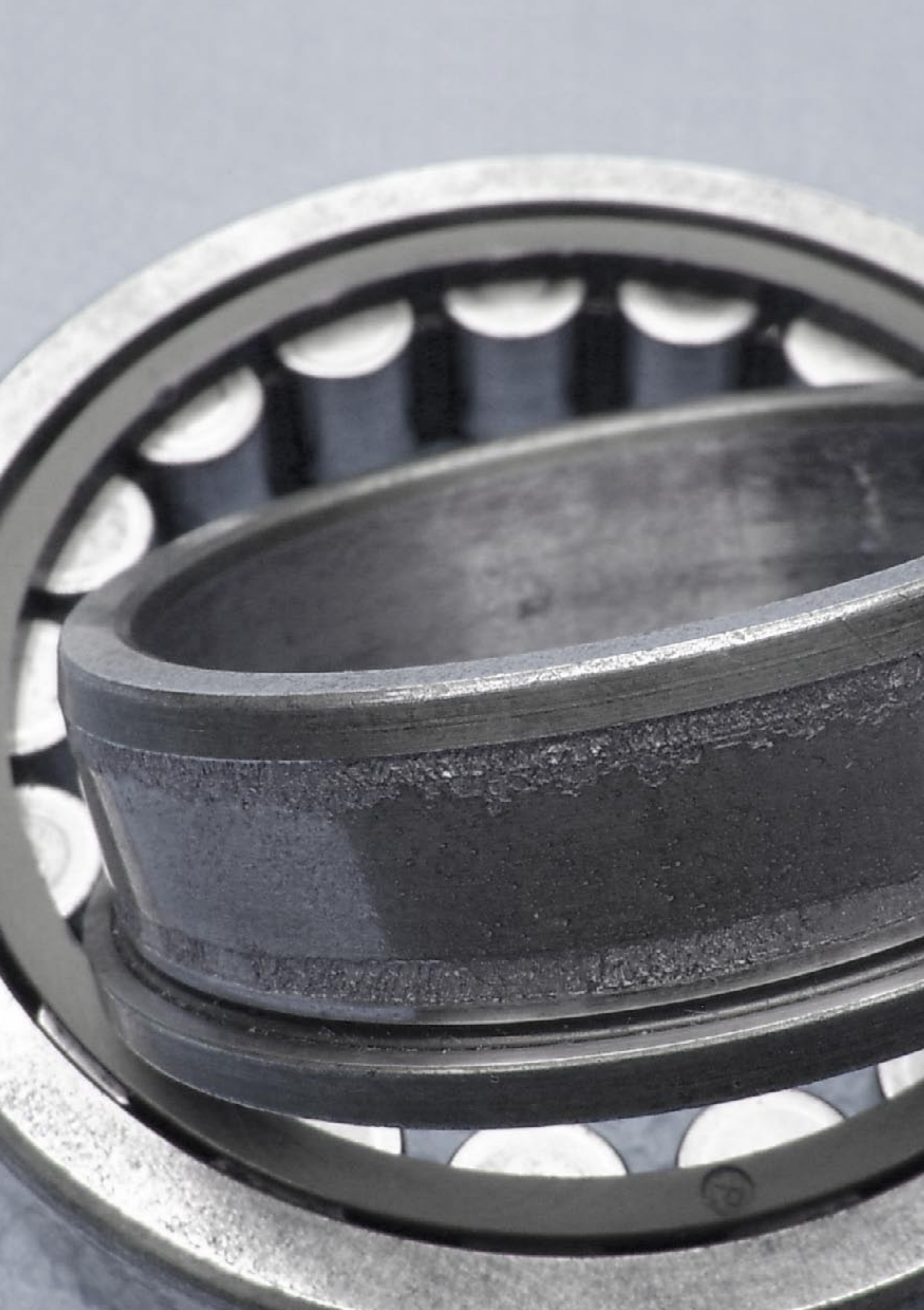


Bearing damage and their causes

Introduction

Rolling bearings are one of the most important components in today's high-tech machinery. When bearings fail, machine downtime occurs that can be costly. Selecting the appropriate bearing for the application is only the first step toward reliable equipment performance. The machine operating parameters, such as loads, speeds, temperature, running accuracy, and operating requirements, are needed to select the most appropriate bearing type and size from a range of available products.

The calculated life expectancy of any bearing is based on eight assumptions:

1 The bearing is of high quality and has no inherent defects.
2 The bearing is the right one for the application.
3 Dimensions of parts related to the bearing, such as shaft and housing seats, are appropriate.
4 The bearing is mounted correctly.
5 The correct lubricant, in the proper quantity, is always available to the bearing.
6 The bearing arrangement is properly protected (sealed).
7 The operating conditions are matched to the bearing arrangement.
8 Recommended maintenance is performed.

If all these conditions are met, the bearing should reach its calculated life. Unfortunately, this is quite hypothetical. There is often something that occurs, which prevents "ideal" operating conditions.

A common mistake in the field is to assume that if a bearing failed, it was because it did not have enough load carrying capacity. Using this rationale, many people go through expensive retrofits to increase bearing load carrying capacity, and end up with additional bearing failures.

