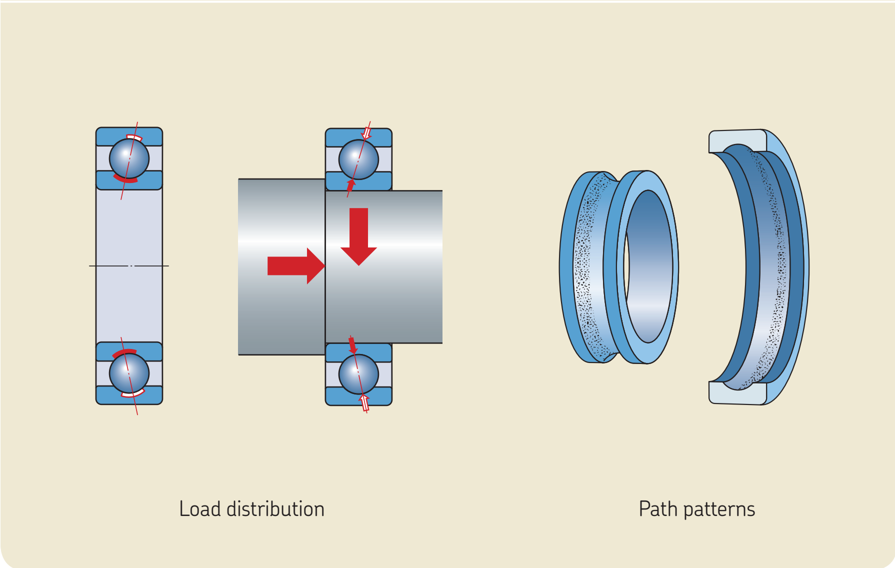


Fig. 12

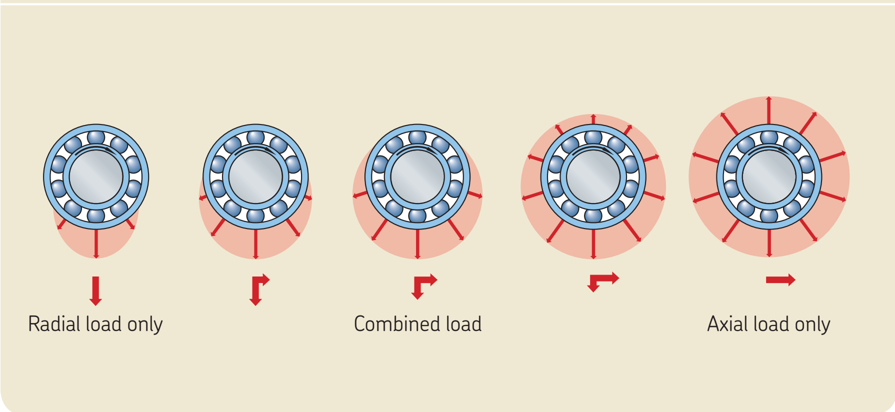
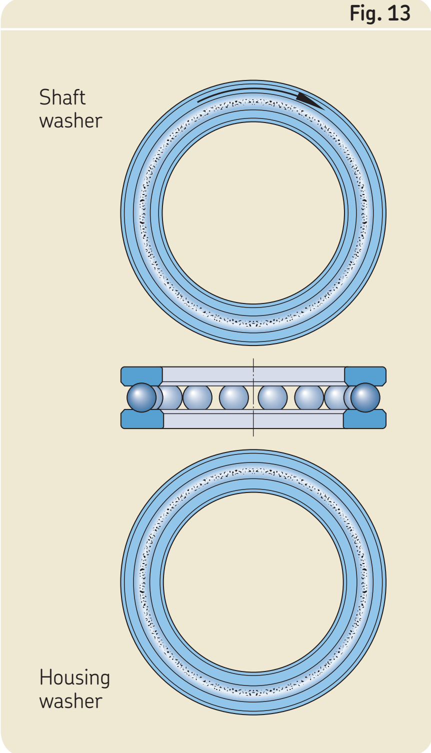


Fig. 13



Raceway path patterns from abnormal operating conditions

Radial bearings – radial load unidirectional and constant

Inner ring rotation – misaligned stationary outer ring

Fig. 14 illustrates how an applied unidirectional and constant radial load acting on the rotating inner ring of a bearing is distributed to the stationary and misaligned outer ring by the rolling elements.

The inner ring has a path pattern around its raceway that is centred and uniform in width but wider than normal.

The outer ring has a path pattern that goes from one side of the outer ring to the other. The width and length of the path pattern depend on the magnitude of misalignment, the load and the clearance in the bearing. The path pattern can be anywhere from 150° to 360°.

This condition can occur when the bearing seats are misaligned, abutment faces not perpendicular or the shaft deflects beyond normal limits.

Outer ring rotation – misaligned stationary inner ring

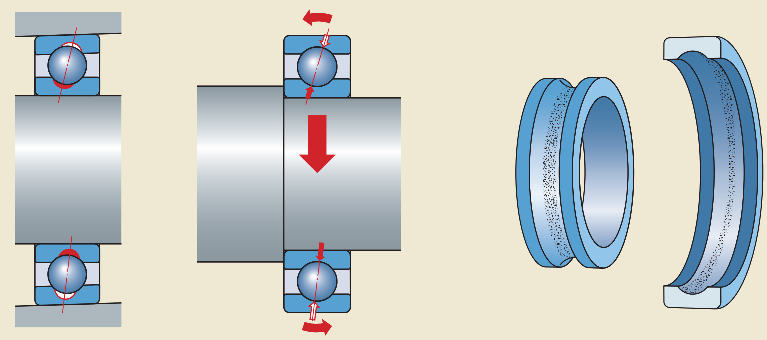
Fig. 15 illustrates how an applied unidirectional and constant radial load acting on the rotating outer ring of a bearing is distributed to the stationary and misaligned inner ring by the rolling elements.

The outer ring has a path pattern around its raceway that is centred and uniform in width but wider than normal.

The inner ring has a path pattern that goes from one side of the inner ring to the other. The width and length of the path pattern depend on the magnitude of misalignment, the load and the clearance in the bearing. The path pattern can be anywhere from 150° to 360°.

This condition can occur when the bearing seats are misaligned, abutment faces not perpendicular or the shaft deflects beyond normal limits.

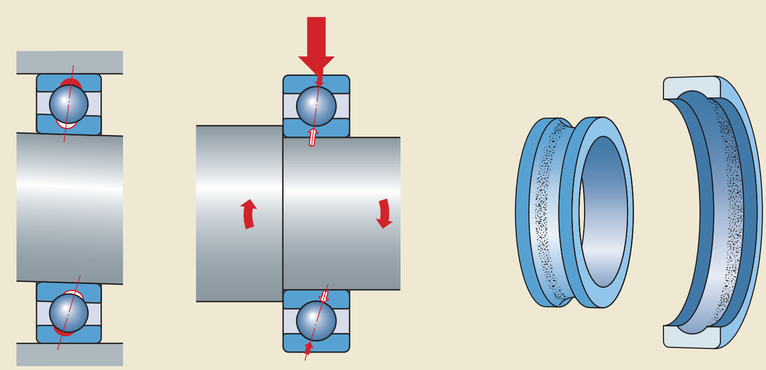
Fig. 14



Load distribution

Path patterns

Fig. 15



Load distribution

Path patterns

Inner ring rotation – oval clamping of the stationary outer ring

Fig. 16 illustrates how an applied uni-directional and constant radial load acting on the rotating inner ring of a bearing is distributed to the stationary and oval clamped outer ring by the rolling elements.

The inner ring has a path pattern around its raceway that is centred and uniform in width but wider than normal.

The outer ring has two diametrically opposed path patterns (load zones). A radially pinched outer ring occurs for any one of the following reasons:

- The housing is mounted on a non-flat surface.
- The two halves of a split housing do not fit concentrically.
- The housing seat is out-of-round due to manufacturing errors, in which case two or more load zones are possible.

Multiple load zones increase the internal loads and the bearing operating temperature, leading to premature bearing damage or failure.

Inner ring rotation – preloading

Fig. 17 illustrates how an applied uni-directional and constant radial load acting on the rotating inner ring of a radially preloaded bearing is distributed to the stationary outer ring by the rolling elements.

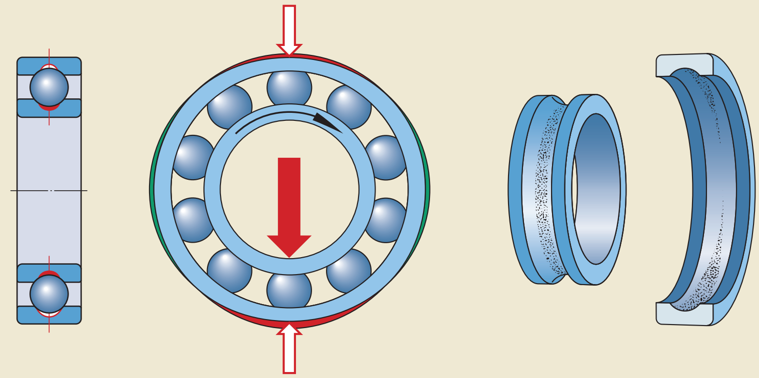
The inner ring has a path pattern around its raceway that is centred and uniform in width.

The outer ring has a path pattern around its raceway that is centred and uniform in width but wider than normal due to the applied load combined with the internal preload.

This condition can be the result of an excessive interference fit on the shaft and/or in the housing. If the fit is too tight, the bearing can become internally preloaded by compressing the rolling elements between the two rings. Too little initial internal clearance can lead to the same problem.

Another possible cause for this condition is an excessive temperature difference between the shaft and housing. This too can significantly reduce the bearing internal clearance. Shaft and housing materials with a different coefficient of thermal expansion can also contribute to clearance reduction.

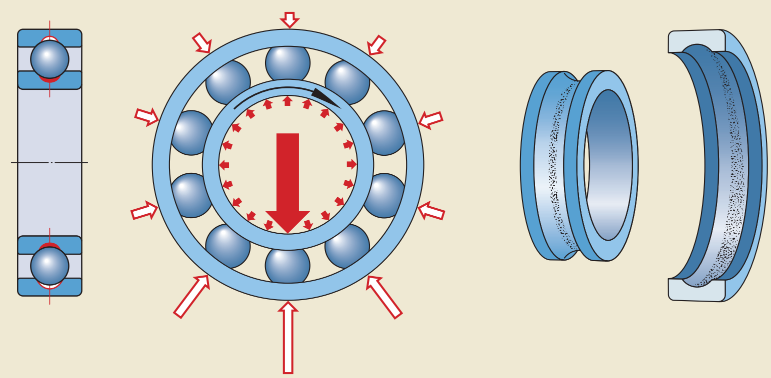
Fig. 16



Load distribution

Path patterns

Fig. 17



Load distribution

Path patterns

Thrust bearings – axial load unidirectional and constant

Rotating shaft washer – eccentrically positioned stationary housing washer

Fig. 18 illustrates how an applied unidirectional and constant axial load on the shaft washer of a thrust ball bearing is distributed to the stationary and eccentrically positioned housing washer by the rolling elements.

The shaft washer has a path pattern around its raceway that is centred and uniform in width but wider than normal.

The housing washer has a path pattern around its raceway that is uniform in width, but off-centre relative to the bearing axis.

Rotating shaft washer – misaligned stationary housing washer

Fig. 19 illustrates how an applied unidirectional and constant axial load on the rotating shaft washer of a thrust ball bearing is distributed to the stationary misaligned housing washer by the rolling elements.

The shaft washer has a path pattern around its raceway that is centred and uniform in width.

The housing washer has a path pattern around its raceway that is centred, but varies in width.

Fig. 18

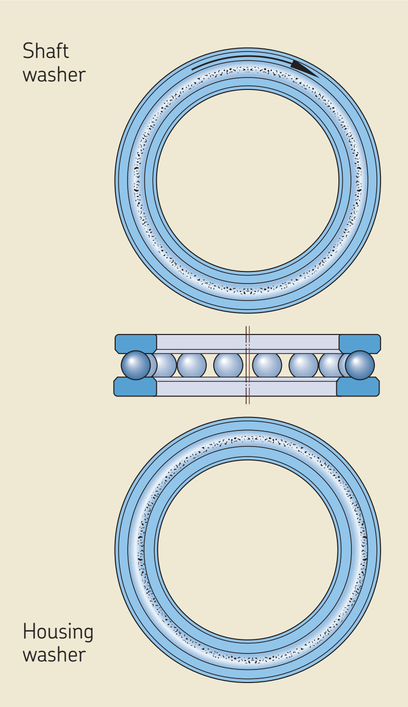
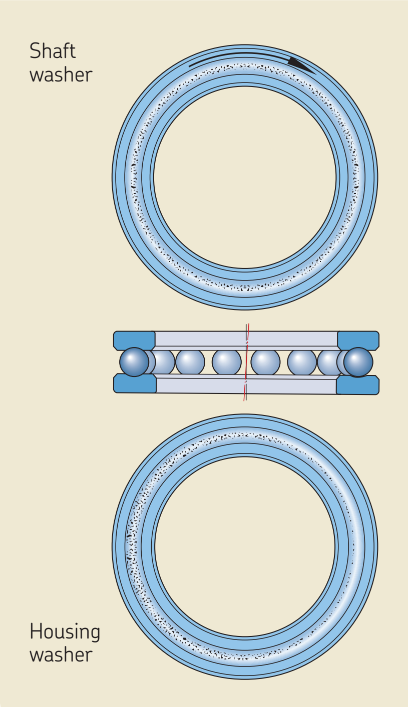


Fig. 19



4 ISO failure modes classification

There is a large number of bearing manufacturers and there are many publications on bearing damage and failure. Different publications may classify bearing damage and failure in different ways and use differing terminology.

Failure modes classification – ISO workgroup

Within the ISO organization, a workgroup was formed in 1995 to define a common classification method and terminology for types of bearing damage. The workgroup established that:

- A cause for failure shows a certain characteristic.
- A certain failure mechanism can be associated with a certain failure mode.
- From the damage observed, one can (try to) define the root cause of failure.

The ISO standard 15243 was published in early 2004. Since that time, additional knowledge and experience on bearing damage has been obtained. An ISO working group has reviewed the information and a and a revised standard ISO 15243-2017 is available since mid 2017.

The SKF and ISO 15243 failure mode classification are identical. The SKF classification is based on three main points:

- It covers all damage and changes in appearance occurring in the bearing during service[1].
- It is restricted to characteristic forms[2] of change in appearance that can be attributed to particular causes (with a high degree of certainty).
- It relies on the evaluation of visible features[3] obtained by non-destructive analysis.

The failure modes are divided into 6 main modes and thereafter into sub-modes (→ **diagram 1**). There are 14 failure modes in total. The features of each mode, together with some typical examples, are covered in this chapter.

The numbering in **diagram 1** is aligned with the ISO 15243 subclause numbering.

There are other reasons for bearing damage, such as manufacturing defects, design problems, etc. These are not classified in the ISO standard and are not dealt with in this publication.

1 “During service”: after the bearing leaves the bearing factory.
2 “Characteristic forms”: what can be classified within the 14 failure modes.
3 “Visible features”: what can be seen including through magnification with light optical microscopes. Destructive analysis is not dealt with in this publication.

Diagram 1

SKF classification adapted from ISO 15243:2004

- **5.1 Fatigue**
  - 5.1.2 Subsurface initiated fatigue
  - 5.1.3 Surface initiated fatigue
- **5.2 Wear**
  - 5.2.2 Abrasive wear
  - 5.2.3 Adhesive wear
- **5.3 Corrosion**
  - 5.3.2 Moisture corrosion
  - 5.3.3 Frictional corrosion
    - 5.3.3.2 Fretting corrosion
    - 5.3.3.3 False brinelling
- **5.4 Electrical erosion**
  - 5.4.2 Excessive current erosion
  - 5.4.3 Current leakage erosion
- **5.5 Plastic deformation**
  - 5.5.2 Overload deformation
  - 5.5.3 Indentations from debris
- **5.6 Fracture and cracking**
  - 5.6.2 Forced fracture
  - 5.6.3 Fatigue fracture
  - 5.6.4 Thermal cracking

Numbering follows ISO 15243:2004 subclause numbers.

Failure modes

Fatigue

Subsurface initiated fatigue

5.1 Fatigue
- 5.1.2 Subsurface initiated fatigue
- 5.1.3 Surface initiated fatigue

- repeated stress changes
- material structural changes
- microcracks under the surface
- crack propagation
- spalling

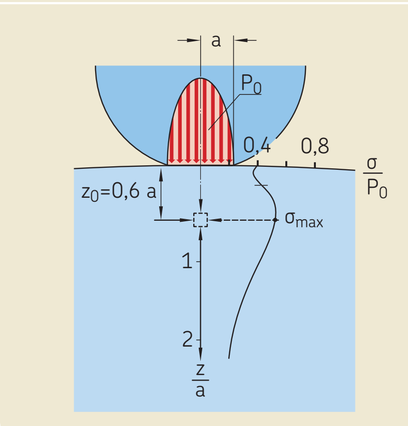
In a rotating bearing, cyclic stress changes occur beneath the contact surfaces of the raceways and rolling elements.

Consider the rotating inner ring of a radial bearing with a radial load acting on it. As the ring rotates, one particular point on the raceway enters the load zone and continues through an area to reach a maximum load (stress) before it exits the load zone. During each revolution, as that one point on the raceway enters and exits the load zone, compressive and shear stresses occur (→ **fig. 1**).

Depending on the load, temperature and the number of stress cycles over a period of time, there is a build-up of residual stresses that cause the material to change from a randomly oriented grain structure to fracture planes.

In these planes, so-called subsurface microcracks develop beneath the surface at the weakest location, around the zone of maximum shear stress, typically at a depth of 0,1 to 0,5 mm (→ **figs. 2** and **3**). The depth depends on the load, material, cleanliness, temperature and the microstructure of the steel. The crack finally propagates to the surface and spalling occurs (→ **fig. 4**).

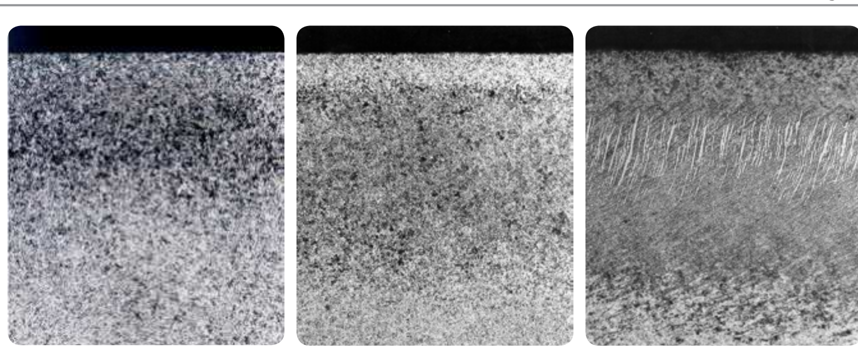
Fig. 1



Compressive and shear stresses beneath the raceway

Changes in structure beneath the raceway surface over time (highly stressed, well lubricated small deep groove ball bearing)

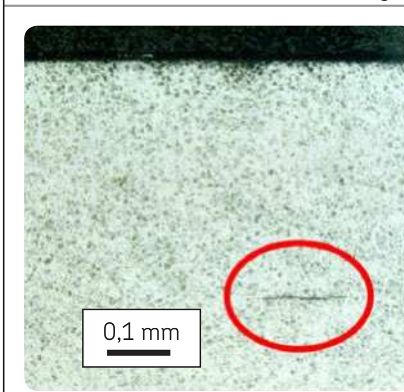
Fig. 2



10 million revolutions | 63 million revolutions | 630 million revolutions

Crack development beneath the raceway surface (~ 0,3 mm)

Fig. 3



The bearing is damaged as soon as spalling occurs. This does not mean that the bearing cannot remain in service. Spalling gradually increases and gives rise to noise and vibration levels in the machine. The machine should be stopped and repaired before the bearing collapses.