Identifying the root cause of the bearing failure is the first step in obtaining reliable equipment performance. One of the most difficult tasks is identifying the primary failure mode (root cause) and filtering out any secondary conditions that resulted from the primary mode of failure.

Bearing damage analysis provides insight into equipment operation and bearing damage. Evidence needs to be collected and interpreted correctly to establish the root cause of the problem. Knowledge, skills and experience are required to separate useful information from false or misleading clues. This is why SKF offers professional damage analysis support.

For additional information about the SKF damage analysis service, contact your local SKF representative or SKF Authorized Distributor.

This chapter of the handbook provides you with the tools to make an initial evaluation of the cause of bearing damage or failure.

Dismounting

During dismounting, SKF recommends the following:

- Take pictures.
  This might help in your investigation later. For example, be sure to photograph the position, quantity and condition of the grease in and around the bearing.
- Take lubricant samples for analysis.
  For grease lubricated applications, take samples from different locations.

NOTE: Refer to the chapter *Dismounting*, starting on **page 252**.

Path patterns

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

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

- dull areas on the raceways and rolling elements, sometimes also very shiny (→ **fig. 2**)
- discoloured inner ring bore and outer ring outside diameter
- cage wear
- fretting corrosion on the inner ring bore or outer ring outside diameter

Whether a bearing shows minor wear or damage, or has failed, a thorough inspection can provide information about what happened to the bearing during operation.

During the inspection, the key is to look for “patterns”. A pattern can be “normal” or it can indicate a problem. The pattern you find can quite frequently identify the root cause of a problem.

A number of common and typical patterns are shown in this chapter.

Fig. 1

Fig. 2

Patterns resulting from normal operating conditions

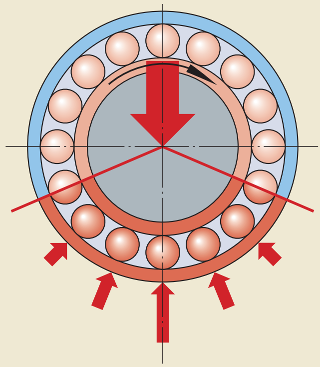
Figs. 3 and **4** illustrate how an applied unidirectional and constant radial load on the rotating inner ring of a bearing is distributed to the stationary outer ring, through the rolling elements.

The large arrow in the 12 o'clock position represents the applied load and the series of small arrows from 4 o'clock to 8 o'clock represent how the load is shared or supported through the rolling elements in the bearing.

As the inner ring is rotating, every point on the ring comes into the load zone. As a result, the entire circumference of the inner ring raceway will have a band in the centre that is uniform in width. This is referred to as a rotating inner ring load zone.

The outer ring is stationary; therefore the load zone is limited to where the rolling elements transmit the load. This is referred to as a stationary outer ring load zone. The load distribution in the outer ring load zone varies. It is heaviest in the direction of the load and decreases in either direction from that point. For most applications, the load zone is approximately 150°.

Fig. 3



- Load zone (≈ 150°)
- Will enter the load zone during rotation
- Clearance in the bearing, unload zone
- Load (shaft) and load distribution (housing)

Fig. 4

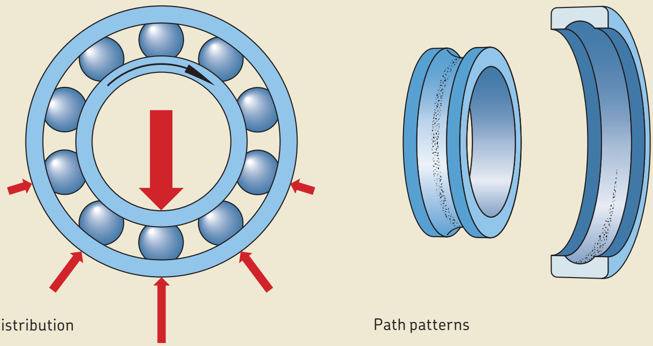
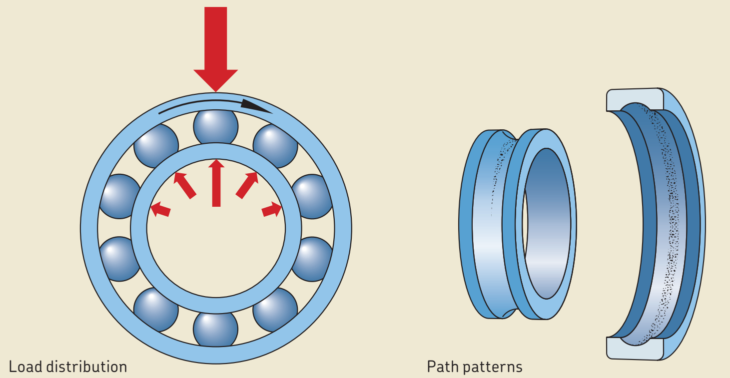


Fig. 5 illustrates how an applied unidirectional and constant radial load on the rotating outer ring of a bearing is distributed to the stationary inner ring through the rolling elements.

As the outer ring rotates, every point on that ring comes into the load zone. As a result, the entire circumference of the outer ring raceway will have a band in the centre that is uniform in width.

The load distribution on the inner ring varies. It is heaviest in the direction of the load and decreases in either direction from that point. For most applications, the load zone is approximately 150°.

Fig. 5



These load patterns will also appear when the inner ring rotates in phase with the load (i.e. imbalanced or eccentric loads) and the outer ring is stationary. Even if the inner ring is rotating, the load on the inner ring is stationary, while the load on the stationary outer ring is rotating (→ **fig. 6**).

Fig. 7 illustrates the effect of a unidirectional and constant axial load on a deep groove ball bearing.

The rotating ring will show a laterally displaced band around its entire circumference.

The stationary ring will show a laterally displaced band on the opposite side. If the magnitude of the axial load is sufficient, the band on the stationary ring will be around its entire circumference.

Fig. 8 illustrates a combination of unidirectional and constant radial and axial loads on a deep groove ball bearing, with a rotating inner ring and stationary outer ring.

The load zone around the entire circumference of the inner ring is displaced laterally.

The load zone of the outer ring is displaced laterally in the opposite direction. The length of the load zone is greater than one that would be produced by just a radial load, but not necessarily 360°.

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

Under pure radial load, only a small section (approximately 150°) of the outer ring will have a path pattern (→ **figs. 3** and **4**, **page 292**).

Under pure axial load, the whole outer ring will show a path pattern, which is laterally displaced (→ **fig. 7**).

Under a combined load, the path pattern will be somewhere in between, depending on the magnitude of the radial load relative to the axial load (→ **fig. 8**).

Fig. 6

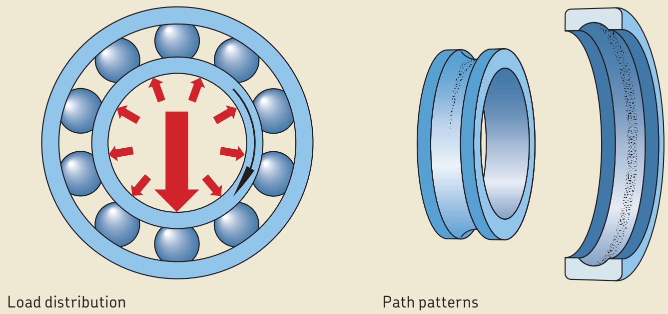


Fig. 7

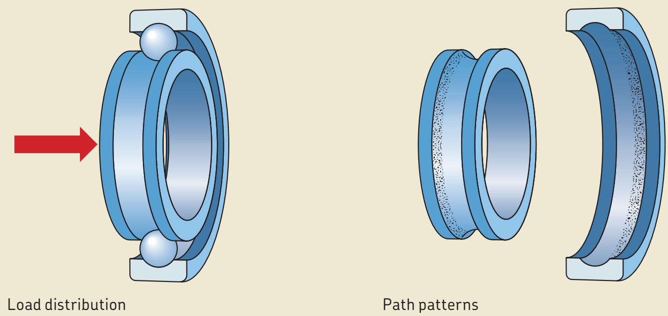
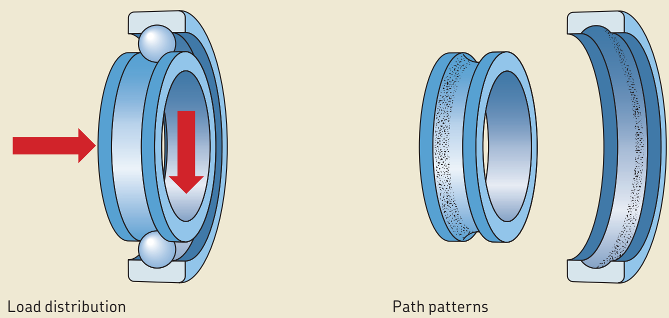


Fig. 8



Patterns resulting from abnormal operating conditions

Fig. 9 illustrates the load zones produced by a unidirectional and constant radial load when a stationary outer ring is misaligned relative to the rotating inner ring.

The entire circumference of the inner ring raceway will have a band in its centre that is uniform in width.

The outer ring will have a band that goes from one side of the outer ring to the other. The path and length of the band depends on the magnitude of misalignment, the load and the clearance in the bearing. The band can be anywhere from 150° to 360°.

This condition can occur when the shaft deflects or if the bearings are in separate housings that do not have concentric housing bores.

Fig. 10 illustrates the load zones produced by a unidirectional and constant radial load when the stationary outer ring is radially pinched (oval clamped).

Under these conditions, the entire circumference of the inner ring raceway will have a band in its centre that is uniform in width.

The outer ring will show two diametrically opposed 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 or a piece of equipment 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 dramatically increase the internal loads and increase the bearing operating temperature, leading to premature bearing damage or failure.

Fig. 11 illustrates the load zones produced by an internally preloaded bearing that is supporting a unidirectional and constant radial load, while the inner ring is rotating and the outer ring is stationary.