The period from initial spalling to failure depends on the type of machine and its operating conditions.

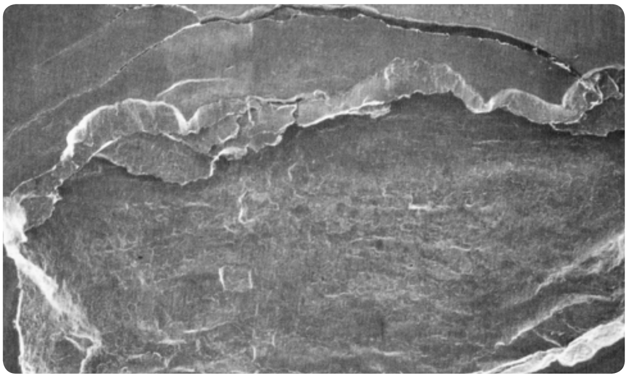
Fig. 5 shows a spall caused by fatigue (high magnification). The bearing ran a long time before the crack came to the surface. This typically occurs in bearings made of very clean steel running under clean and well lubricated operating conditions. Notice the flat bottom of the spalled area and the "neat" cracks around it. These are cracks that have come to the surface and in time, more material will break away.

Fig. 4

Initial subsurface spalling on the inner ring of a deep groove ball bearing

Subsurface spall on an inner ring raceway (high magnification)

Fig. 5



Surface initiated fatigue (surface distress)

5.1 Fatigue

5.1.2 Subsurface initiated fatigue

5.1.3 Surface initiated fatigue

- surface distress
- reduced lubrication regime
- sliding motion
- burnishing, glazing
- asperity microcracks
- asperity microspalls

Surface initiated fatigue basically comes from damage to the rolling contact surface asperities, which is generally caused by inadequate lubrication.

Inadequate lubrication can be caused by a number of different factors. If the surface is damaged, for instance by the over-rolling of solid contaminants, lubrication is no longer optimal and the lubricant film is reduced or becomes inadequate. This can also occur if the amount or type of lubricant is not appropriate for the application and the contact surfaces are not adequately separated. The resulting metal-to-metal contact causes the surface asperities to shear over each other, which together with microslip between the rolling contact area surfaces, creates a burnished or glazed surface. Thereafter, microcracks may occur at the asperities, followed by microspalls, finally leading to surface initiated fatigue. There is a risk of surface initiated fatigue in all bearings if the oil film does not fully separate the rolling contact surfaces.

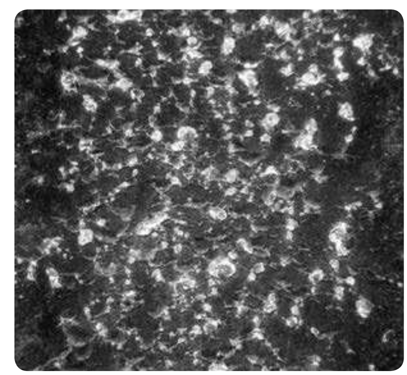
The risk increases if there is sliding in the rolling contact area. All rolling bearings show some microslip (also called microsliding) in the rolling contact area due to their specific geometry and elastic deformation of the rolling elements and raceways under load.

Another frequently overlooked cause of surface initiated fatigue is the use of EP additives. EP additives can become aggressive, especially at elevated temperatures, and can accelerate microspalling.

Surface initiated fatigue, in general, is the consequence of surface asperities coming in direct contact under mixed or boundary lubrication conditions (→ **fig. 6a**). When the loading and the frictional forces reach a given magnitude, small cracks form on the surface (→ **fig. 6b**). These cracks may then develop into microspalls (→ **fig. 6c**).

Generally, these microspalls are only a few microns in size and the surface just looks dull and grey (→ **fig. 7**). Only under a micro-

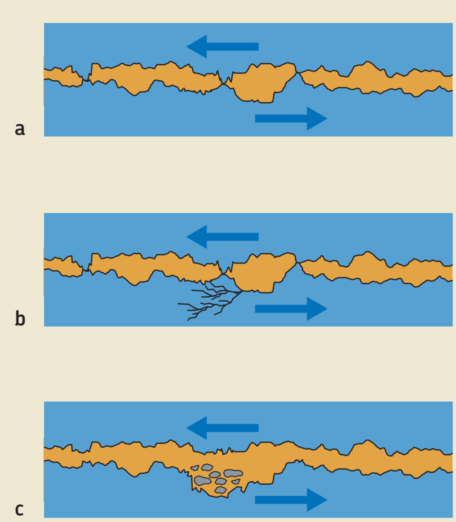
Fig. 8



Microspalls and cracks on the raceway surface (high magnification)

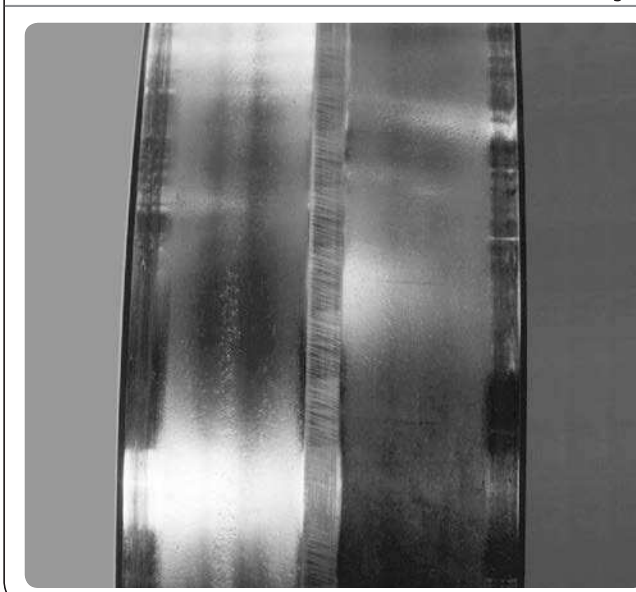
Mechanism of surface initiated fatigue

Fig. 6



Microspalls on the inner ring raceways of a spherical roller bearing

Fig. 7



scope can cracks and spalls be detected (→ **fig. 8**).

Fig. 9 shows the start of spalling following surface initiated fatigue due to inadequate lubrication.

Fig. 10 shows the progression of surface initiated fatigue into overall spalling.

Depending on when the bearing is stopped and analyzed, it can be hard to determine the root cause.

To diagnose lubricant film failure, it is not enough to look only at the rolling contact surfaces and the condition of the lubricant. The properties of the lubricant, the quantities used or needed, and the operating conditions should be evaluated to judge the adequacy of the lubricant. Over a period of time, the following stages of damage from inadequate lubrication may occur and can be observed on the surface:

1 Fine roughening or waviness (may even be shiny)
2 Small cracks
3 Local spalling
4 Spalling over the entire surface

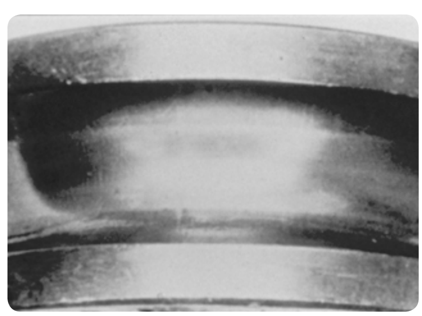
Fig. 9

Initial spalling resulting from surface initiated fatigue on the inner ring raceway of a deep groove ball bearing

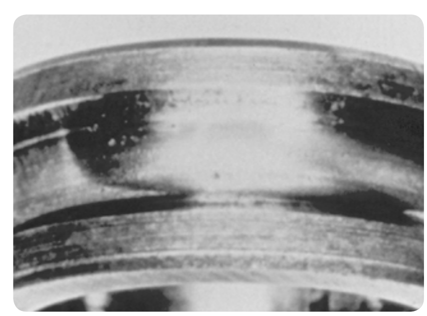
4

Progress of surface initiated fatigue on the inner ring of a deep groove ball bearing

Fig. 10



1 Fine roughening or waviness



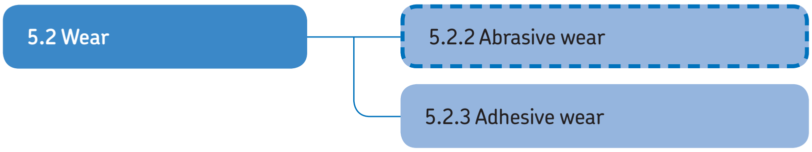
2 Small cracks

3 Local spalling

4 Spalling over the entire surface

Wear

Abrasive wear



- progressive removal of material
- inadequate lubrication
- ingress of dirt particles (contaminants)
- dull surfaces (mostly)
- degenerative process

Abrasive wear means progressive removal of material.

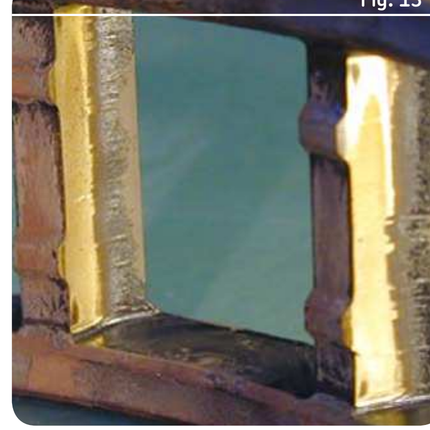
Initially, a bearing experiences some very light wear during the running-in stage, mostly just showing a path pattern (→ **fig. 11**).

Most of the time, real abrasive wear occurs due to inadequate lubrication or the ingress of solid contaminants. Abrasive wear is generally characterized by dull surfaces (→ **fig. 12**).

Abrasive wear is a degenerative process that eventually destroys the microgeometry of a bearing because wear particles further reduce the lubricant's effectiveness. Abrasive particles can quickly wear down the raceways of rings and rolling elements, as well as cage pockets. **Fig. 12** shows abrasive wear on the outer ring of a spherical roller bearing. The depth of the wear can also be seen. (There is also a waviness pattern from vibration.)

The cage is a critical part of the bearing. Rings and rolling elements are hardened to approximately 60 HRC. Most metal cages are unhardened (sheet metal or brass). Under poor lubrication conditions, the cage may be the first component to wear. **Fig. 13** shows pocket wear in a solid brass cage.

Fig. 13



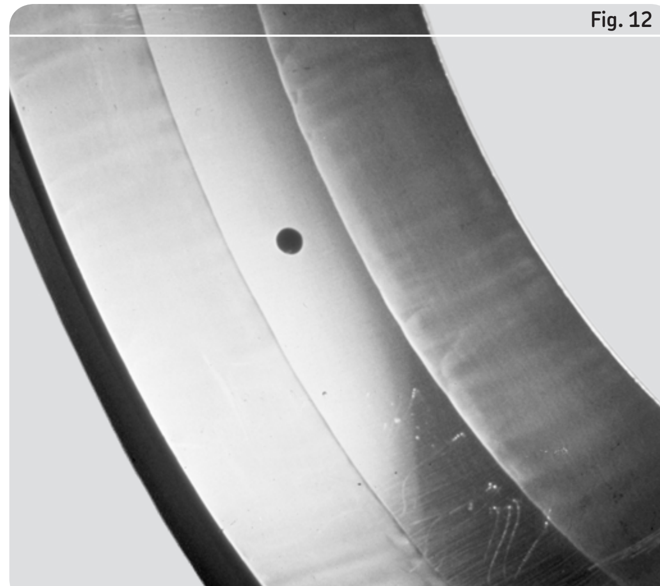
Abrasive wear on the cage bars of a cylindrical roller bearing

Light abrasive wear on the outer ring of a spherical roller thrust bearing

Fig. 11

Advanced abrasive wear on the outer ring of a spherical roller bearing (dull and matt raceways)

Fig. 12



Polishing wear is a special form of abrasive wear. The raceway surfaces of new bearings are shiny but not highly reflective (mirror-like). Real mirror-like surfaces in a bearing that has been in service (→ **fig. 14**) result from inadequate lubrication caused by a thin oil film, and particles that are acting as a polishing agent. This allows metal-to-metal contact, which leads to abrasive wear and plastic deformation of the asperities (→ **fig. 15**). The surfaces may become extremely shiny – all depending on the size of the particles, their hardness and running time.

Mirror-like surfaces can be advantageous, provided abrasive wear and plastic deformation are confined to the asperities only.

In some cases, polishing wear can go beyond the asperities to severely alter the shape of the raceways. The inner and outer ring raceways, and most probably the rollers, have worn down but are still mirror-like.

This level of abrasive wear results from a combination of factors: the viscosity of the oil is too low and there is an excessive amount of very small abrasive particles in the oil. Other factors can include a combination of low speeds, heavy loads and an insufficient oil film.

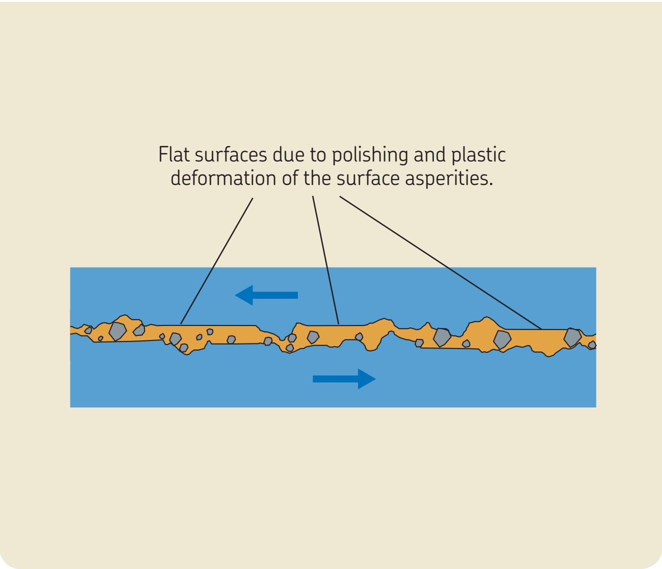
To avoid this type of damage, increase the viscosity of the lubricant and monitor the cleanliness of the lubricant regularly.

Polishing wear (mirror-like raceway surfaces) on the inner and outer rings of a spherical roller bearing

Fig. 14

Process of polishing wear in a bearing

Fig. 15



Adhesive wear (smearing)

5.2 Wear
- 5.2.2 Abrasive wear
- 5.2.3 Adhesive wear

- accelerations
- skidding/smearing/galling
- material transfer / frictional heat
- tempering/rehardening with stress concentrations and cracking or spalling
- light loads

Adhesive wear is a type of lubricant-related damage that occurs between two mating surfaces sliding relative to each other (→ **fig. 16**).

It is characterized by the transfer of material from one surface to another (smearing). It is typically accompanied by frictional heat, which can sometimes temper or reharden the mating surfaces.

The frictional heat produces local stress concentrations, which can cause cracking or spalling in the contact areas.

Smearing is not common under normal operating conditions. The relative sliding speed must be much higher than the micro-slip induced by the bearing geometry and elastic deformation in the rolling contact area.

Smearing (adhesive wear) due to severe accelerations

Under certain conditions, smearing can occur on the surface of the rolling elements and in the raceways of rolling bearings operating at relatively high speeds. Outside the load zone, the rolling element rotation is retarded because the rings do not drive the rolling elements.

The rolling elements are therefore subjected to rapid (sudden) acceleration when they enter the load zone (→ **fig. 17**). This sudden acceleration can cause sliding, which can generate enough heat, so that the two surfaces melt together at the points of metal-to-metal contact (→ **fig. 16**). This welding process causes material to be transferred from one surface to the other, which also leads to higher friction (→ **fig. 18**).

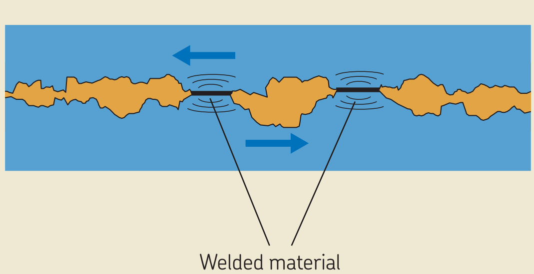
During this process, there is also tempering and rehardening of the material. This can lead to local stress concentrations and a high risk that cracks will form, causing the bearing to fail prematurely. Cracks can occur at 90° to the sliding direction.

The phenomenon of smearing is also called galling or scuffing.

Smearing is a dangerous type of surface damage because the surfaces affected normally become progressively rougher. As surface roughness increases, the oil film thickness decreases, which increases metal-to-metal contact and bearing wear enters a vicious cycle. Large bearings are quite sensitive to smearing. The weight of the rolling elements becomes important and they slow down considerably outside the load zone. When re-entering the load zone they are almost instantly accelerated to the rotational speed, but due to the rolling element weight it occurs with (partial) sliding.

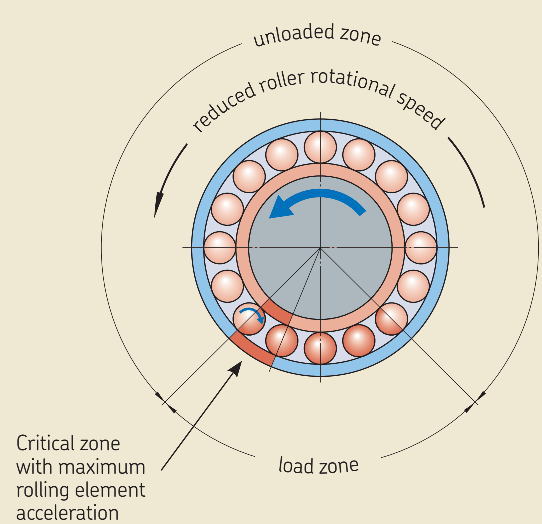
Principle of adhesive wear

Fig. 16



Highest risk for adhesive wear when rolling elements accelerate as they enter the load zone

Fig. 17



Smearing due to gyroscopic effects also occurs in ball bearings. In these cases, the balls change their contact angle when they are outside the load zone but are forced back (with slip) to their correct contact angle as they enter the load zone.

Smearing (adhesive wear) due to too light loading

Smearing can also occur between rolling elements and raceways when the load is too light relative to the speed of rotation.

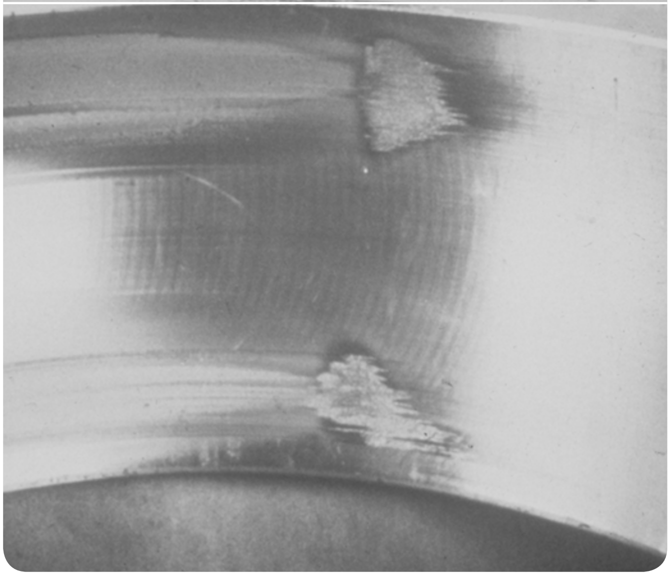
Ways to overcome smearing include, but are not limited to:

- increasing the load
- using smaller bearings
- using hybrid bearings (lighter rolling elements)
- applying protective coatings
- using a different cage execution
- reviewing oil/grease selection

Other examples of smearing (adhesive wear)

Smearing can also occur between the cage and its contact surface and between the roller ends and guide flanges. **Fig. 19** shows a roller from a spherical roller thrust bearing that was riding against the guide flange. The roller end has smearing damage caused by inadequate lubrication.