Under these conditions, the entire circumference of the inner ring raceway will have a band in its centre that is uniform in width.

The outer ring will also show a 360° load zone, but the pattern will usually be wider where the applied load is combined with the internal preload.

This condition can be the result of excessive interference fits on the shaft and/or in the housing. If the fits are 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.

NOTE: Refer to the section *Recommended fits and tolerances*, on **page 35**.

Fig. 9

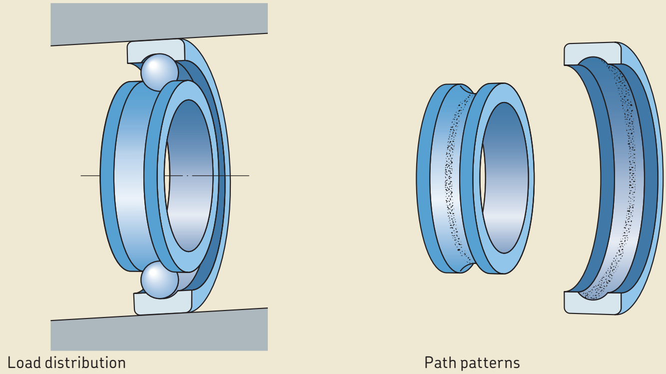


Fig. 10

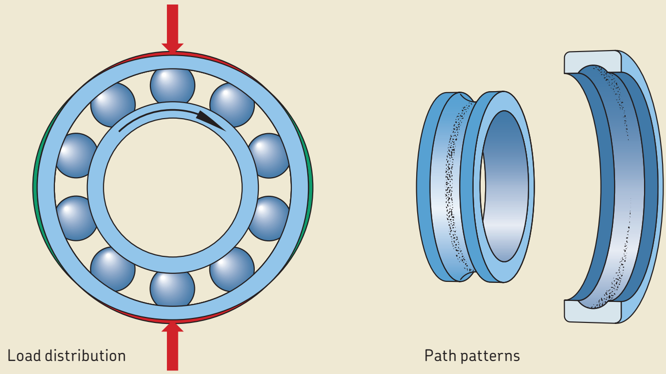
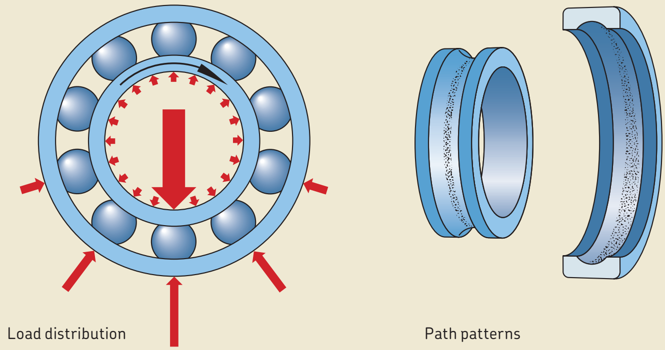


Fig. 11



Bearing damage

Because of the increasing attention given to prevent bearing damage and failures from recurring, the International Organization for Standardization (ISO) has developed a methodology for classifying bearing damage and failures (ISO 15243:2004). This standard recognizes six main groups of failure modes and sixteen subgroups, all related to post-manufacturing sustained damage. The standard is based primarily on features that are visible on the rolling elements, raceways and other functional surfaces. It also identifies the mechanisms involved for each type of failure.

Most bearing damage can be linked back to the six main groups as well as the various subgroups shown in **table 1**. Definitions of the failure modes are provided in **table 2**.

Most damage resulting from these mechanisms can be detected and monitored easily when condition monitoring is part of a comprehensive maintenance programme. Using vibration analysis, the first signs of bearing damage can be detected, enabling maintenance personnel to take corrective actions in a timely manner. This can significantly reduce costly, unexpected downtime and can avoid catastrophic failures that damage adjacent components. It also enables maintenance staff to examine the damaged bearing at an early stage to determine the root cause, and take the necessary steps to prevent the problem from recurring.

NOTE: Refer to the chapter *Inspection*, starting on **page 216**.

Most bearing damage can be classified into two damage categories: pre-operational and operational. Pre-operational damage occurs prior to or during bearing installation, while operational damage occurs while the bearing is in operation.

Causes of pre-operational damage:

- incorrect shaft and housing fits
- defective bearing seats on shafts and in housings
- static misalignment
- faulty mounting practices
- passage of electric current through the bearing (excessive voltage)
- transportation, handling and storage

Causes of operational damage:

- material fatigue
- ineffective lubrication
- ineffective sealing
- vibration (false brinelling)
- operational misalignment
- passage of electric current through the bearing (current leakage)

Table 1

ISO classification of bearing damage and failure modes

Main group	Subgroup
Fatigue	Subsurface initiated fatigue Surface initiated fatigue
Wear	Abrasive wear Adhesive wear

Corrosion	Moisture corrosion
	Frictional corrosion
	  Fretting corrosion
	  False brinelling

Electrical erosion	Excessive voltage Current leakage
Plastic deformation	Overload Indentation from debris Indentation from handling
Fracture and cracking	Forced fracture Fatigue fracture Thermal cracking

Table 2

Failure mode definitions and explanations

Failure mode	Definition and/or explanation
Fatigue	A change in the material structure that is caused by the repeated stresses developed in the contact areas between the rolling elements and the raceways. Fatigue is manifested visibly as spalling of particles from the surface. The time between beginning and advanced spalling varies with speed and load.
Subsurface initiated fatigue	The initiation of microcracks below the raceway surface. When these microcracks propagate to the surface, they produce spalls (flaking).
Surface initiated fatigue	Distress of the surface. Failure of the rolling contact metal surface asperities (roughness) due to inadequate lubrication.
Wear	The progressive removal of material resulting from the interaction of two sliding or rolling/sliding contacting surfaces during operation.
Abrasive wear	The result of inadequate lubrication or the ingress of contaminants.
Adhesive wear	The material transfer from one surface to another with friction heat, sometimes with tempering or rehardening of the surface.
Corrosion	The deterioration of a metal surface as a result of oxidation or a chemical reaction on metal surfaces.
Moisture corrosion	Oxidation of the surfaces in the presence of moisture.
Frictional corrosion	The chemical reaction activated by relative micromovement between mating surfaces under certain friction conditions.
Fretting corrosion	The oxidation and wear of surface asperities under oscillating micro-movement.
False brinelling	The formation of shallow depressions resulting from micromovement caused by cyclic vibrations when a machine is at a standstill. Equally spaced depressions matching the rolling element pitch appear in the raceways.
Electrical erosion	The damage to contact surfaces (removal of material) caused by the passage of electric currents.
Excessive voltage	Sparking and localized heating from current passage in the contact area because of ineffective insulation.
Current leakage	The generation of shallow craters from (low) current passage. The craters are closely positioned to one another. They develop over time into flutes parallel to the rolling axis and are equally spaced.
Plastic deformation	Permanent deformation that occurs whenever the yield strength of the material is exceeded.
Overload	Overloading by static or shock loads, leading to plastic deformation (true brinelling).
Indentation from debris	Particles that are over-rolled in the contact areas form dents in the raceways and rolling elements. The size and shape of the dents depend on the nature of the particles.
Indentation from handling	Bearing surfaces that are dented or gouged by hard, sharp objects.
Fracture	The ultimate tensile strength of the material is exceeded and complete separation of a part of the component occurs.
Forced fracture	A fracture resulting from a stress concentration in excess of the material's tensile strength.
Fatigue fracture	A fracture resulting from frequently exceeding the fatigue strength limit of the material.
Thermal cracking	Cracks that are generated by high frictional heating. They usually occur perpendicular to the direction of the sliding motion.

Pre-operational causes of damage

Incorrect shaft and housing fits

An incorrect shaft or housing fit can result in either excessive clearance or excessive preload, which can produce any of the following conditions:

- ring creep (ring turns on its seat)
- fretting corrosion
- cracked rings
- reduced load carrying capacity
- induced loads
- excessive operating temperatures

Therefore, the proper fit is critical to the service life of the bearing and the performance of the application.

If a bearing ring rotates and the load is unidirectional and constant, an interference fit is required. The degree of interference or tightness is governed by the magnitude of the load and the bearing type and size. Typically, the heavier the applied load, the tighter the required fit.

If a bearing ring is stationary and the load unidirectional and constant, it is typically fitted with a loose fit (clearance fit). Recommended fits can be found in **Appendix A**, starting on **page 334**. Values for deviations and resultant fits are listed in **Appendix B**, starting on **page 338**.

The presence of shock loads or continuous vibration requires a heavier interference fit on the ring that rotates relative to the load.

In the case of a bearing ring with a rotating load zone, lightly loaded bearings, or bearings that operate at very low speeds, a lighter fit or, in some cases a loose fit, can be applied.

Sometimes, it is not possible to assemble a piece of equipment if the recommended fits are applied. In these cases, contact the SKF application engineering service.

Consider two examples: In the front wheel of a car, the direction of the load is constant, i.e. the road surface is always exerting an upward force on the wheel. Thus, the rotating outer ring has an interference fit in the wheel hub, while the stationary inner ring has a loose fit on the axle spindle.

Bearings in a conventional electric motor have stationary outer rings relative to the load and have a loose housing fit, but the inner rings rotate relative to the load and are mounted with an interference fit.

There are some cases where it is necessary to mount both the inner and outer rings of a bearing with an interference fit. This is the case, for example, with cylindrical roller and CARB toroidal roller bearings, which can accommodate axial expansion of the shaft within the bearing, rather than through sliding of one of the bearing rings on its seat. This can also be the case for applications where heavy shock loads occur.