Fig. 18



Smearing on the raceways of a spherical roller bearing outer ring (smearing marks at the entrance of the load zone)

Fig. 19

Smearing on a roller thrust face of a spherical roller thrust bearing

Corrosion

Moisture corrosion

5.3 Corrosion
- 5.3.2 Moisture corrosion
- 5.3.3 Frictional corrosion

- oxidation/rust (corrosion)
- chemical reaction
- corrosion pits/flaking
- etching (water/oil mixture or chemicals)

Ineffective sealing arrangements can allow moisture, water and aggressive liquid contaminants to enter the bearing. When the quantity of liquid contaminants exceeds the ability of the lubricant to adequately protect the steel surfaces, rust will form.

Oxidation

A thin protective oxide film is formed on clean steel whose surfaces are exposed to air. However, this film is not impenetrable and if water or corrosive agents make contact with the steel surfaces, oxidation will occur.

Corrosion

Corrosion is perhaps the most common cause of premature bearing failure in paper machines and process equipment in the food and beverage industries. Bearings in these machines are exposed to the ingress of water and other liquids as part of the operational process. Water can also be introduced during washdowns while the machine is being cleaned at standstill, resulting in greyish-black patches coinciding with the rolling element pitch (→ **fig. 20**).

Etching

At standstill, free water in the lubricant will accumulate at the bottom of the bearing. The water concentration will be highest at a certain distance from the rolling contact (→ **fig. 21**). The reason is that the free water is heavier than the oil and will sink until it comes to a suitable gap between the rolling element and the raceway. This can lead to deep-seated corrosion, called etching (→ **fig. 22**). Etching is even more likely to occur in applications where there are aggressive chemicals and high temperatures, like the dryer section of a paper machine.

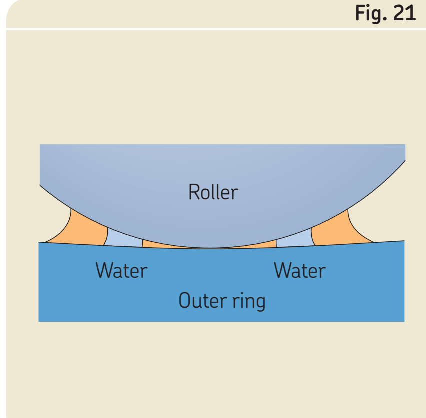
Etching usually leads to premature, extended spalling as the material is subjected to a structural change and the surfaces in the load zone are reduced to such an extent that overloading occurs. The best way to avoid corrosion is to keep the lubricant free from water and aggressive liquids by adequately sealing the application. Using a lubricant with good rust-inhibiting properties also helps.

Corrosion on the outer ring and roller of a spherical roller bearing

Fig. 20

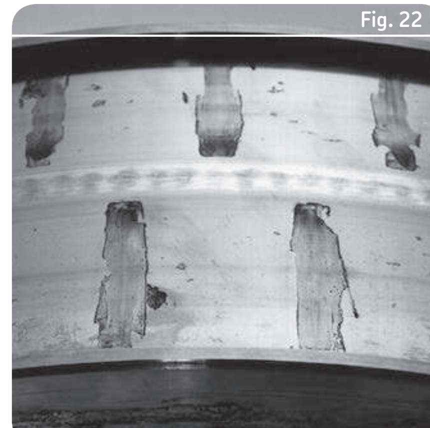
Free water in the lubricant accumulates at the bottom of the bearing

Fig. 21



Initial patches of etching at rolling element pitch on the inner ring raceways of a spherical roller bearing

Fig. 22

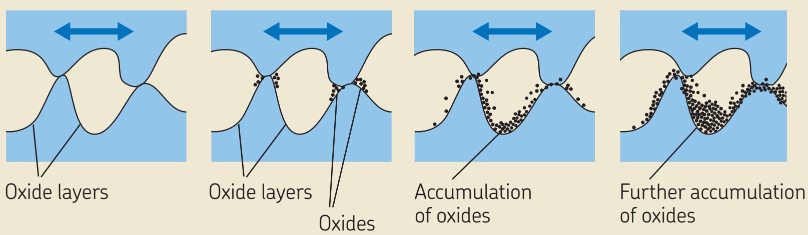


Frictional corrosion – Fretting corrosion

- 5.3 Corrosion
  - 5.3.2 Moisture corrosion
  - 5.3.3 Frictional corrosion
    - 5.3.3.2 Fretting corrosion
    - 5.3.3.3 False brinelling

- micromovement between mating parts
- oxidation of asperities
- powdery rust / loss of material
- occurs at interfaces transmitting loads

Fig. 23



Schematic view of different stages in development of fretting corrosion

4

Fretting corrosion occurs when there is relative movement between a bearing ring and its seat on a shaft or in a housing. Fretting is usually caused by a too loose fit or form inaccuracies.

The relative movement may cause small particles of material to become detached from the bearing surface and its seat. These particles oxidize quickly when exposed to air and the result is iron oxide (→ **fig. 23**). Iron oxide is larger in volume than iron (steel). As a result of the fretting corrosion, the bearing rings may not be evenly supported, which can have a detrimental effect on the load distribution in the bearing.

Corroded areas also act as fracture notches.

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

Depending on the chemical reaction, corrosion could appear as:

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

Fig. 24 shows fretting corrosion resulting from a shaft surface that was not properly machined or from shaft bending (due to a cantilever load or an overhung load).

Fig. 25 shows fretting corrosion from very heavy loading or an inadequate seat.

To avoid fretting corrosion or to slow the process, either the tolerances (fit) should be adjusted, or a special anti-fretting paste or coating should be applied.

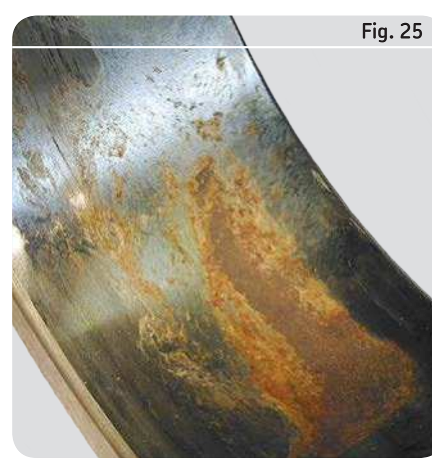
SKF does not recommend the use of specially formulated adhesives to avoid fretting corrosion.

Fretting corrosion on an inner ring bore resulting from an inadequate shaft seat or shaft bending

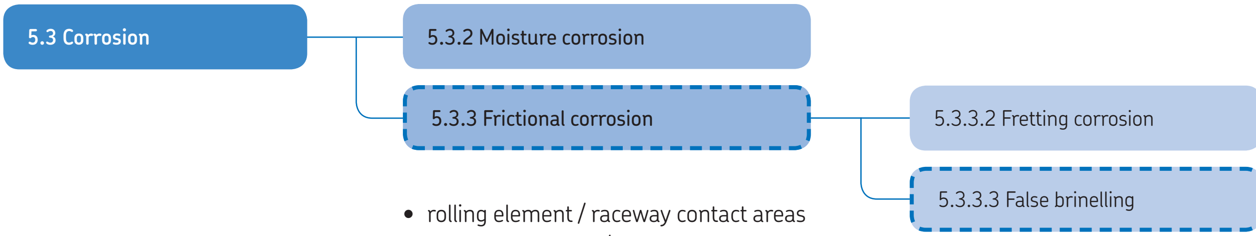
Fig. 24

Fretting corrosion on an inner ring bore resulting from heavy load or inadequate shaft seat

Fig. 25



Frictional corrosion – False brinelling



- rolling element / raceway contact areas
- micromovements / elastic deformation
- vibrations
- corrosion/wear → shiny or reddish depressions
- when stationary: at rolling element pitch
- when rotating: parallel “flutes”

False brinelling occurs in the contact area due to micromovements and/or resilience of the elastic contact under cyclic vibrations. Depending on the intensity of the vibrations, lubrication conditions and load, a combination of corrosion and wear can occur, forming shallow depressions in the raceway. In the case of a stationary bearing, the depressions appear at rolling element pitch:

- sphered depressions for ball bearings
- longitudinal depressions for roller bearings

False brinelling in grease lubricated applications is typically a reddish-brown, while very shiny mirror-like depressions appear in oil lubricated applications.

In many cases, it is possible to discern rust at the bottom of the depressions. This is caused by oxidation of the detached particles, which have a large area in relation to their volume, as a result of their exposure to air.

There is usually much less damage to the rolling elements.

Fig. 26 shows severe false brinelling damage caused to the outer ring of a self-aligning ball bearing at standstill.

Fig. 27 shows false brinelling damage on the outer ring of a cylindrical roller bearing. The root cause is vibration during standstill. The bearing was mounted in auxiliary equipment, with long standstill periods. Several sets of “flutes” can be observed at roller pitch, each set resulting from a period of standstill. The magnitude of damage depends on the level of vibration, frequency of vibration, and length of standstill.

Fig. 26

Severe false brinelling on the outer ring raceway of a self-aligning ball bearing

False brinelling (“flutes”) on the outer ring raceway of a cylindrical roller bearing

Fig. 27

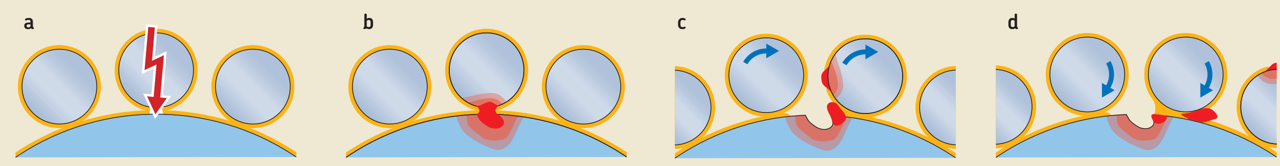
Electrical erosion

Excessive current erosion

5.4 Electrical erosion
- 5.4.2 Excessive current erosion
- 5.4.3 Current leakage erosion

- progressive removal of material
- high current: sparking
- localized heating at extremely short intervals: melting/welding
- craters up to 0,5 mm

Fig. 28



a: Electric current passes

b: A kind of electric arc welding happens between the ring and rolling element

c: Melted material solidifies and breaks away

d: Excess material on the rolling element wears away

Lubricant | Molten material | Rehardened material | Annealed material

Mechanism of excessive current erosion

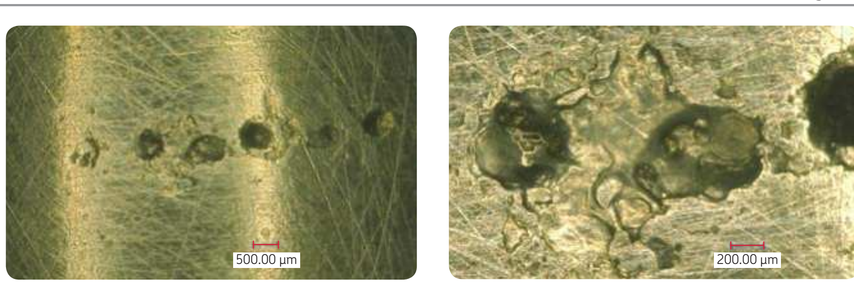
When an electric current (→ **fig. 28**) passes from one ring to the other via the rolling elements, damage will occur (**a**). At the contact surfaces, the process is similar to electric arc welding (high current density over a small contact surface, **b**). The material is heated to temperatures ranging from tempering to melting levels. This leads to the appearance of discoloured areas, varying in size, where the material has been tempered, rehardened or melted. Craters also form where the material has melted and consequently broken away due to the rotation of the rolling element (**c**). The excess material on the rolling element wears away (**d**). Appearance: Craters in raceways and rolling elements. Sometimes zigzag burns can be seen in ball bearing raceways. Local burns are visible on the raceways and rolling elements.

Fig. 29 shows an example of a spherical roller bearing subjected to an excessive electrical current. A number of rather large craters can be seen on the roller. A magnification clearly shows the craters with the molten material around their edges.

Fig. 30 shows damage caused by excessive electrical current in a deep groove ball bearing, both on the outer ring raceway and ball. Notice the zigzag burns.

Excessive current erosion on the roller of a spherical roller bearing

Fig. 29



Craters of 0,5 mm in size | Magnification

Excessive current erosion on the outer ring raceway and ball of a deep groove ball bearing

Fig. 30

Current leakage erosion

5.4 Electrical erosion
- 5.4.2 Excessive current erosion
- 5.4.3 Current leakage erosion

- low current intensity
- shallow craters closely positioned
- development of flutes on raceways and rollers, parallel to rolling axis
- dull, light to dark grey discolouration

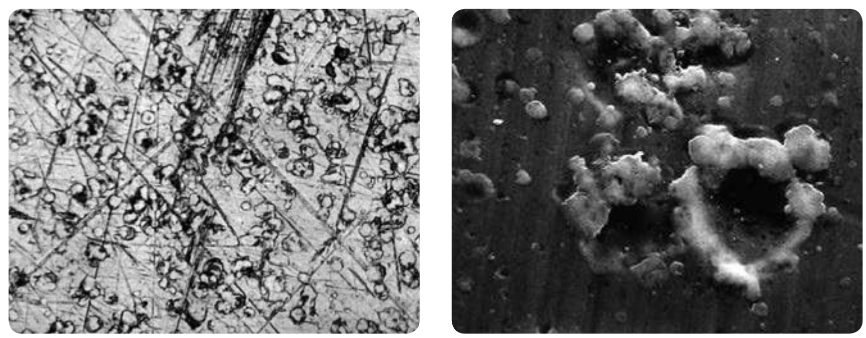
In the initial stage of current leakage erosion damage, the surface is typically damaged by shallow craters that are closely positioned to one another and smaller in diameter compared to the damage from excessive current. This happens even if the intensity of the current is comparatively low. The craters are shown in **fig. 31** at 500x magnification and 5000x magnification.

A washboard pattern may develop from craters over time. The pattern appears on the raceways (→ **figs. 32** and **34**). For roller bearings, the washboard pattern also appears on the rollers (→ **fig. 34**). In ball bearings, the balls typically become discoloured (dull, light to dark grey) over their entire surface.

The extent of the damage depends on a number of factors: current intensity, duration, bearing load, speed and lubricant.

A cross section of a bearing is shown in **fig. 33** at 500x magnification. The white area shows that the metal has been rehardened, typically 66 to 68 HRC. This material is very hard and brittle. Below the rehardened area is a black layer, annealed by the heat, which is softer (56 to 57 HRC) than the surrounding bearing material.

Fig. 31

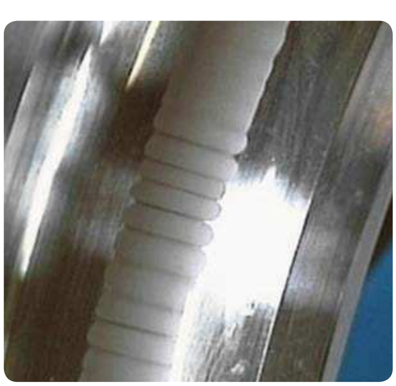


Magnification 500x   Magnification 5000x

Craters from current leakage erosion

Washboarding caused by current leakage erosion

Fig. 32



Changes in material hardness resulting from current leakage

Fig. 33

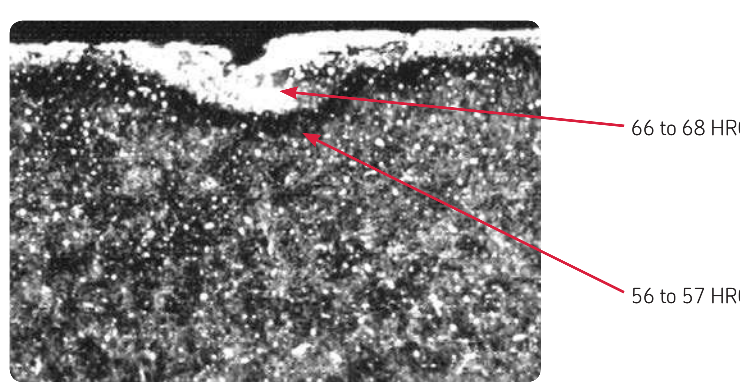
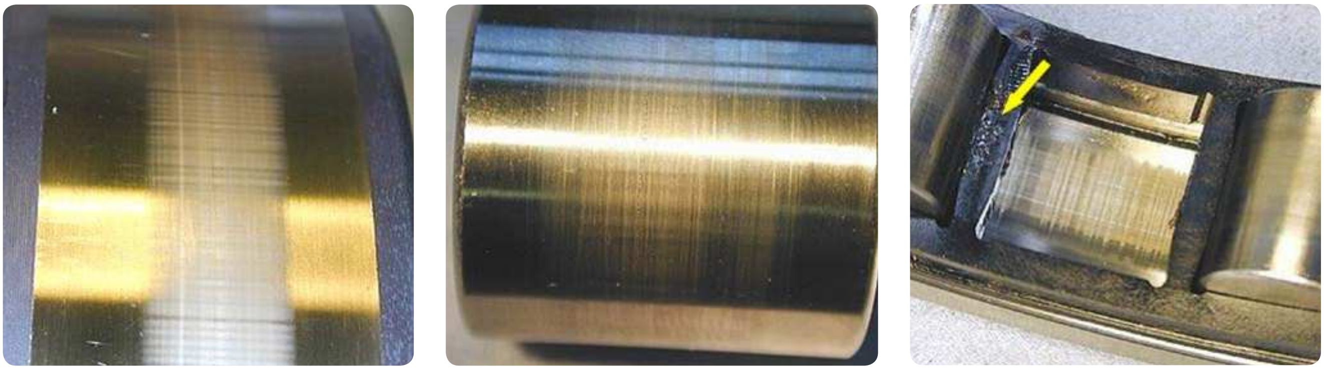


Fig. 34 shows damage to a cylindrical roller bearing due to current leakage. Washboarding is developing on the raceways and rollers. Notice the grease on the cage pockets. At the start of this failure mode, the grease is gradually carbonized and loses its ability to form a lubricant film. This eventually leads to surface initiated fatigue, spalling and even sudden seizure.

4

Washboarding on inner and outer rings and roller raceways

Fig. 34



Plastic deformation

Overload deformation

- 5.5 Plastic deformation
  - 5.5.2 Overload deformation
  - 5.5.3 Indentations from debris

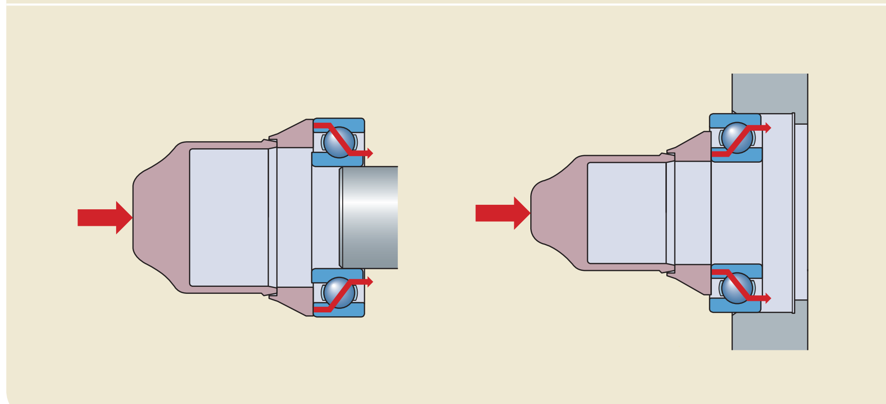
- static or shock loads
- plastic deformation depressions at rolling element pitch
- handling damage
- localized overloading
- nicks caused by hard/sharp objects

Overload deformation can be caused by static overloading, shock loads or improper handling. In any of these cases, the resulting damage looks the same, which is why they are combined into one failure sub-mode.

Fig. 35 shows a case where a cage was hit directly, causing it to deform. If this bearing were put into operation, high noise and vibration levels would result.

Raceways and rolling elements may become dented if the mounting force is applied through the rolling elements (→ **fig. 36**), or if the bearing is subjected to abnormal loading while stationary. The distance between the indentations is at rolling element pitch (→ **fig. 37**).