Improper shaft or housing fits, or fits that are unnecessarily loose, can enable the inner or outer ring to rotate on its seat. This relative movement is called ring creep. The relative movement generates friction and can result

Fig. 12

Abrasive wear due to outer ring creep
ISO classification: Abrasive wear

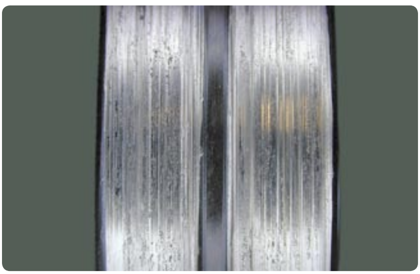
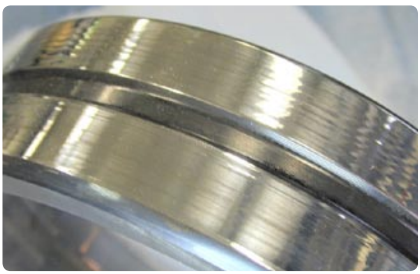


Fig. 13

Polishing wear due to outer ring creep
ISO classification: Abrasive wear



in wear or smearing. The damage is not always confined to the seat surface, but can also have its effect on the side faces of the ring(s). **Fig. 12** shows abrasive wear, while **fig. 13** shows polishing wear.

Fits that are too loose can result in a speed difference between contact surfaces. Sometimes a loose fit cannot be avoided, for example, for four row tapered roller bearings on the roll necks in rolling mills. Typically, the inner ring has a loose fit for mounting/dismounting reasons. Due to the loose fit, there is a speed difference between the inner ring and the shaft seat (creep), and between the inner ring side face and its abutment. These speed differences in the contact zone will generate heat. In some cases, the localized heat can be so intense that material is transferred from the bearing ring to its sliding surfaces or vice versa (smearing) (→ **fig. 14**). The heat can also produce heat cracks in the material (→ **fig. 14**), which will eventually cause the ring to crack (thermal cracking).

An interference fit between an inner ring and shaft will induce hoop (tensile) stresses in the ring. If the interference fit is excessive, the resultant hoop stresses can exceed the strength of the ring, causing it to fracture (→ **fig. 15**).

Bearing arrangements typically consist of a locating and a non-locating bearing. The non-locating bearing is designed to accommodate thermal expansion of the shaft, either within the bearing or by moving on its seat in the housing. To move on its seat, the outer ring requires a loose fit. If the fit is too tight or the outer ring is cocked in the housing, the ring will not move. This induces heavy axial loads in the bearing system. These heavy axial loads can produce any of the following conditions: premature material fatigue, excessive heat, inadequate lubrication, excessive wear or surface initiated spalling (→ **fig. 16**). The result is drastically reduced bearing service life.

Fig. 14

Different speeds in the contact area between the bearing and a distance ring caused smearing (circumferential marks). The resultant heat caused thermal cracks in the bearing ring (perpendicular to the smearing marks).
ISO classification: Adhesive wear and thermal cracking

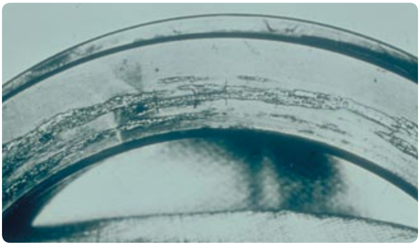


Fig. 15

Ring cracking due to an excessive interference fit
ISO classification: Forced fracture

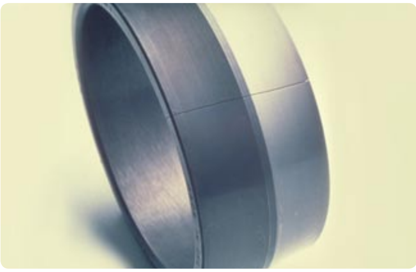


Fig. 16

A housing fit that is too tight for a non-locating bearing will induce heavy axial loads, drastically reducing bearing service life.
ISO classification: Subsurface initiated fatigue (from too heavy loads) or surface initiated fatigue (from lubrication problems)

Damage and failure due to defective shaft or housing seats

The formulas used to calculate bearing life make basic assumptions. One of those assumptions is that shaft and housing seats meet geometrical specifications. Unfortunately, there are other other factors that can negatively affect components that were manufactured to the most exacting specifications. For example, shaft and housing seats can be deformed, i.e. tapered, out-of-round, out-of-square, or thermally distorted. The same condition can be produced by a bearing seat in a housing that was correctly manufactured, but became distorted when it was secured to the machine frame or support surface.

While the section *Incorrect shaft and housing fits*, starting on **page 300**, dealt with poorly selected fits, this section focuses on distorted bearing seats and the damage they can cause.

Fretting corrosion occurs when the fit is too loose and there is relative movement between a bearing ring and the shaft or housing. The relative movement, which is typically caused by form inaccuracies or shaft bending (deflection), causes small particles of material to become detached from the surface of the shaft or housing seat. These particles oxidize quickly when exposed to air.

As a result of fretting corrosion, the bearing rings may not be evenly supported, which will have a detrimental effect on the load distribution in the bearing. Fretting corrosion appears as rust on the outside surface of the outer ring (→ **fig. 17**) or in the bore of the inner ring (→ **figs. 18** and **19**). Iron oxide has a larger volume than pure iron. Therefore, the bearing geometry might change; the raceway path pattern could be heavily marked at corresponding positions.

Fretting corrosion is common in applications where operating conditions cause the seats to deform under load. This is very often the case in heavily loaded applications.

NOTE: Fretting corrosion Fe_3O_4, also called magnetite (→ **fig. 17**), can be black – or Fe_2O_3, also called hematite, is red or reddish brown (→ **figs. 18** and **19**).

Fig. 17

"Heavy" fretting corrosion occurs often in heavily loaded applications. The fretting corrosion is in the load zone of the outer ring seat.
ISO classification: Fretting corrosion

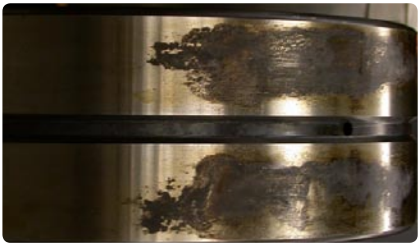


Fig. 18

Fretting corrosion from an incorrect shaft fit
ISO classification: Fretting corrosion

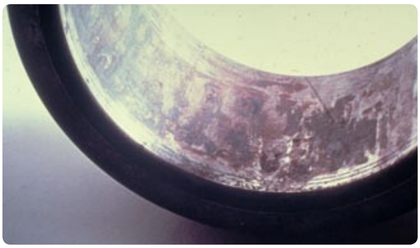
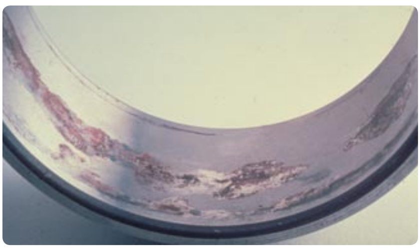


Fig. 19

Fretting corrosion from either an imperfect shaft seat (machining) or shaft deflection
ISO classification: Fretting corrosion



Over time, incorrect contact will result in advanced fretting corrosion. The corroded areas also act as fracture notches (→ **figs. 20** and **21**).

Bearing seats that are concave, convex, or tapered, cause a bearing ring to make poor contact across its width. The ring, therefore, deflects under load and fatigue fractures commonly appear circumferentially along the raceway.

Fig. 22 is a mirror picture of a self-aligning ball bearing outer ring that was mounted in an out-of-round (oval) housing bore. The stationary outer ring was pinched in two places – 180° apart – resulting in preload at these two locations. The preload generated excessive forces, which resulted in premature material fatigue and subsurface initiated spalling.

The preload also generated heat and led to a poor lubrication condition. Notice the heavy fretting corrosion (180° apart) on the outer ring outside diameter corresponding to the two load zones.

Fig. 20

Fretting corrosion can lead to ring fracture. The ring cracks at its weakest point – the lubrication groove.
ISO classification: Fretting corrosion and forced fracture

Fig. 21

The outer ring of this bearing was not well supported in the housing seat. Fretting corrosion led to high stresses in the outer ring and ultimately resulted in a forced fracture.
ISO classification: Fretting corrosion and forced fracture

Fig. 22

The outer ring of this self-aligning ball bearing is placed against a mirror. Two load zones and spalling can be seen 180° apart. The damage resulted from an out-of-round housing seat.
ISO classification: Subsurface initiated fatigue

Static misalignment

Static misalignment, a common cause of overheating and/or premature spalling is present when any of the following conditions exist:

- The inner ring is seated against a shaft shoulder that is not square with the bearing seat.
- The outer ring is seated against a housing shoulder that is not square with the housing bore.
- The two housing bores are not concentric or coaxial.
- A bearing ring is fitted improperly against its shoulder and left cocked on its seat.
- The outer ring of a non-locating bearing is cocked on its seat.

Self-aligning bearings cannot cure all misalignment faults. For example, when the rotating inner ring of a self-aligning bearing is not square with its shaft seat, it will wobble as it rotates. This can cause lubrication problems, and either premature wear and/or early surface initiated fatigue.

Thrust ball bearings can show signs of early fatigue when mounted on supports that are not perpendicular to the shaft. In these cases only one short section (arc) of the stationary ring carries the entire load. When the rotating ring of a thrust ball bearing is mounted on an out-of-square shaft shoulder, the ring wobbles as it rotates. The wobbling rotating ring loads only a small portion of the stationary ring and causes early fatigue.

Where two housings supporting the same shaft do not have a common centre line, only self-aligning ball or roller bearings will be able to function without inducing bending moments that otherwise result in shaft deflections and misalignment. Deep groove and angular contact ball bearings as well as cylindrical and tapered roller bearings can accommodate only very small misalignments. Misalignment in these bearings typically causes edge loading, which can result in premature fatigue.

The double row angular contact ball bearing as shown in **fig. 23** was misaligned. It resulted in two load zones 180° apart. The heavy induced loads led to an ineffective lubrication condition. Both the heavy loads and lubrication problem led to premature bearing damage, which started as surface spalling.