Fig. 36



Overload deformation resulting from an incorrect mounting method

Plastic deformation on the cage of an angular contact ball bearing resulting from poor handling

Fig. 35

Indentations at ball pitch on the raceway of a double row angular contact ball bearing resulting from incorrect mounting

Fig. 37

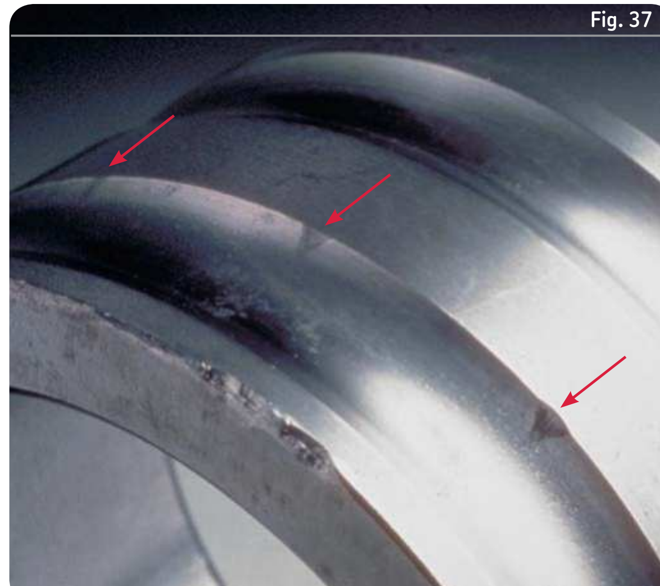
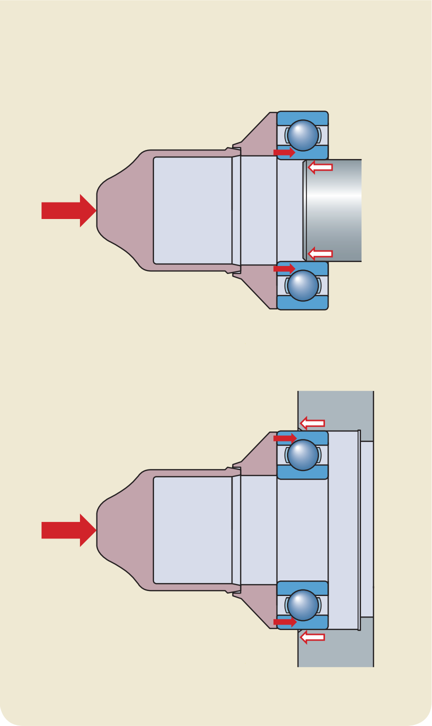


Fig. 38



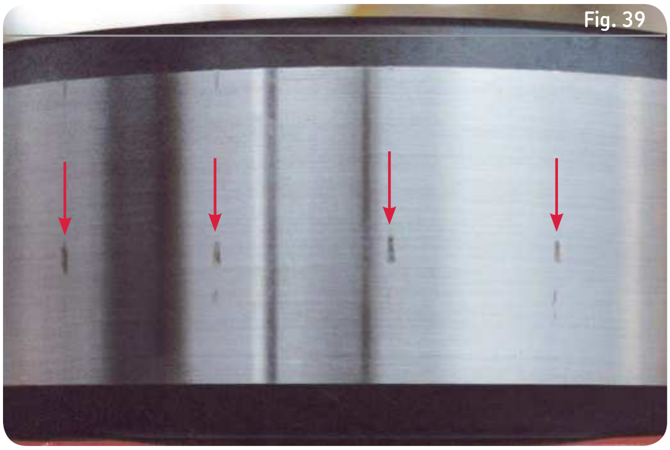
Correct mounting

The solution: always use the correct mounting tools and methods (→ **fig. 38**).

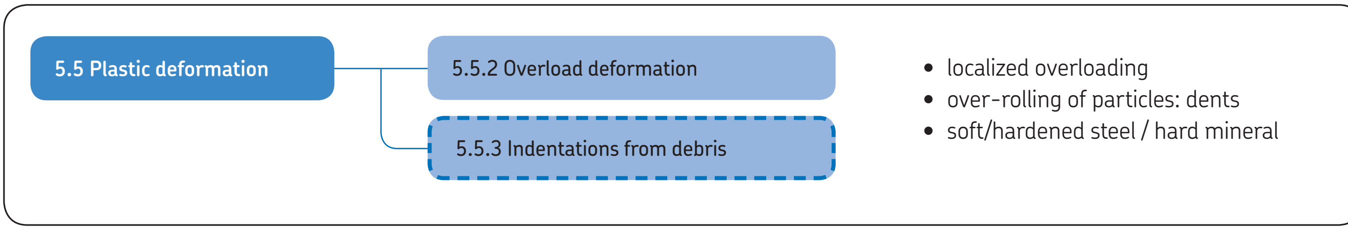
Handling is critical during manufacturing, transport, storage and mounting. Poor handling is characterized by local overloading and visible “nicks” caused by hard and/or sharp objects. **Fig. 39** shows an example of poor assembly of a cylindrical roller bearing in the mounting stage. The rollers have made nicks on the inner ring raceway at roller pitch. If put into service, high noise and vibration levels will result.

Inner ring of a cylindrical roller bearing with nicks that occurred during mounting

Fig. 39



Indentations from debris



Solid contaminants can be introduced into a bearing via the seals or lubricant. They can also be the result of wear or damage to an adjacent component, such as a gear.

When a solid contaminant is over-rolled by the rolling elements, it is pushed into the raceway and causes an indentation. The particle producing the indentation need not be hard. Even rather soft particles, when big enough, can be harmful.

Raised material around the edges of an indentation initiate fatigue. When the fatigue level reaches a certain point, it leads to premature spalling, originating at the back end of the indentation (→ **fig. 40**). The spall starts as a surface crack.

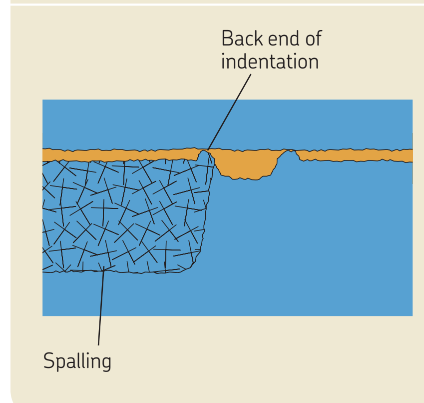
The SKF life theory makes it possible to calculate the life reduction caused by indentations. The most important operating data required for the calculation are the bearing type and size, rotational speed, bearing load, viscosity ratio, and the size, hardness and concentration of the contamination particles.

Lubricant cleanliness and careful handling during mounting are important factors in the prevention of indentations.

Fig. 41 shows spalling in a deep groove ball bearing, resulting from an indentation. The over-rolling direction is from bottom to top. The V-shape is a typical sign of indentation damage in a bearing where the initial spalling opens up from the back end of the indentation.

Fig. 42 clearly shows the consequences of indentations (spherical roller bearing inner ring). The over-rolling direction is from right to left. A rather large and soft contaminant was trapped in the raceway and over-rolled. At the bottom of the dent, grinding lines are still visible. Also notice the raised rim around the dent. To the left, behind the dent, there is a large spall (black colour) where material has been detached. There are also some cracks, where the material is about to be detached.

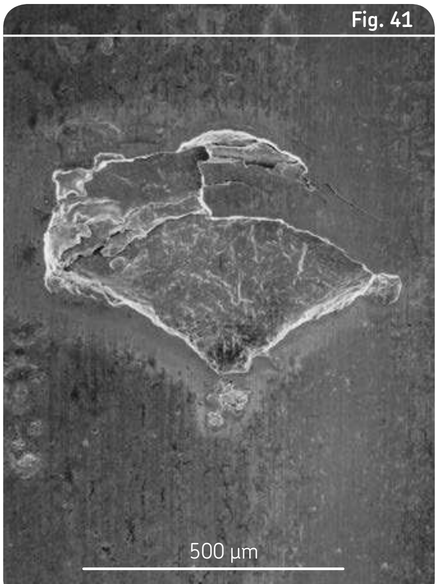
Fig. 40



Spalling starting at the back end of an indentation

Spalling resulting from an indentation in the inner ring of a deep groove ball bearing

Fig. 41



Spalling resulting from an indentation in a spherical roller bearing

Fig. 42

Fracture and cracking

Forced fracture

- 5.6 Fracture and cracking
  - 5.6.2 Forced fracture
  - 5.6.3 Fatigue fracture
  - 5.6.4 Thermal cracking

- stress concentration beyond material tensile strength
- impact/overstressing

A forced fracture results when stress concentrations exceed the tensile strength of the material. Local overloading and overstressing are two common causes of a forced fracture.

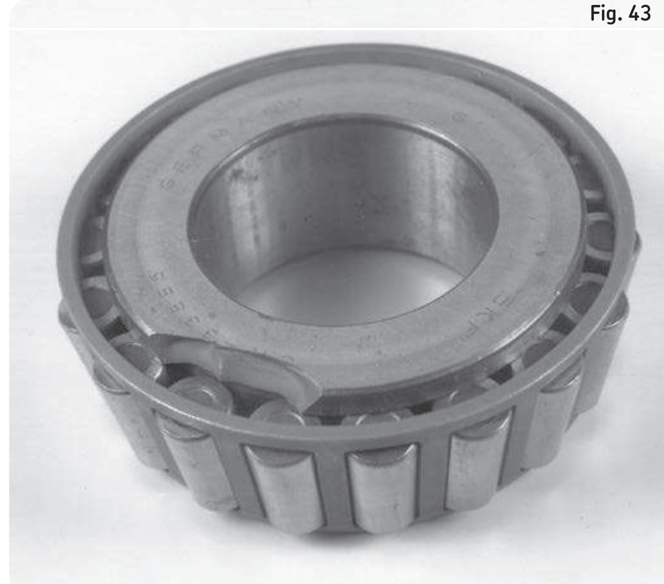
Fig. 43 shows rough treatment, a common cause for fracture. It happens when bearings are mounted cold, with a hammer and chisel.

Hitting the ring directly can cause fine cracks to develop, which will quickly turn into through-cracks when the bearing is put into operation.

Excessive drive-up (→ **fig. 44**) on a tapered seat can cause an inner ring to fracture. The hoop (tensile) stresses, arising in the ring as a result of excessive drive-up, cause the ring to crack through in service. Martensite hardened rings are more sensitive to this than bainite hardened rings.

The same result may occur when bearings are heated and mounted on oversized shafts.

Fig. 43



Fracture on the large shoulder of a tapered roller bearing inner ring resulting from rough treatment

Fractured inner ring of a spherical roller bearing with a tapered bore resulting from excessive drive-up

Fig. 44

Fatigue fracture

5.6 Fracture and cracking

- 5.6.2 Forced fracture
- 5.6.3 Fatigue fracture
- 5.6.4 Thermal cracking

- exceeding fatigue strength under bending
- crack initiation/propagation
- finally forced fracture
- rings and cages

A fatigue fracture starts when the fatigue strength of a material is exceeded under cyclic bending. Repeated bending causes a hairline crack which propagates until the ring or cage develops a through crack.

Fig. 45 shows an example of a cracked outer ring of a spherical roller bearing. The bearing was mounted in a housing with insufficient support in the load zone. As a result, the bearing outer ring was subjected to cyclical bending stress, until the ring developed a through crack.

Fatigue fracture of an outer ring of a spherical roller bearing

Fig. 45

Thermal cracking

5.6 Fracture and cracking

- 5.6.2 Forced fracture
- 5.6.3 Fatigue fracture
- 5.6.4 Thermal cracking

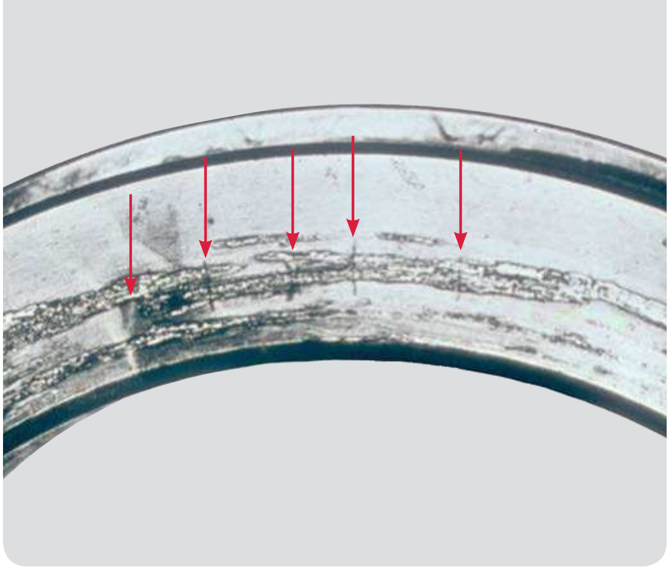
- substantial sliding and/or insufficient lubrication
- high frictional heat
- cracks at right angles to the sliding direction

Two surfaces sliding against each other generate frictional heat. If the sliding is substantial, the heat can cause cracks, which are generally at right angles to the direction of the sliding.

A typical example is shown in **fig. 46**. A rotating inner ring was fitted with a loose fit and subjected to an axial load. Due to creep, there was a sliding movement between the bearing side face and the shaft shoulder or spacer, which resulted in smearing. The frictional heat results in transverse cracks and eventually the ring will crack through.

Transverse thermal cracks on the small side face of the inner ring of a tapered roller bearing

Fig. 46



5 Damage and actions

In support to chapter 4, ISO failure modes classification, a number of additional illustrations are shown in this chapter.

It is not possible to cover all kinds of damage. Bearing damage will look different depending on: bearing type, bearing size, operating conditions, lubrication, contamination, etc. So, a limited number of cases are presented here.

The illustrations are classified per sub-mode – following ISO classification. For each sub-mode, a list of possible actions is provided. For each illustration the bearing type and damaged component is indicated, as well as the possible root cause.

Subsurface initiated fatigue

Actions:

- Make sure you have the right bearing for the actual application conditions and their variations (load, temperature, speed, misalignment, mounting, etc.)
- Use modern, state-of-the-art quality bearings
- If available, use SKF Explorer performance class bearings, which provide extended life
- Make sure adjacent components are properly designed and manufactured
- Mount correctly

Deep groove ball bearing inner ring
Material fatigue

Spherical roller bearing inner ring
Material fatigue

Tapered roller bearing inner ring
Spalling on one side of the raceway only, resulting from misalignment and consequent edge loading, leading to higher stress and failure

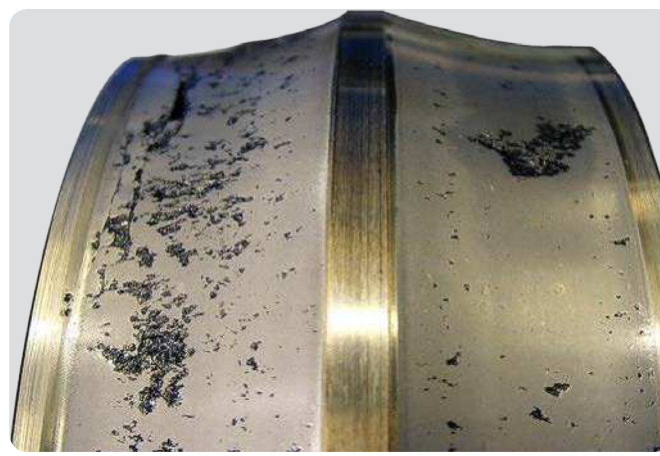
Self-aligning ball bearing outer ring
Spalling at 180° apart, resulting from excessive load due to oval clamping

Surface initiated fatigue

Actions:

- Make sure you have the right bearing for the actual application conditions and their variations (load, temperature, speed, misalignment, mounting, etc.)
- Make sure the lubrication is adequate: right lubricant, right quantity, right time
- Improve the surface separation capability of the lubricant (lubricant viscosity, additives, grease formulation)
- Check the lubricant quality at regular intervals
- Reduce the contamination (improved sealing, oil filtration)

Spherical roller bearing inner ring
Inadequate lubrication, surface distress with incipient spalling



Spherical roller bearing inner ring
Inadequate lubricant film. Initially, abrasive wear due to contamination, developed into surface distress and spalling.

Spherical roller bearing outer ring
Initially, abrasive wear due to contamination, developed into surface distress and advanced spalling

Tapered roller bearing outer ring
Inadequate lubricant film leading to surface distress and advanced spalling

Cylindrical roller bearing inner ring
Inadequate lubricant film, excessive misalignment, advanced surface distress

Cylindrical roller bearing outer ring
Inadequate lubricant film, some misalignment, advanced surface distress

Tapered roller bearing inner ring
Inadequate lubricant film, surface distress over a large area

Deep groove ball bearing inner ring
Excessive axial load, resulting in too thin lubricant film and surface distress

Double row angular contact ball bearing inner ring
Excessive misalignment, resulting in excessive loads, with two load zones 180° apart.

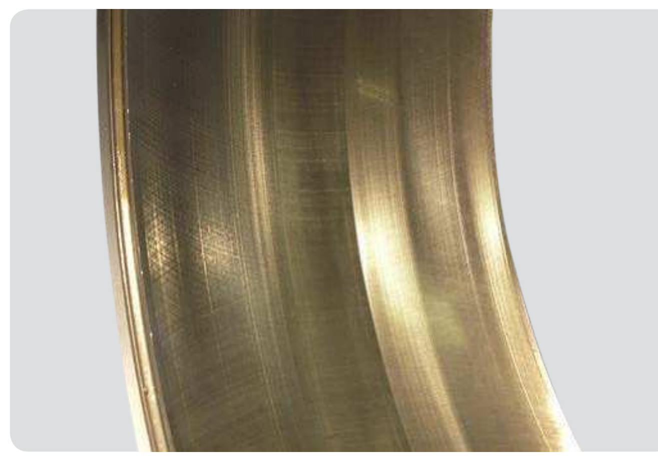
Deep groove ball bearing inner ring
Impact during mounting, resulting in spalling at ball pitch

Abrasive wear

Actions:

- Make sure an adequate sealing arrangement is in place considering the operational conditions
- Make sure the lubrication is adequate: right lubricant, right quantity, right time
- Check the quality of the lubricant at regular intervals
- Check the quality of the sealing arrangement at regular intervals
- Make sure housing and shaft fits are adequate to avoid creep

Spherical roller bearing inner ring
Contamination and resulting inadequate lubrication leading to abrasive wear of the raceway tracks – slightly shiny

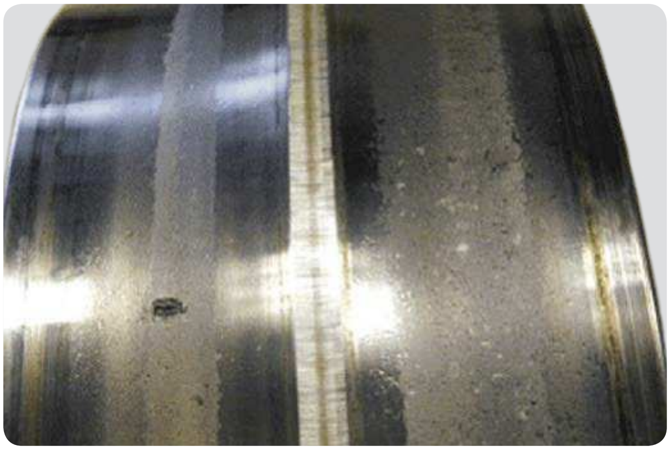


Spherical roller bearing outer ring
Abrasive wear of the raceway tracks in an early stage

Spherical roller bearing outer ring
Abrasive wear of the raceway tracks. The axially loaded one also partly discolored indicating inadequate lubrication and heat generation. The other raceway track shows a narrower load pattern with a matt appearance.

Spherical roller bearing inner ring
Contamination by fine particles – abrasive wear of the raceway tracks – rather shiny. Due to cage pocket wear, a groove has been cut by the cages on either side.

Spherical roller bearing inner ring
Contamination and resulting inadequate lubrication leading to abrasive wear of the raceway tracks – one raceway track more damaged due to axial load



Spherical roller bearing inner ring
Ingress of contaminants leading to inadequate lubrication, abrasive wear on the tracks and one incipient spall

Spherical roller bearing inner ring
Inner ring stationary – heavy abrasive wear – two wear zones: one with heavy wear; then creep of the inner ring with subsequent second wear zone

Angular contact ball bearing cage
Abrasive wear of the cage pockets due to inadequate lubrication and vibration. Cage bars worn away.

Spherical roller bearing outer ring
Ring creep in the housing from inadequate fit – abrasive wear marks on the outside surface

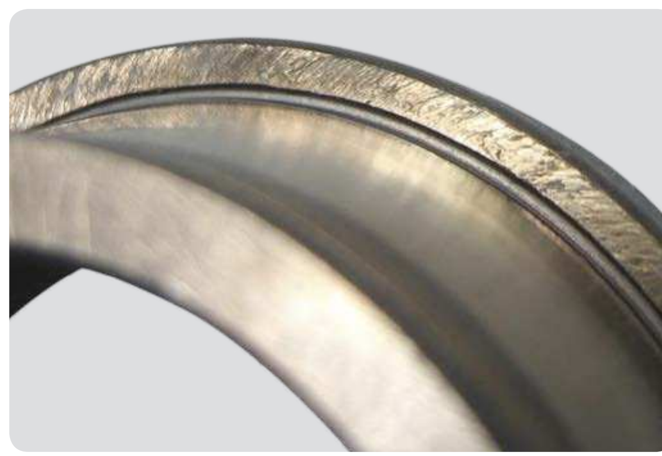
Spherical roller bearing outer ring
Ring creep in the housing from inadequate fit – polishing wear on the outside surface

Adhesive wear

Actions:

- Make sure the bearing is adequately loaded
- Make sure the sealing arrangement is operating efficiently
- Consider bearing downsizing
- Verify lubricant selection (viscosity, AW and EP additives)
- Consider using coatings
- Consider using hybrid bearings

Spherical roller bearing inner ring
Too low load combined with inadequate lubrication



Tapered roller bearing inner ring
Contamination and inadequate lubrication resulting in adhesive wear of the flange as well as a shiny raceway

Tapered roller bearing – roller
Contamination and inadequate lubrication leading to adhesive wear marks on the large roller end face

Spherical roller thrust bearing outer ring
Initially adhesive wear, then excessive heat generation, finally jamming

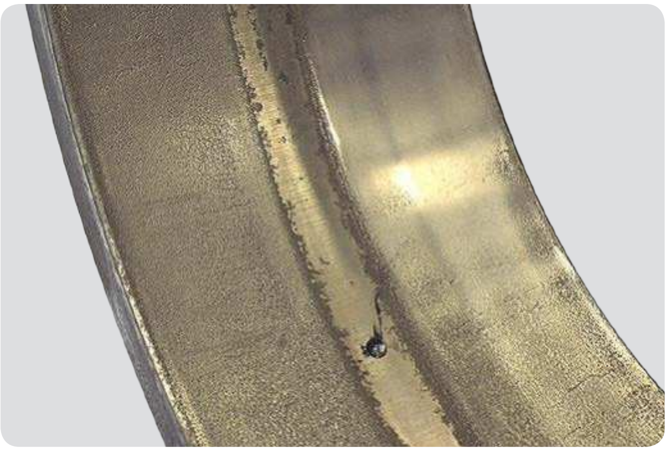
Moisture corrosion

Actions:

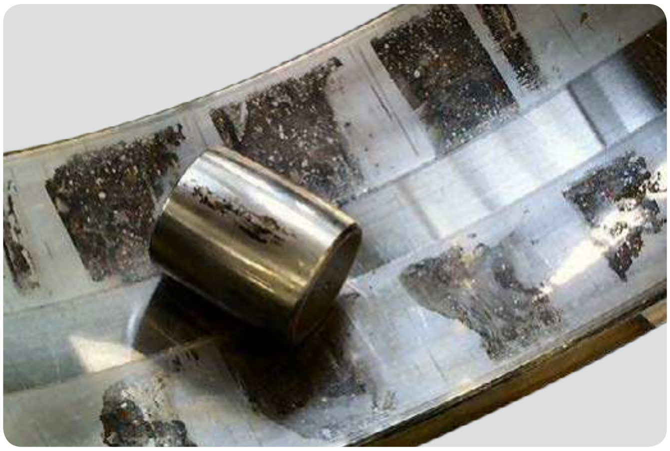
- Make sure the bearing arrangement is adequately protected
- Consider using sealed bearings in respect of the operating environment
- Make sure the lubrication is adequate: right lubricant, right quantity, right time
- Do not unpack bearings until mounting them
- Protect mounted bearings adequately

Tapered roller bearing in a pump unit
Seal failure, bearing corrosion and reddish discoulored grease

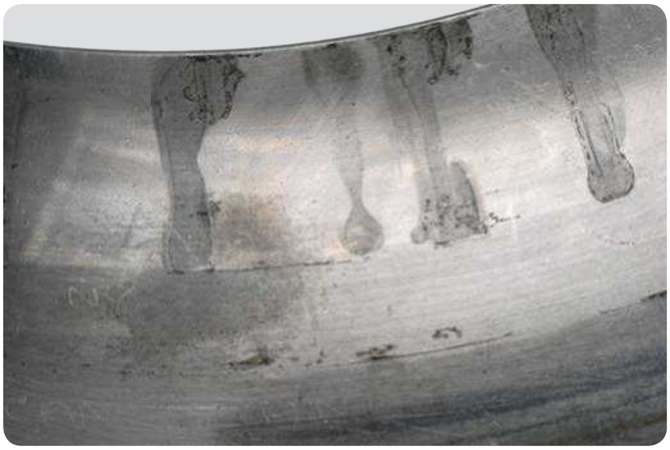
Spherical roller bearing – roller
Corroded roller due to severe water penetration into the bearing



Spherical roller bearing outer ring
Sealing arrangement failure, corrosive substance entered the bearing

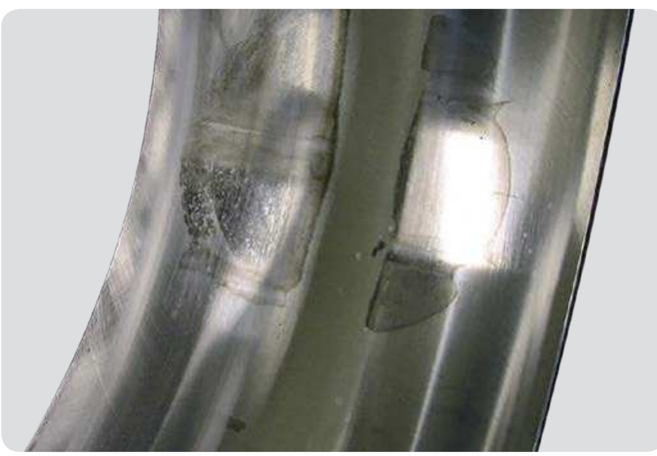


Spherical roller bearing outer ring and roller
Too high water content in the lubricant, standstill corrosion of raceway at roller pitch



Spherical roller bearing outer ring
Too high water content in lubricant, sets of etching marks at roller pitch at standstill

Spherical roller bearing inner ring
Lubricant contaminated by water, etching marks at roller pitch at standstill



Spherical roller bearing outer ring
Sealing arrangement failure, corrosion at standstill

Tapered roller bearing – roller
Rusty surface on raceway resulting from finger perspiration

Fretting corrosion

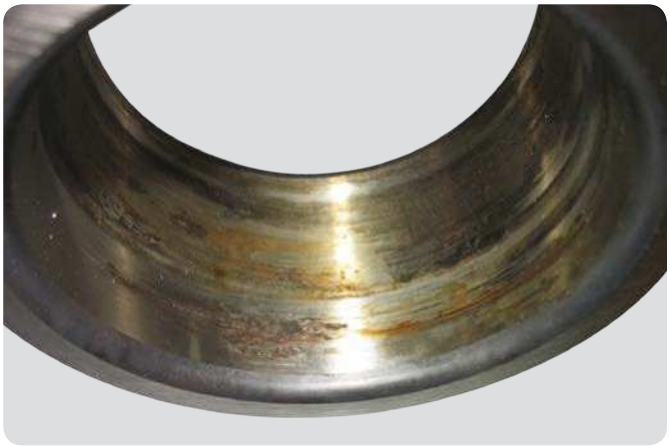
Actions:

- Select appropriate fits
- Make sure the bearing seats are adequately machined
- Make sure the bearing seats conform to dimensional and geometrical specifications (even after overhaul of the machine)
- In the case of loose fits, consider applying an anti-fretting paste or coatings on one of the bearing surfaces

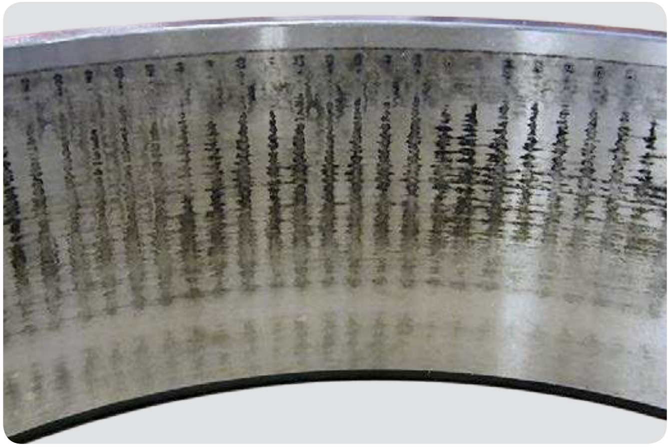
Cylindrical roller bearing inner ring
Inappropriate shaft fit (too loose)

Cylindrical roller bearing inner ring
Inappropriate shaft fit, uneven support

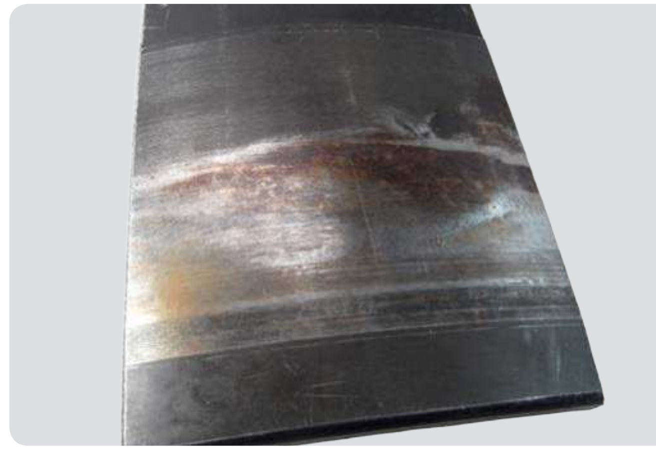
Cylindrical roller bearing inner ring
Inappropriate shaft fit, uneven support



Tapered roller bearing inner ring
Inappropriate shaft fit



Tapered roller bearing inner ring
Micromovement marks corresponding to shaft machining waviness



Tapered roller bearing outer ring (phosphated)
Uneven ring support

Spherical roller bearing outer ring
Brown coloured fretting corrosion area from micromovements due to advanced raceway spalling, with scratches due to dismounting

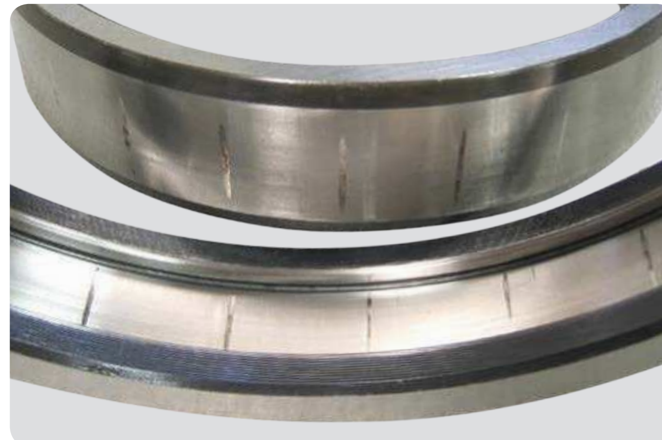
Spherical roller bearing outer ring
Inadequately supported ring

Spherical roller thrust bearing shaft washer
Inadequate seat

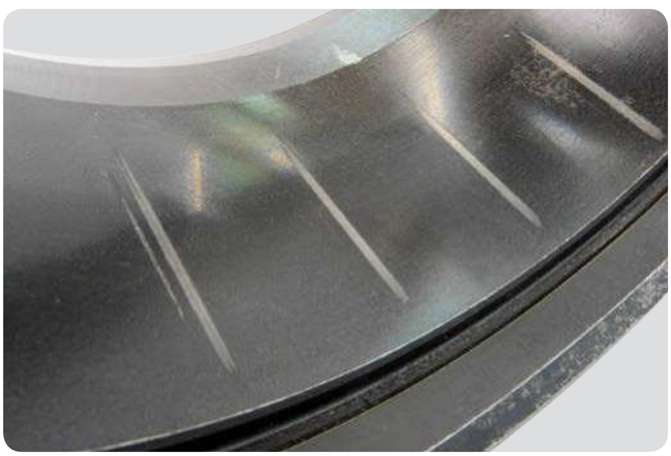
False brinelling

Actions:

- Do not expose bearings to vibrations at standstill
- Consider installing vibration damping pads
- Apply lubricant with anti-brinelling properties
- Rotate standby machines at regular intervals
- Use adequate bearing designs for vibratory applications



Cylindrical roller bearing inner and outer rings
Exposure to vibrations at standstill, false brinelling marks at roller pitch



Double row tapered roller bearing outer ring
Exposure to vibrations at standstill, false brinelling marks at roller pitch

Thrust ball bearing shaft washer
Exposure to vibrations at standstill, several sets of false brinelling marks at ball pitch

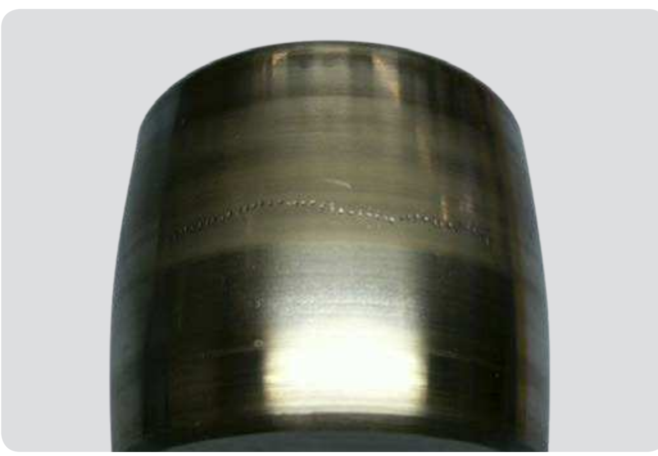
CARB toroidal roller bearing inner ring
Exposure to vibrations at standstill with small oscillatory movements, false brinelling marks at roller pitch

Spherical roller bearing outer ring
Exposure to excessive vibrations at standstill, sets of false brinelling marks at roller pitch

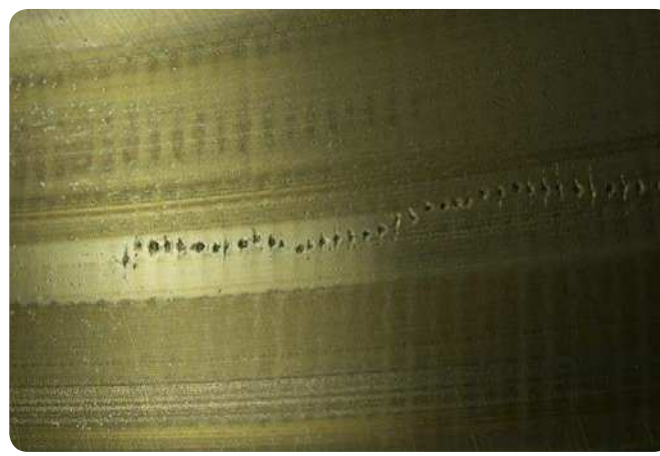
Excessive current

Actions:

- Make sure earthing connections are installed properly
- Use insulated bearings (INSOCOAT or hybrid bearings)



Spherical roller bearing – roller
Excessive current resulting in a large number of craters in a bead-like formation



Spherical roller bearing – roller
Enlarged view of craters in a bead-like formation

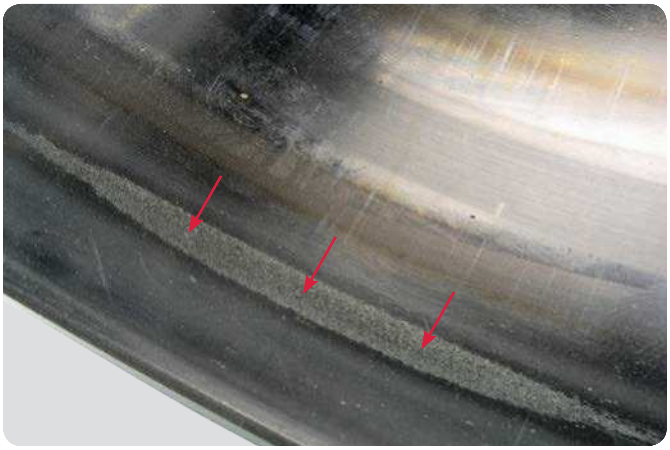
Spherical roller bearing – roller
Excessive current resulting in a large number of craters in a zig-zag formation

Deep groove ball bearing inner ring and ball
Excessive current resulting in a number of craters in zig-zag formation on the ball and raceway

Current leakage

Actions:

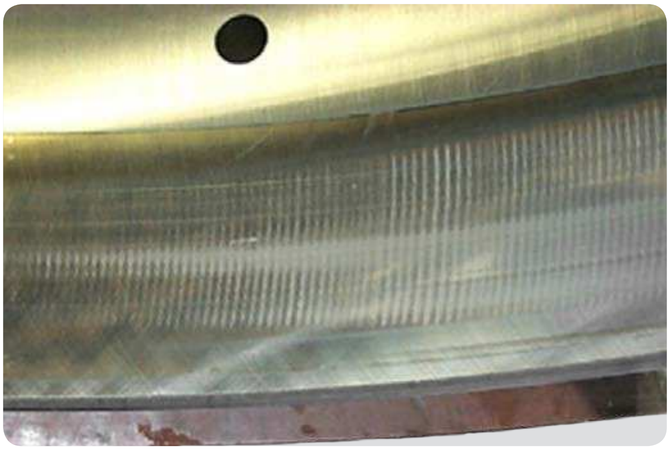
- Use symmetric cabling
- Make sure the stator and rotor are properly aligned
- Use insulated bearings (INSOCOAT or hybrid bearings)
- Make sure earthing connections are installed properly



Spherical roller bearing outer ring
Damage in early stage: dull grey zone with small shallow craters

Cylindrical roller bearing outer ring
Early stage of washboarding

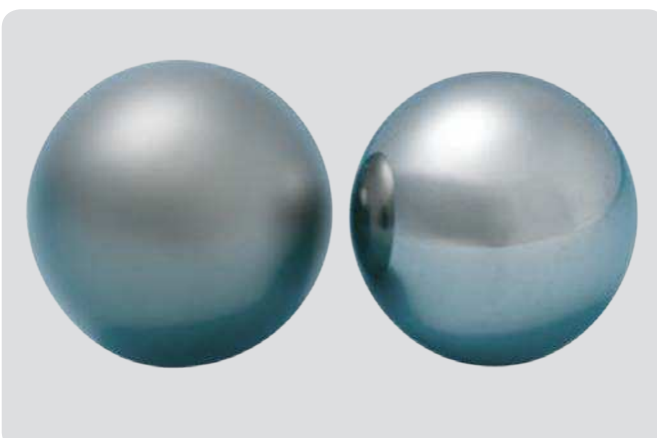
Tapered roller bearing outer ring
Early stage of washboarding



Spherical roller bearing outer ring
Current leakage

Cylindrical roller bearing outer ring
Advanced stage of washboarding

Deep groove ball bearing outer ring and ball
Washboarding in the outer ring and dull ball surface



Deep groove ball bearing – balls
Left: damaged ball – dull surface
Right: new ball – shiny surface

Cylindrical roller bearing outer ring with cage, rollers and grease
Current leakage resulted in burnt grease (black) on the cage bars

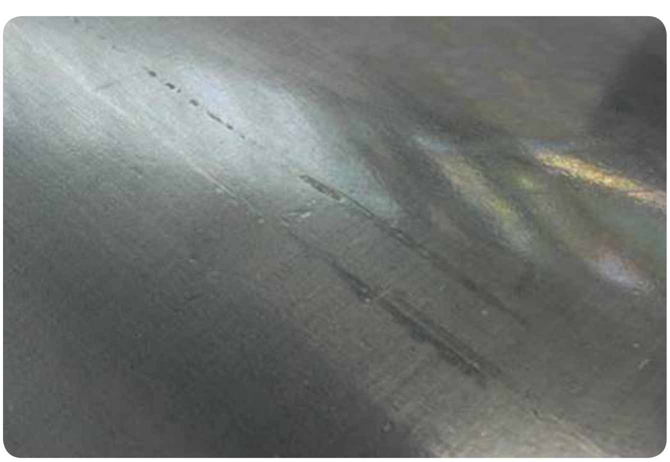
Overload

Actions:

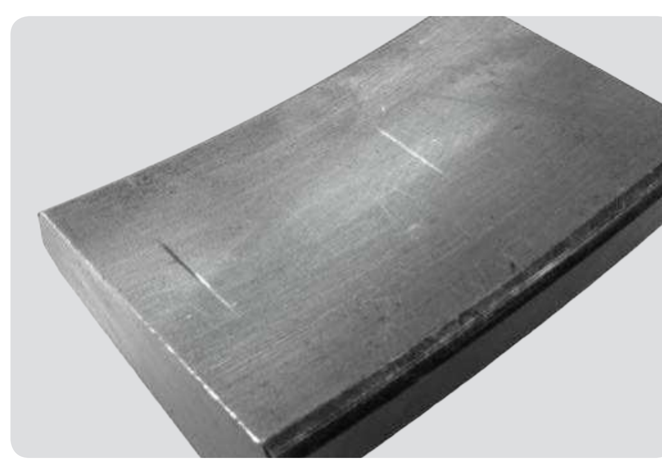
- Use appropriate methods for mounting bearings
- Use appropriate tools or mounting dollys as required
- Follow mounting procedures and instructions carefully

Cylindrical roller bearing inner ring
During mounting, inner and outer rings were not aligned properly. Axial marks at roller pitch.

Cylindrical roller bearing inner ring
During mounting, inner and outer rings were not aligned properly. Axial marks at roller pitch.



Tapered roller bearing outer ring
Scoring during handling

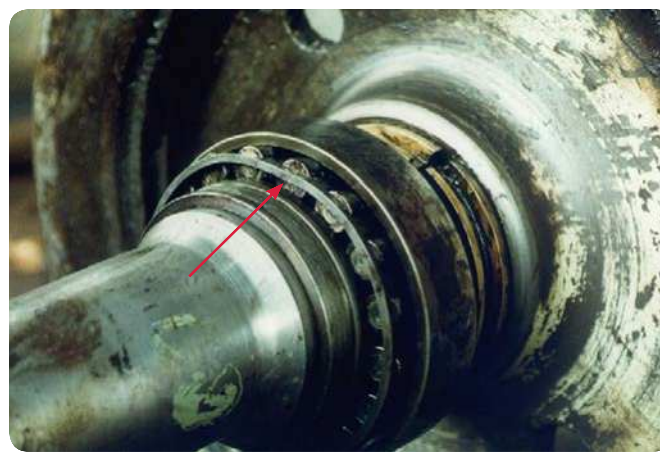


Tapered roller bearing outer ring
Scoring during mounting

Double row tapered roller bearing outer ring
Overload impact and misalignment at standstill, resulting in deformation and subsequent spalling at roller pitch

Spherical roller thrust bearing – roller
Heavy impact, plastic deformation

Deep groove ball bearing outer ring
Plastic deformation at ball pitch from applying mounting force to the wrong ring

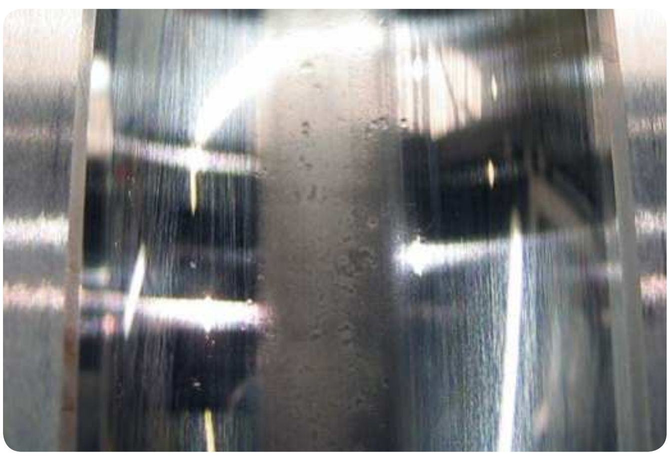


Tapered roller bearing mounted on a railway wheel set
Cage was hit directly during mounting, resulting in permanent deformation (flattening)

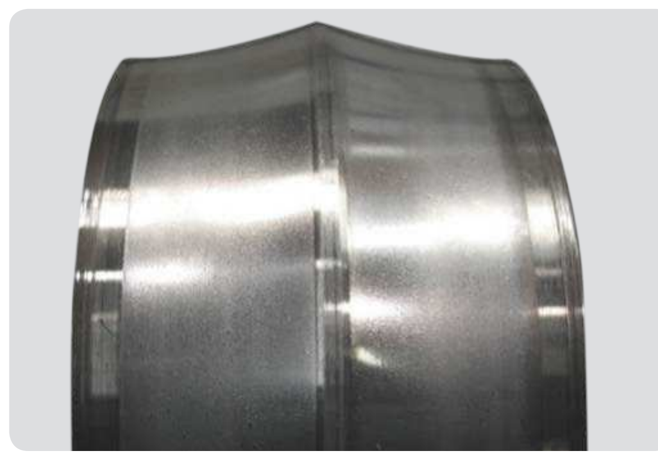
Indentations

Actions:

- Make sure to work in clean conditions
- Use adequate sealing to protect the bearing
- Make sure the lubrication is adequate: right lubricant, right quantity, right time
- Never drop a bearing
- Treat bearings carefully

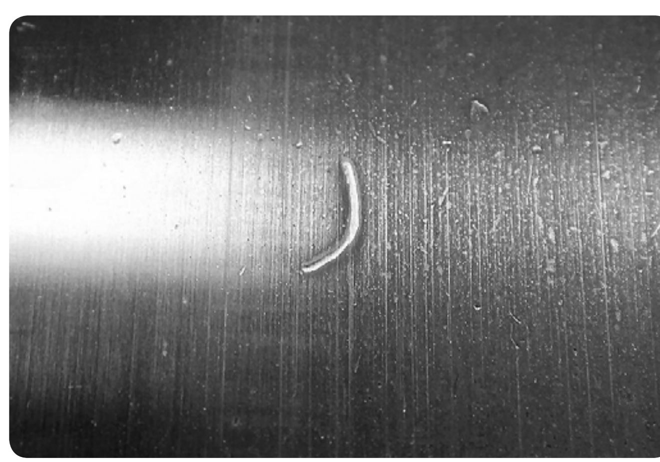


Deep groove ball bearing inner ring
Dents resulting from overrolling of hard particles – inadequate sealing arrangement



Spherical roller bearing inner ring
Many small dents resulting from overrolling of small hard particles – inadequate sealing arrangement

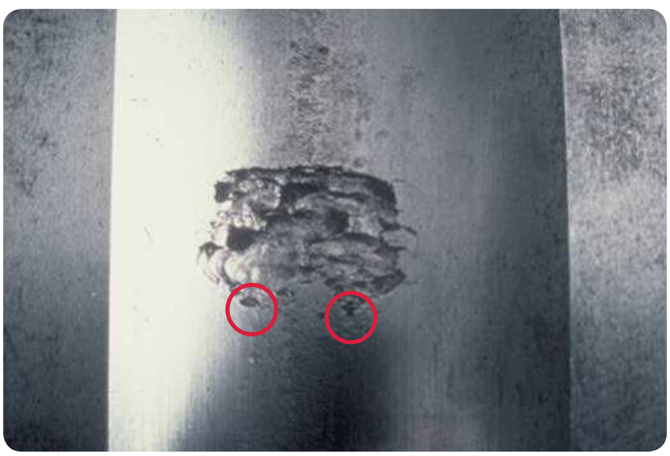
Spherical roller bearing outer ring
Overrolling of hard particles that entered the bearing during mounting – lack of cleanliness



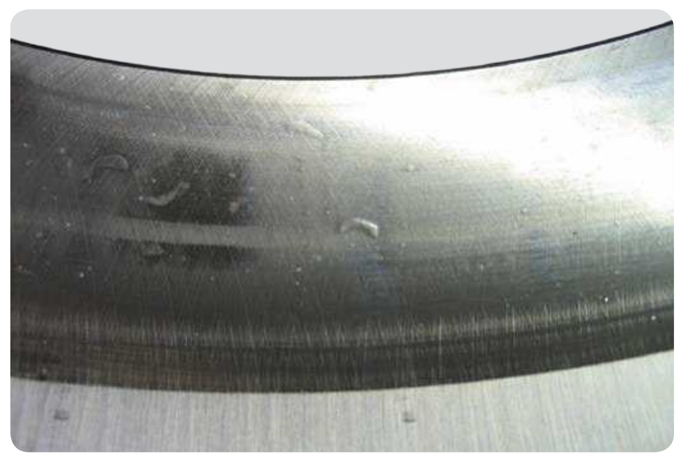
Spherical roller bearing outer ring
Overrolled swarf/chip will lead to spalling

Tapered roller bearing inner ring
Overrolling of big and hard particles that entered the bearing due to inadequate sealing arrangement

Deep groove ball bearing – ball
Damage resulting from hard particles in very contaminated lubricant



Deep groove ball bearing inner ring
Overrolling of particles with sequential spalling starting at the back of the dents



Spherical roller bearing outer ring
Overrolling of swarf entered during mounting – lack of cleanliness

Forced fracture

Actions:

- Select appropriate fits
- Use appropriate methods for mounting bearings
- Use appropriate tools or mounting dollys as required
- Follow mounting procedures and instructions carefully
- Never use brute force on bearings or apply mounting forces through the rolling elements

Tapered roller bearing inner ring
The bearing was fitted to an oversized shaft

Deep groove ball bearing outer ring side face
Fracture at seal anchorage groove due to impact when mounting the bearing

Self-aligning ball bearing outer ring
Fracture resulting from excessive misalignment and balls running over the raceway edge

Cylindrical roller bearing – inner ring, outer ring and rollers
Seized bearing – forced fracture of cage due to lubrication problem

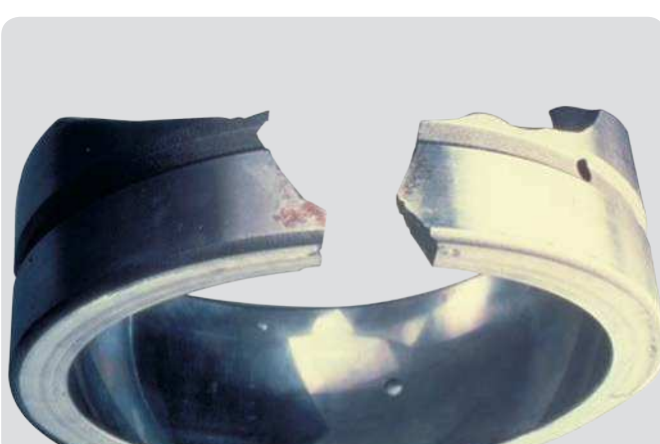
Fatigue fracture

Actions:

- Make sure bearing seats conform to geometrical specifications
- For split housings, make sure the two halves join correctly
- Bearing seats should be clean (no swarf or chips, which could create local stress rise)
- Use appropriate tools and methods for mounting

Cylindrical roller bearing inner ring
Very heavy spalling – fatigue fracture as sequential damage

Spherical roller bearing inner ring
Very heavy spalling – fatigue fracture as sequential damage



Spherical roller bearing outer ring
Fatigue fracture resulting from inadequate housing seat (swarf trapped at the bottom of the housing)

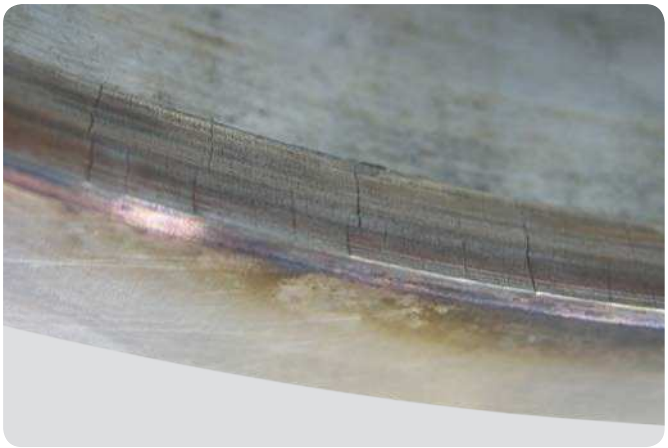
Spherical roller bearing outer ring
Inadequate housing seat leading to fretting corrosion and finally fatigue fracture

Thermal cracking

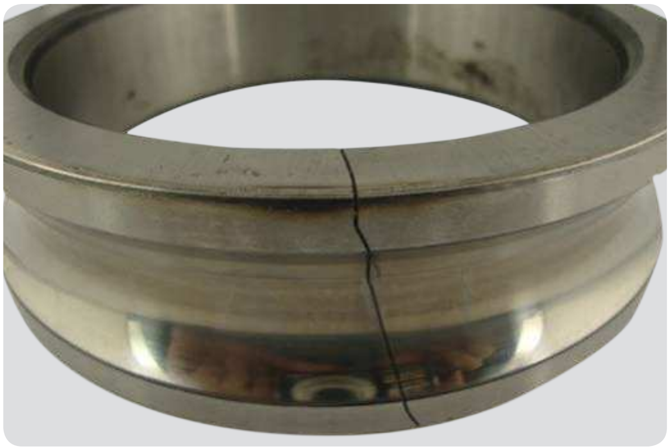
Actions:

- Lubricate sliding surfaces or apply coatings to reduce local peak temperatures
- Make sure the lubrication is adequate: right lubricant, right quantity, right time
- Check for application specific solutions with the SKF application engineering service

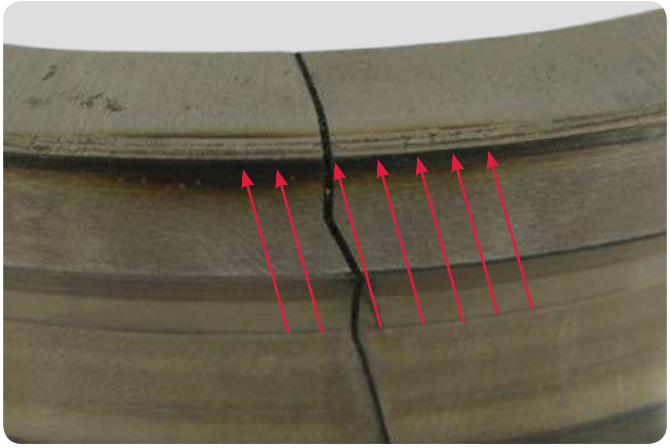
Cylindrical roller bearing outer ring
Thermal cracks at both shoulder-cage contact due to inadequate lubrication



Cylindrical roller bearing outer ring
Thermal cracks at shoulder-cage contact due to inadequate lubrication



Deep groove ball bearing inner ring
Ring fractured due to excessive friction against a stationary part of the bearing assembly



Deep groove ball bearing inner ring
Enlarged view of fractured ring, with many heat cracks along the inner ring shoulder

6 Other investigations

The scope for the ISO standard 15243 is limited to:

- damage and changes in appearance occurring in a bearing during service
- changes in appearance that can be attributed to particular causes with a high degree of certainty
- damage assessment using non-destructive methods

With these limits, it is not always possible to determine the root cause of a failure. More in-depth investigations might be necessary. SKF offers a variety of in-depth inspection services in three areas of expertise:

Metallurgy

- evaluation of all types of heat treatment
- testing for micro and macro inclusions, microstructure anomalies, carbide network and segregations, grain size, fibre flow, surface defects, hardenability and other metallurgical parameters
- hardness testing, determining tensile strength, yield strength and elongation, component testing and other technical parameters
- metallurgical examinations
- support in the development of specifications for materials, testing and heat treatment
- ultrasonic immersion testing service (complete rings, rollers, etc.)

Failure and performance analysis

- failure analysis of bearings and other components (e.g. housings, camshafts) from production, rig tests or field returns
- metallography and material testing

Microstructure evaluation

Material samples preparation

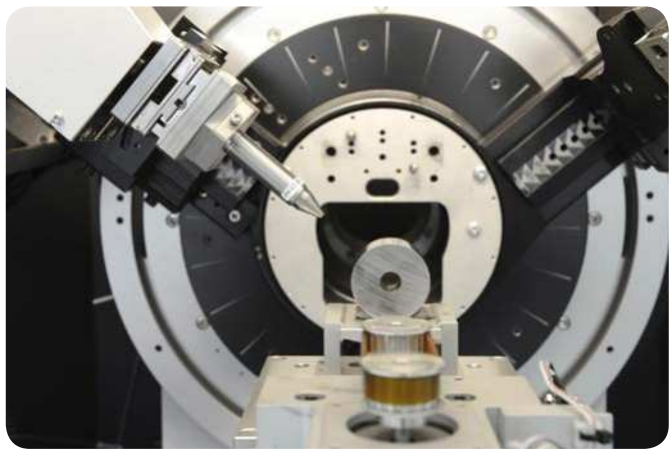
Ultrasonic test rig

- microanalysis of particles and bearing contamination, reaction layers and coatings
- X-ray diffraction (XRD) based material response analysis of bearings from rig tests or the field to identify the mechanism and progress of material loading
- XRD to measure levels of retained austenite
- material and technology consultancy

Chemistry – properties and performance

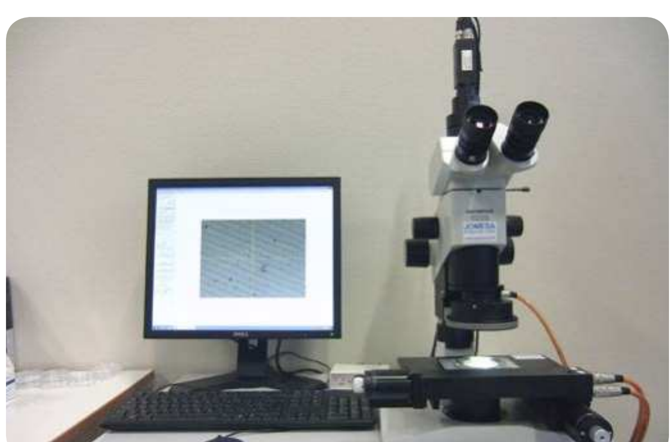
- evaluation of physical and chemical properties of lubricants, polymers and seal materials
- grease and oil testing to determine remaining grease life and levels and types of contamination
- elemental analysis of materials
- testing the chemical composition of metals by optical emission spectrometry, inert gas fusion or combustion methods
- evaluation of preservatives and coatings
- compatibility testing of lubricants, polymers and seal materials
- cleanliness assessment of lubricants and bearings, including particle counting and gravimetric investigation

Scanning electron microscope



X-ray diffraction apparatus

Cleanliness assessment (contamination analysis) – rinsing



Cleanliness assessment (contamination analysis) – automatic evaluation

7 Case studies

This chapter deals with a few case studies. Although some were complex, in-depth investigations enabled SKF engineers to determine the failure sequence and suggest corrective measures.

Train derailment

Background information

Industry: Railway
Application: SKF axleboxes for goods wagons (→ **figs. 1** and **2**), 20-tonne axle payload
Bearings: 2 x SKF 229750 J/C3R505 per axlebox
Problem: Derailment

Goods wagons equipped with "Y-25" bogies, incorporating axleboxes with a double spring suspension

Fig. 1

A train hauling cargo passed a hot box detector (a device placed at intervals on tracks to detect hot running bearings). Everything appeared normal.

But, 35 km later, the train derailed. The axle of a wheelset had broken. The wagon in question had been overhauled not long before by an authorized railway repair shop.

Observations and description of bearing and axlebox damage

This was clearly more than a "hot runner" (→ **fig. 3**). The outer ring of the inboard bearing was severely deformed. Based on the level of deformation, the metal reached a temperature well over 800 °C (*1 470 °F*).

There was a gap between the outer ring of the inboard bearing and the labyrinth seal, measuring 21 mm (**fig. 3**, bottom left).

The shaft spacer had a width of only 14 mm.

Failure analysis

There are two different versions of this axlebox that are almost identical:

- The early version, the one discussed here, designed for a 20-tonne axle payload, used a 35 mm spacer between the bearing inner rings.
- The later version, designed for a 22,5-tonne axle payload, used a 14 mm spacer between the bearing inner rings. The shorter spacer resulted in a shorter, stronger shaft, to accommodate the heavier payload.

Apparently, the shorter spacer was installed during the overhaul. As a result, the bearing inner rings were not properly axially clamped and able to move on their shaft seat towards the outboard side, which increased shaft bending. Also the outer rings were not properly positioned in the axle box housing, leading to axial contact in the labyrinth seals. This resulted in high frictional heat, bearing seizure, shaft fracture and derailment.

Conclusions

Installing a wrong component, even a small spacer, led to very high overall cost (rail tracks, catenary, hours of traffic disruption, six wagons to the scrap yard).

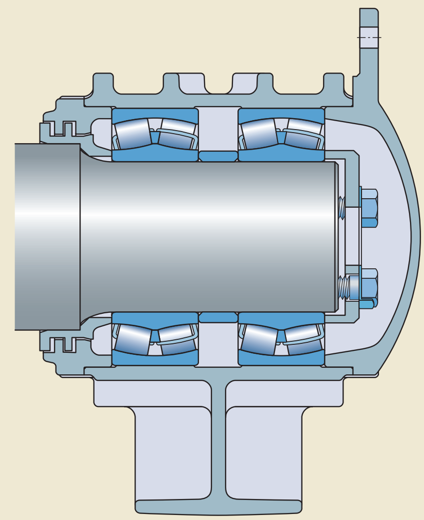
Recommendations to the customer

Improve maintenance instructions and make sure they are unambiguous.

Corrective actions

The customer reviewed and improved the maintenance instructions, to make sure such accidents would not reoccur.

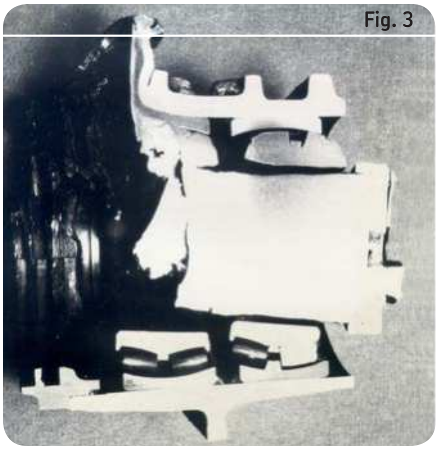
Fig. 2



Typical axlebox bearing arrangement for 20-tonne axle payload
Both the inner rings of the inboard and outboard bearing are held in place by a labyrinth collar on the shaft, a 35 mm spacer between the inner rings, and an end plate. The axlebox is located axially by a split labyrinth cover on the inboard side and an end cover on the outboard side.

Remains of the failed axlebox (cut), as presented for the failure analysis

Fig. 3



Variable speed electric motor problem

Background information

Industry: Pulp and paper
Application: Variable speed electric motor in the reel section (→ **fig. 4**) of a tissue paper machine, 400 VAC with frequency converter
Bearings: Non-locating: NU 322 ECM/C3VL024 (insulated)
Locating: 6322 M/C3VL024 (insulated)
Speed: Variable, 1 000 to 1 500 r/min
Lubrication: SKF LGEP 2 grease – manual lubrication
Problem: Average bearing service life only 1–2 months

Observations and description of bearing damage

After only one month of operation, there was severe damage to the cylindrical roller bearing. (The ball bearing was not affected.) The machine was stopped because of high vibration levels.

Inner ring

There was heavy wear on the raceway. The wear was irregular; some flats were observed. The raceway was dull and grey in colour (→ **fig. 5a**).

Outer ring

There was heavy wear on the raceway (load zone). The wear was irregular. Marks similar to those caused by vibration (washboarding) were visible. The raceway was dull and grey in colour (→ **fig. 5b**).

The insulation coating on the outside surfaces was intact.

Failure analysis

The visual inspection only revealed an irregular waviness pattern, which looked like heavy wear from vibration.

Looking very closely at the damaged rings and from discussions with the customer, there were two possible causes:

1) excessive vibration
2) current passing through the bearings

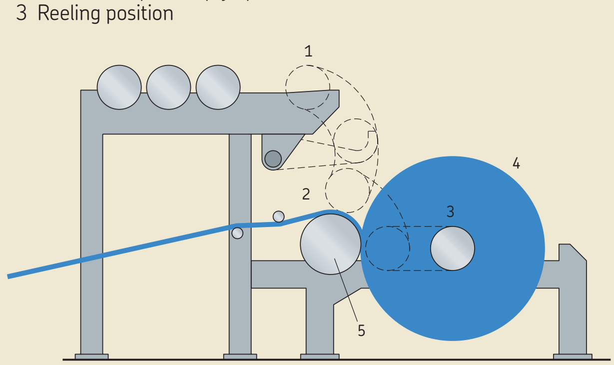
However, the customer confirmed that "insulated" bearings were used, and all machines were properly supported by new rubber pads to dampen vibration.

Neither of the two possible causes seemed definitive, and the bearing was taken back to the laboratory for further investigation.

Typical layout of a Jumbo roll (reel spool)

Fig. 4

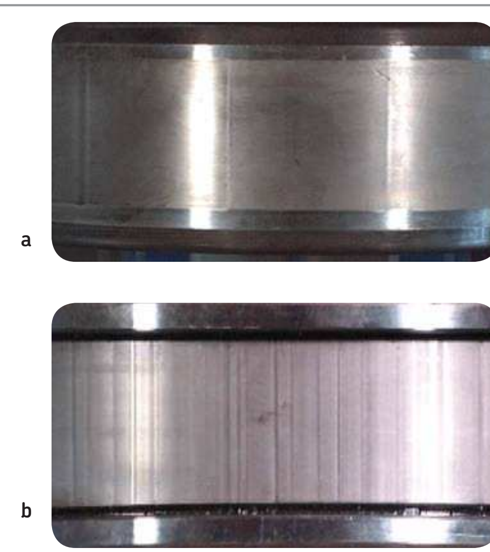
1 Reel spool storage
2 Web turn-up to empty spool
3 Reeling position
4 Jumbo roll
5 Reel drum



The reel drum is driven by the variable speed electric motor

Heavy wear and vibration marks on the inner ring (a) and outer ring (b) raceways of the cylindrical roller bearing

Fig. 5



When the bearing was cut, and a section put under a microscope, some interesting conclusions could be made:

The raceway surface showed microcraters that were the result of a damaging electrical current passing through the bearing (current leakage) (→ **figs. 6** and **7**).

This led to washboarding. After that (and continuously) a large amount of material had worn off, and had led to the strange pattern on the raceways of the inner and outer rings.

Conclusions

The failure mode is clearly current leakage erosion (ISO 5.4.3).

Recommendations to the customer

Check the electrical system.

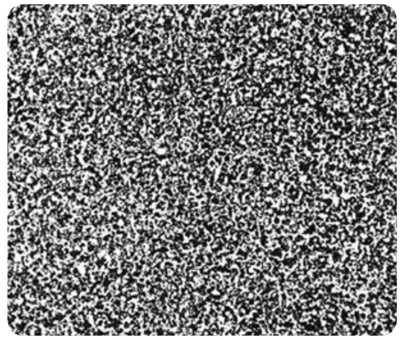
Corrective actions

As current leakage was identified as the root cause of the bearing damage, the customer inspected the entire electrical system.

The inspection showed that during one of the motor repairs, the grounding (earth) cable was disconnected and not reconnected.

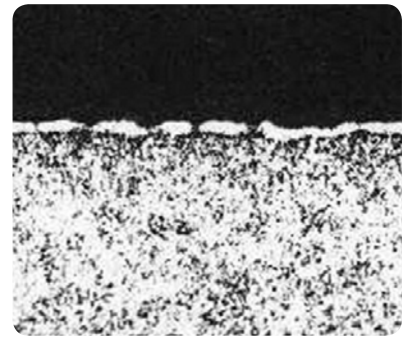
Once the grounding cable was reconnected and another set of insulated bearings was installed, no further problems were reported.

Fig. 6



The inner ring raceway surface under 150x magnification showing a very large number of microcraters

Fig. 7



Cross section of the inner ring under 500x magnification
The thin, light strip on top (underneath the black space) is the raceway surface. This is material that was rehardened due to the heat developed in the contact area. Below the light area, there is a thin, dark strip that had been annealed. The lower part is the steel with normal hardness.

Clay mill problem

Background information

Industry: Construction
Application: Clay mill in a brick factory
Bearing: SKF 24044 CCK/C3W33 – locating bearing
Loads: Unknown, but relatively heavy, with shock loads
Speed: Below 100 r/min
Temperature: Approx. 30 °C (*85 °F*)
Lubrication: SKF LGEP 2 grease
Relubrication: 30 g every 30 hours
Problem: Premature bearing failure – 1,5-years service life

Observations and description of bearing damage

Radial clearance

After washing and before disassembly, radial internal clearance of the bearing was measured at 0,900 mm. A new bearing measures between 0,250 and 0,320 mm.

When the inner ring was swivelled, rollers fell out from the cage pockets.

Inner ring

The bore showed no signs of fretting corrosion and the side faces were undamaged. The raceways showed severe abrasive wear. On both raceways, the cages had cut a groove at the edge of the raceway, indicating that the cages were making contact with the raceways. The raceways were dull and grey in colour (→ **fig. 8**).

There were small corrosion spots, but not over-rolled.

Some transverse smearing marks (at roller pitch) resulted from dismounting the bearing.

Outer ring

The raceways showed heavy abrasive wear, and were dull and grey in colour (→ **fig. 9**). There were also transverse smearing marks (at roller pitch) from dismounting.

Severe fretting corrosion was visible on the outside surface (→ **fig. 10**), which was the result of ring creep movements under heavy load and uneven ring support.

The side faces of the outer ring also showed fretting corrosion (→ **fig. 11**), which further confirms ring creep.

Rollers

The rollers were dull and grey in colour. Smearing marks from dismounting were visible (→ **fig. 12**).

Cages

The pockets of the window-type cages exhibited abrasive wear. The cage bars were worn substantially (→ **fig. 13**).

Guide ring

The guide ring showed no signs of wear or damage.

Grease

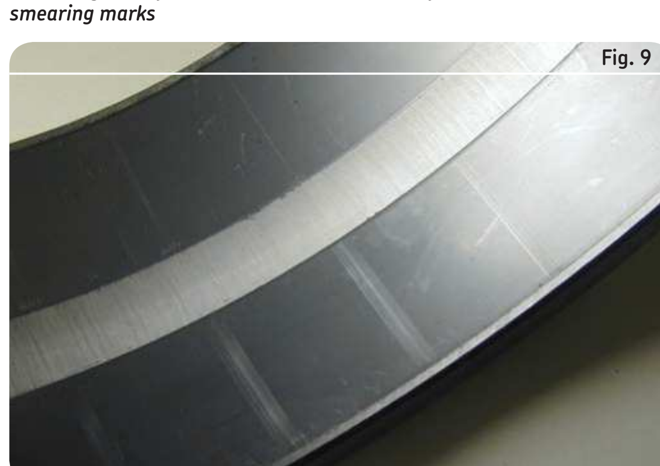
The grease was heavily contaminated and discoloured in comparison to fresh grease.

Inner ring: Heavy abrasive wear on the raceways and a circumferential groove at both raceway edges

Fig. 8

Outer ring: Heavy abrasive wear on the raceways and transverse smearing marks

Fig. 9



SKF

Failure analysis

There was a huge amount of abrasive wear in the bearing. The cage pocket clearance had increased substantially, making the cage drop and cut a groove at the edge of the raceway.

Clearly, there was a problem with lubrication resulting from clay that entered the bearing cavity.

Conclusions

The failure mode is clearly abrasive wear (ISO 5.2.2).

Recommendations to the customer

Improve the sealing arrangement to protect the bearing. This can be done by:

- relubricating daily
- using sealed SKF Explorer spherical roller bearings
- using a labyrinth seal that has a relubrication feature
- replacing the current sealing solution with SKF taconite seals
- installing a continuous relubricator for the sealing arrangement to further extend bearing life

Check the lubrication pipes and grease fittings for blockage.

Check the bearing seat in the housing and repair if needed.

Corrective actions

The customer improved the sealing arrangement and reduced lubrication intervals.

Fig. 10

Outer ring: Fretting corrosion on the outside surface

Fig. 11

Outer ring: Fretting corrosion on the side face

Roller: Dull and grey colour

Fig. 12

Cage: Pocket wear

Fig. 13

Jaw crusher problem

Background information

Industry: Mining
Application: Jaw crusher (→ **figs. 14**, **15** and **16**)
Bearings: SKF 231/500 CAK/C3W33
Problem: Premature bearing failure (main shaft bearing, outboard)

The customer had been using only high quality bearings. The main shaft bearings were replaced every five years. After the last overhaul, the bearings failed within two years.

The customer asked SKF to determine the root cause of the premature failures.

Observations and description of bearing damage

Inner ring

There was heavy abrasive wear on the raceways (→ **fig. 17**). No other marks were visible.

Outer ring

There was heavy spalling on the raceways in a small area of the load zone. There were heavy vibration marks over a large part of the load zone (→ **fig. 18**).

There was heavy fretting corrosion on the outside surface corresponding to the load zone (→ **fig. 19**).

Cage

The cage pockets exhibited heavy and irregular wear (→ **fig. 20**).

Failure analysis

The bearing inspection highlighted two problems:

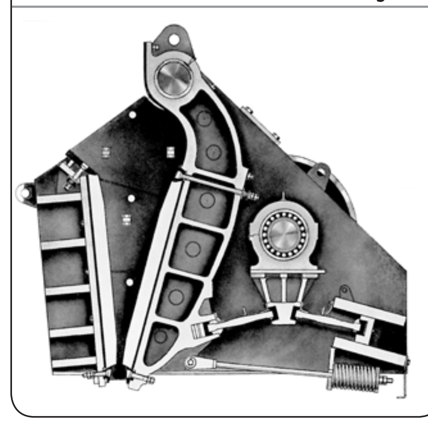
1) The outer ring showed damage in the same area of the load zone on both the outside surface (fretting corrosion) and the raceways (spalling), which indicated a problem with the bearing seat in the housing.

   The abrasive wear on the inner ring raceways was probably secondary damage due to the spalling, as the condition of the lubricant was found to be unacceptable.
2) The waviness on the outer ring raceways and the severe cage wear indicated a serious vibration problem during operation.

Fig. 14

Typical large jaw crusher

Fig. 15



Principle of a double-toggle jaw crusher

Conclusions

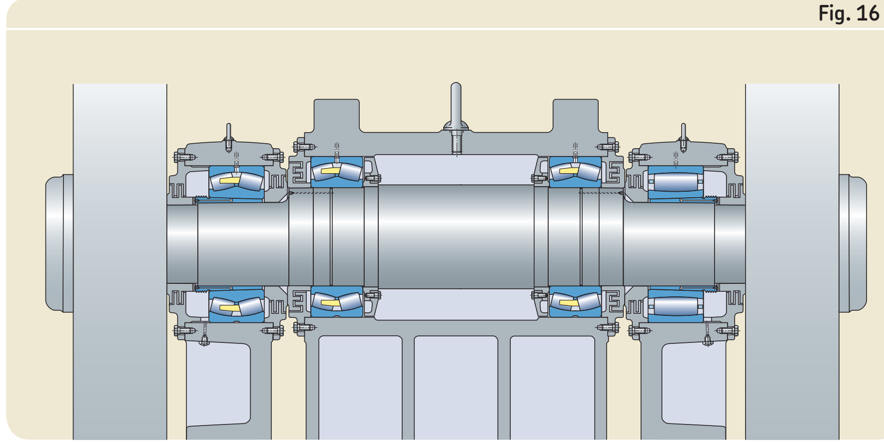
The cause of the failure appeared to be the fretting corrosion from a damaged outer ring seat (ISO 5.3.3.2).

Recommendations to the customer

1) Check the bearing seat in the housing. Repair if needed.
2) Locate the source/cause of vibration during operation.

Typical jaw crusher bearing arrangement

Fig. 16



Corrective actions

1) An inspection of the housing confirmed that the bearing seat had become worn and was no longer providing adequate support in the load zone. This caused severe fretting corrosion on the outside surface of the outer ring and subsequent distortion of the raceways in the load zone. The distortion caused premature spalling.
2) A thorough mechanical review of the application showed that material was not discharging adequately, which caused the crusher to "bottom out" and act as a compactor. This explained the excessive vibration and the heavy external loads that accelerated fretting corrosion and the waviness on the raceways.

During a planned shutdown, the bearing seat was repaired and the discharge end of the crusher redesigned. Since the modifications, no further problems have been reported.

Fig. 17

Inner ring: Abrasive wear on the raceways

Fig. 18

Outer ring: Load zone spalls and vibration marks on the raceways, at the bottom of the ring

Fig. 19

Outer ring: Heavy fretting corrosion in the load zone of the outside surface

Fig. 20

Cage: Heavy pocket wear

7

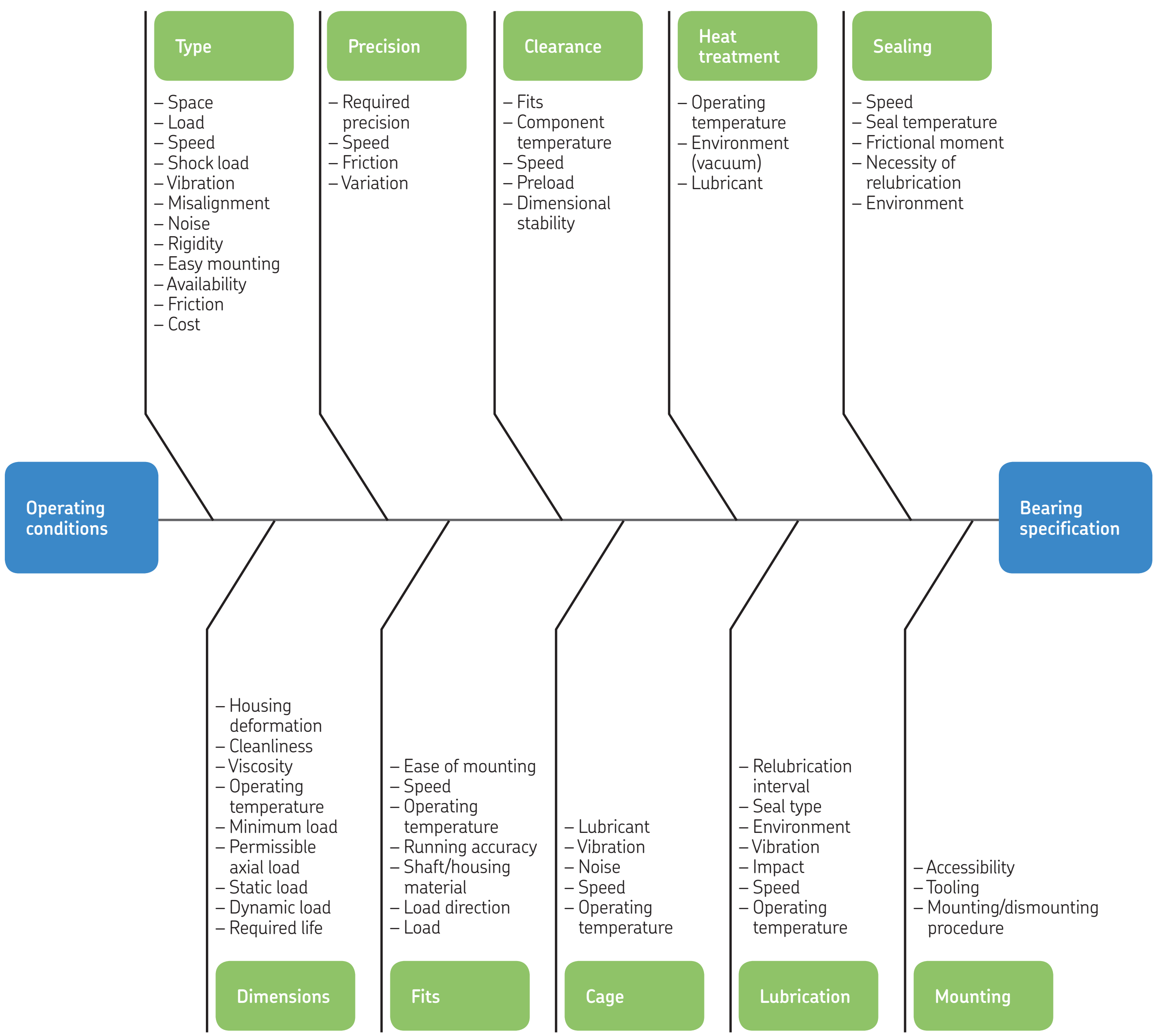
8 Appendices

Appendix A: SKF classification adapted from ISO 15243:2004[1)]

- **5.1 Fatigue**
  - 5.1.2 Subsurface initiated fatigue
  - 5.1.3 Surface initiated fatigue
- **5.2 Wear**
  - 5.2.2 Abrasive wear
  - 5.2.3 Adhesive wear
- **5.3 Corrosion**
  - 5.3.2 Moisture corrosion
  - 5.3.3 Frictional corrosion
    - 5.3.3.2 Fretting corrosion
    - 5.3.3.3 False brinelling
- **5.4 Electrical erosion**
  - 5.4.2 Excessive current erosion
  - 5.4.3 Current leakage erosion
- **5.5 Plastic deformation**
  - 5.5.2 Overload deformation
  - 5.5.3 Indentations from debris
- **5.6 Fracture and cracking**
  - 5.6.2 Forced fracture
  - 5.6.3 Fatigue fracture
  - 5.6.4 Thermal cracking

[1)] Compared to ISO 15243:2004, in failure mode 5.5, Plastic deformation, the submodes "Overload deformation" and "Indentations from handling" have been merged into "Overload deformation". Failure mode 5.4.2 has been corrected into "Excessive current erosion".

Appendix B: Factors influencing bearing selection



Appendix C: Bearing damage and failures – modes and causes

Which surfaces show changes?		What kind of changes?	Which one of the below changes?	Related ISO failure modes
Any surfaces, on any of the components of the bearing		Discoloration	Moisture corrosion	5.3.2
			Coloured layers and deposits	5.2.3 / 5.6.4
		Fractures and cracks	Ring fracture without other visible changes in the fracture area	5.6.2
			Ring fracture in connection with smearing marks	5.2.3 / 5.6
			Ring fracture in connection with heat discoloration	5.2.3 / 5.6
			Ring fracture in connection with grinding burns	5.6.3
			Ring fracture in connection with impact / mechanical damage	5.5.2 / 5.6
			Ring fracture in connection with fretting corrosion or moisture corrosion	5.3.2 / 5.3.3.2 / 5.6
On specific surfaces	On mating surfaces	Fretting corrosion wear	Reddish surface	5.3.3.2
			Polished surface	5.2.3
	On raceways and rolling elements	Changes only on running track of rings or rolling elements	Surface damage due to over-rolled particles (indentations)	5.5.3
			Surface damage due to outbreaks (spalls)	5.1.2 / 5.1.3
			Surface wear	5.2.2
			Surface initiated fatigue	5.1.2
			Surface damage, appearance of flutes (shiny / reddish / dull grey at flute bottoms)	5.4.3 / 5.3.3.3
			Surface damage, appearance of nicks, grooves, smearing	5.5.2 / 5.6
			Circumferential band marks on rolling elements	5.2.2
			Shiny, polished appearance	5.2.2
		Changes at regular pitch distance on a part of the running track of a ring(s)	Plastic deformations	5.5.2 / 5.6
			Standstill vibration marks (at rolling element pitch)	5.3.3.3
			Score marks	5.5.2
			Corrosion marks, crevice corrosion, etching marks	5.3.2
		Single, local changes at irregular pitch distances on a part of the running track of a ring(s)	Spalls (subsurface fatigue)	5.1.2
			Surface damage: appearance of impact marks, grooves, scratches and indentations	5.5.2
			Smearing marks on one or more locations over the circumference	5.2.3
			Local discoloration (overheating)	5.2.3
			Current passage craters	5.4.2
			Local corrosion	5.3.2
	On cages		Fracture of cage bars, cage rings, rivets	5.6.3 / 5.6.2
			Wear on guiding surfaces	5.2.2 / 5.2.3

● = high correlation
○ = low correlation

Possible causes

Lubricant, lubrication							Operating conditions and maintenance										Handling and mounting						Design and adjacent parts							Bearing manufacturing		
Not enough lubricant	Too much lubricant	Viscosity too low	Inappropriate additives or thickener	Oxidized lubricant	Solid contaminants in the lubricant	Lubricant contaminated by water	Static or dynamic load too high	Insufficient load	Speed too high	Speed too low	Rapid changes in direction of load or rotation	Exposure to vibration	Current passage, current leakage	External heat / insufficient cooling	Insufficient maintenance	Oil filter clogged / internal contamination	Inappropriate storage conditions	Exposure to vibration during transport	Wrong clearance or preload setting	Wrong radial or axial preload	Misalignment	Damage during mounting	Geometrical form errors of shaft or housing seat	Inconsistent support of rings	Inappropriate fits and tolerances	Ineffective seal	Worn seals	Insufficient heat removal	Difficult assembly due to design	Material, heat treatment	Machining and assembly	Handling
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Appendix D: Collecting information

Whenever bearing damage or a failure occurs, it is very important to collect and document any relevant information to facilitate subsequent root cause analysis.

A short overview of what needs to be considered is summarized below.

General information

- company and contact persons
- machine – application description
- problem description

Operating data

- drawings and photographs of the machine with adequate details to understand the bearing system and bearing arrangement
- application data (speed, loads, temperature, lubrication method, lubricant used, lubricant renewal specifications, drive system, bearing designation, shaft and housing fits specifications, sealing, required bearing life, and operating time)

Monitoring data

- condition monitoring history (vibration levels, temperature readings, and sound recordings)
- lubricant analysis history

During dismounting

- Document any visible damage on the equipment (loose bolts, damaged/worn adjacent parts including seals, and scratches).
- Take lubricant samples from inside the bearing and the surrounding area. Store the samples in clean receptacles and label them.
- Mark the bearing ring mounting location in the machine as well as its relative position against the shaft/housing.
- Take photographs and write notes during the procedure.
- Dismount the bearing with care and document the dismounting method when damage cannot be avoided.
- Mark the bearing parts.
- Protect the bearings from dirt and moisture in an appropriate receptacle for further analysis by SKF representatives. Do not clean the bearings!
- Check the bearing seats. Document dimensions and appearance.

Fig. 1

Fig. 2

Tips for taking good photographs (smartphone, digital camera):

- Make overall and detail (zoom) photographs of the various parts and features that should be documented.
- Do not set the camera to full auto mode and don't use a flash. Instead, use manual mode to control exposure and sensor sensitivity where possible (ISO values).
- Use macro mode if the camera has it.
- Set the camera to its native ISO. This is often the smallest ISO number. High ISO numbers will create noise that hides details.
- Use a tripod (→ **fig. 1**) and the camera's self-timer in an area where there are several light sources so that shadows are avoided.
- As cameras may not focus correctly on a steel surface due to lack of contrast, focus on a ruler (→ **fig. 2**) or pencil placed next to the damage. The ruler has the advantage that it also indicates dimensions.
- After taking a photograph always look at it and zoom in to check that it is in focus.

Appendix E: Glossary

This glossary contains the most common terms and expressions used when dealing with bearing damage and failure. The terms are listed alphabetically. Where applicable, reference to ISO 15243 is mentioned.

abrasion
A wear process between two contacting surfaces, loaded against and moving relative to each other. The wear is due to either hard particles entrained between the contacting surfaces or hard protrusions on one or both of them. (ISO 5.2.2)

abrasive wear
The progressive removal of material from a surface or surfaces due to *abrasion*. (ISO 5.2.2)

adhesive wear (smearing)
The damage that occurs when two inadequately lubricated surfaces slide against each other under load. Smearing causes material from one surface to be transferred to another, leaving a "torn" appearance. (ISO 5.2.3)

asperity
The small protrusion (high point) on machined surfaces measured as surface roughness or surface profile.

brinelling
→ *overload*

build-up (built-up edge)
The displaced material that stands proud of a surface around the edge of an *indentation*. (ISO 5.5.3)

burnishing (glazing)
Smoothing action, cumulative *plastic deformation* leads to flattening of *asperities*, altering the original manufactured surface of a sliding or rolling surface to a more polished condition. (ISO 5.1.3)

butterfly
A typical "appearance" looking like the wings of a butterfly, when *etching* a material structure for (oxide) *inclusions*.

cage ageing
The loss of mechanical properties that occurs over time to polymer cages. Higher temperatures or aggressive lubricants can cause accelerated ageing. Also, stamped brass cages can age prematurely when exposed to ammonia.

chatter mark
Rib-like mark on a raceway that results when there is an inadequate lubricant film and the bearings are subjected to vibration.

contact microslip
→ *microslip*

contact stress (Hertzian contact stress)
Stress at the surface when two solid bodies make contact under a certain load.

contaminant
Solid particle or liquid that penetrates the bearing environment and adversely affects its performance.

corrosion
An oxide layer as a result of a chemical reaction with a metal surface. (ISO 5.3)

crack
Discontinuity within the bulk of material without complete separation resulting from material stresses. See also *microcrack* and *grinding* crack. (ISO 5.6)

crater
Macroscopic pits, looking like craters, that occur on the raceways and rolling elements when damaging electric current passes through a bearing. (ISO 5.4)

creep
The relative rotation between a bearing ring and its seat on the shaft or in the housing.

current leakage erosion
Damage to rolling contact surfaces caused by the passage of electric current. (ISO 5.4.3)

damage
Any change to a component that impairs its functionality.

dark etching area (DEA)
→ *dark etching region*

dark etching region (DER, dark etching area, DEA)
The dark etching region is an area underneath the surface where accumulated stresses result in changes in the metallurgical structure, which colour dark when *etching* the material. (ISO 5.1.2)

defect
Material or product fault introduced by the manufacturing or assembly process of a bearing or its components.

deformation
Changes to the normal shape of an object. The result can be permanent (*plastic deformation*) or temporary (*elastic deformation*).

dent
→ *indentation*

dull surface
A non-reflective surface that results from *abrasive wear*. (ISO 5.2.2)

edge loading
A load that extends to the edge of one or more rolling elements as a result of excessive misalignment and/or excessive load.

elastic deformation
A forced change in shape of a component that does not cause stress beyond its elastic limit. The component returns to its original shape when removing the deforming force.

electrical erosion
Macro- or microcraters caused by local melting, when high levels of damaging electric current passes through rolling contacts of a bearing. (ISO 5.4)

electrical pitting
Microcraters that result when low levels of damaging electric current passes through rolling contacts of a bearing. (ISO 5.4)

erosion
The progressive loss of material resulting from the mechanical interaction between a solid surface and *contaminants*.

etching
A process that uses chemicals to reveal the structure of a metal.

excessive current erosion
Large craters in the raceways and rolling elements possibly accompanied by discoloured or burnt lubricant through local overheating. (ISO 5.4.2)

failure
Defect or *damage* that prevents a bearing from fulfilling its intended purpose.

false brinelling
Permanent depressions at rolling element pitch into raceways caused by vibration induced micromovement of the rolling elements, whilst the bearing is static. The appearance can be similar to *overload* (brinelling), but there will not be a *build-up* around the depressions. (ISO 5.3.3.3)

fatigue
The weakening (changes in the metallurgical structure) of rolling element and/or raceway contact surfaces in a bearing, caused by accumulation of stresses or material imperfections.

fatigue fracture
The breaking through of a bearing ring or other component as the result of the propagation of a fatigue initiated crack. (ISO 5.6.3)

flaking
→ *spalling*

fluting
→ *washboarding*

forced fracture
A *fracture* resulting from a stress concentration in excess of the material's tensile strength. (ISO 5.6.2)

fracture
Propagation of a *crack* to complete separation. (ISO 5.6)

fragment
A small part that has broken away or separated from a larger object.

fretting corrosion
A type of damage, where micromovement between two contacting components causes microscopic debris to be instantly oxidized, leaving a blackish red surface discolouration. (ISO 5.3.3.2)

friction
The resistive force that is encountered when one object is moved relative to another that it is in loaded contact with.

frosting
The dull lustreless appearance on a bearing raceway as a result of inadequate lubrication. The wear is characterized by fine slivers of metal pulled from the raceway. (ISO 5.1.3)

furrow
A long, deep score on the surface of a raceway. (ISO 5.5.2)

galling
A type of *adhesive wear*. Local surface welding gives rise to material being torn from one of the surfaces leaving large cavities in it. (ISO 5.2.3)

glazing
→ *burnishing*

gouge
Scoring damage to a surface caused by another component, that is loaded against it, being forced to slide across it. (ISO 5.5.2)

grinding burns
Alteration (tempering, *rehardening*) of near-surface structure due to excessive frictional heating when grinding. Visible on the surface after *etching*.

grinding crack
Crack caused by local heating and rapid cooling during grinding.

halo
A small circle that is lighter in colour than the surrounding area.

Hertzian contact stress
→ *contact stress*

inclusion
Body of unintended foreign material included in a matrix material. See also *macro inclusion*.

indentation (dent)
Damage caused by impressing a solid component into a surface to form a permanent *(plastic) deformation*. Seen in rolling bearings as denting of the raceways due to the over-rolling of solid *contaminants* or failure debris. Indentations may be sharp (from metal particles), rounded (from soft debris) or multi-fragment (from brittle debris). The original surface finish is likely to be seen at the bottom of the indentation and displaced material will form a raised edge around the indentation *(build-up)*. (ISO 5.5.3)

interference fit (press fit)
A fastening between two parts compressed on each other due to friction in the mating surface.

macro inclusion
Impurity or a particle, usually a slag inclusion formed either by local oxidation or the entrapment of particles from the refractory lining during the tapping of the steel; and which can be seen on a polished and etched surface at a magnification of ten times or less or by ultrasonic testing.

microcrack
Microscopic cracks that can occur on or below the surface of a bearing component.

microspalling
Microscopic *spalling* of the *asperities* on the contact surfaces.

microslip (contact microslip) (microsliding)
The partial sliding between contacting surfaces in rolling bearings due to geometry effects.

moisture corrosion
The chemical reaction that occurs when water or another chemical condenses on a metal surface, enabling it to interact with oxygen (oxidize). (ISO 5.3.3)

nick
Plastic depression, caused by impressing (statically or by impact) a hard, possibly sharp object into a surface of a contact component.

oval clamping (oval pinching)
Squeezing a bearing ring diametrically, which makes the ring oval.

overload (brinelling, true brinelling)
Permanent sets of *indentations* in bearing raceways at rolling element pitch when the static load limit of the material is exceeded under load. The *indentations* reflect the rolling element shape and are surrounded by a *build-up* formed by displaced material. (ISO 5.5.2)

parallel fluting
→ *washboarding*

path pattern
Change in appearance of a part of a bearing area, due to contact with another bearing part; i.e. rolling elements and a raceway.

peeling
A type of *surface initiated fatigue* that occurs as a result of inadequate lubrication. The damage appears as if a thin slice of metal has been peeled away. (ISO 5.1.3)

pitting
A generic term used to describe a type of local damage that is seen as small holes, craters or cavities. Causes of pitting include *surface initiated fatigue*, *corrosion*, *electrical erosion*, *indentations* from debris.

plastic deformation
The permanent *deformation* of a shape that does not involve the removal of material. This type of damage occurs when a load exceeds the yield strength of the material. (ISO 5.5)

ploughing
→ *scoring*

polishing wear
An extremely mild form of *abrasive wear* that results in a highly polished, reflective surface. (ISO 5.2.2)

press fit
→ *interference fit*

rehardening
The metallurgical change that occurs when local heating reaches or exceeds the temperature at which austenite forms, and then cools rapidly.

residual stress
The stresses that remain in a component after the original causes of the stress (manufacturing, loads, temperature) have been removed.

rolling contact fatigue
Surface or *subsurface initiated fatigue* that occurs in a rolling bearing due to repetitive stress cycles in operation. (ISO 5.1)

running-in
The breaking-in process of a new bearing or application to stabilize friction and frictional heat.

scoring (ploughing, scratching)
Scoring (grooving) of a bearing ring or rolling element due to either the embedding of hard debris into softer components such as cages, that then runs against a roller or raceway as the bearing operates, or to the scraping of bearing components over one another during assembly. (ISO 5.5.2)

scratching
→ *scoring*

scuffing
Type of *adhesive wear*, local damage caused by solid phase welding between sliding surfaces, without local surface melting. (ISO 5.2.3)

seizing
When a bearing can no longer be moved or rotated, most commonly due to it being blocked or friction welding of components.

skidding
A kind of *adhesive wear*. The sliding motion of a rolling element on a raceway during operation, under load, resulting in surface damage, slivery frosted in appearance.

smearing
→ *adhesive wear*

smoothing
The removal or flattening of asperities or other surface imperfections, to create a smoother surface.

spalling (flaking)
The loss of small spalls of material as a result of *fatigue (subsurface* or *surface initiated fatigue)*. (ISO 5.1)

subsurface initiated fatigue
Spalling of a raceway surface as a result of subsurface cracks propagating to the surface. (ISO 5.1.2)

surface distress
→ *surface initiated fatigue*

surface initiated fatigue (surface distress)
The damage resulting from inadequate lubrication in terms of film thickness and/or lubricant cleanliness that leads to metal-to-metal contact, and eventually *microcracks* or *microspalling* at the surface. (ISO 5.1.3)

thermal cracking
Cracks in a bearing ring that result from excessively high temperatures combined with high *residual stresses*. The excessive temperatures are normally the result of frictional heating when gross sliding occurs between loaded surfaces. (ISO 5.6.4)

true brinelling
→ *overload*

washboarding (fluting, parallel fluting)
Flutes that develop after craters are formed by electric current leakage. This type of damage is found on the raceways of ball and roller bearings and rollers, but not on balls. The flutes are parallel to the rolling axis and are generally equally spaced. (ISO 5.4.3)

wear
The gradual removal of material from a surface. (ISO 5.2)

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