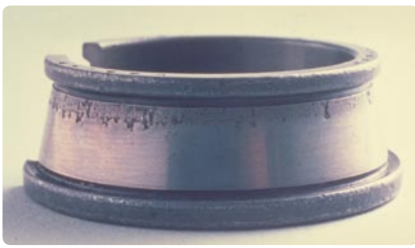
The tapered roller bearing shown in **fig. 24** was installed in a misaligned housing. The load was carried only over a small area at the edge. The resulting very high stresses in this area led to material fatigue and premature subsurface initiated spalling.

Fig. 23

Misaligned double row angular contact ball bearing: The misalignment resulted in two load zones 180° apart. Heavy loads, resulting stresses and lubrication problems led to premature bearing failure.
ISO classification: Surface initiated fatigue

Fig. 24

Misalignment of the housing caused edge loading in this tapered roller bearing. The result: premature bearing failure.
ISO classification: Subsurface initiated fatigue



Faulty mounting practices

Abuse and neglect before and during mounting often lead to damage and premature fatigue or failure.

One of the primary causes of early fatigue failures is impact damage during handling, mounting, storage, and/or operation.

In these cases, the impact is higher than the strength of the material (overload), which plastically deforms. Damage starts at the point of deformation and ultimately results in premature bearing failure.

Fig. 25 shows that the mounting force, applied to the wrong ring, passed through the rolling elements. This can also occur if the bearing is subjected to abnormal loading while not running. As the impact load is an axial load, dents can be found in the rings that are axially displaced from the centre. The distance between the dents is the same as the rolling element spacing.

Fig. 26 shows damage to the inner ring of a double row angular contact ball bearing. In this case the mounting force was applied via the outer ring. The resulting plastic deformation is equally spaced indentations that correspond to the distance between the balls.

Fig. 27 shows the resulting damage to a deep groove ball bearing after it has been in operation for some time.

Another cause of early fatigue failures is the presence of contaminants trapped in the bearing or housing. The contaminants can be introduced during mounting or could be the result of residual contaminants from a

Fig. 25

Mounting force applied to the wrong ring
ISO classification: Overload

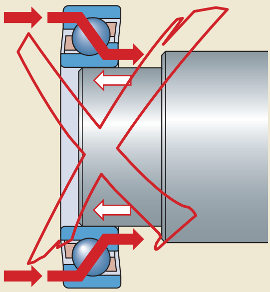


Fig. 26

Damage caused by impact during mounting
ISO classification: Overload

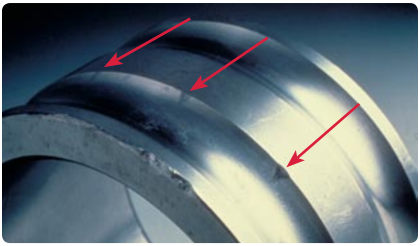


Fig. 27

Fatigue caused by impact damage during mounting
ISO classification: Overload

11

previous bearing failure. Contaminants can also be introduced as a result of the housing manufacturing process.

The effect of trapping a chip between the outside diameter of the bearing and the bore of the housing will also lead to premature bearing failure.

Cylindrical roller bearings can be damaged easily during assembly. This can happen, for example, with NU design bearings after the inner ring is fitted to the shaft and the outer ring with the cage and roller assembly is in the housing. If the shaft is askew during assembly, and not rotated, the rollers can scratch (plough) the raceway of the inner ring (→ **fig. 28**), causing indentations in the form of long, transverse streaks. Notice that the spacing (→ **fig. 29**) of the damaged area matches the distance between the rollers.

NOTE: This can be avoided: Lubricate all components well and rotate the inner ring while mounting. For larger bearings, a mounting sleeve should be used (→ **fig. 30**).

Fig. 28

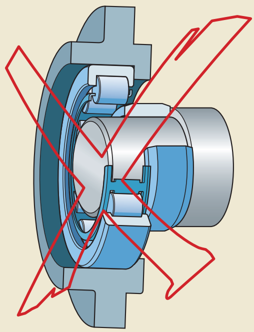
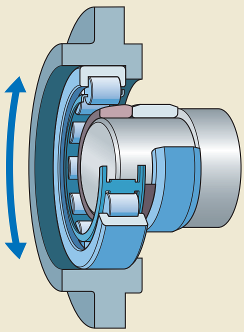


Fig. 29

Assembly damage on a cylindrical roller bearing
ISO classification: Indentation by handling

Fig. 30



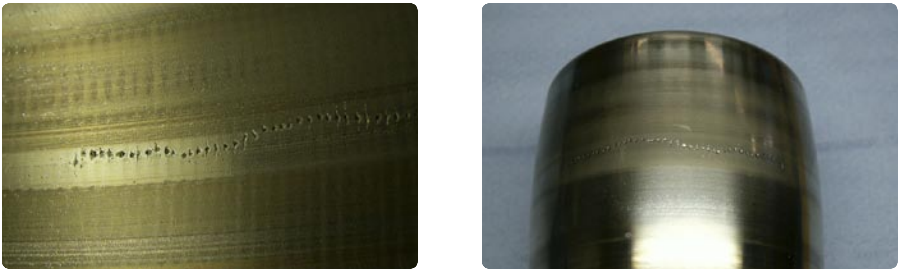
Passage of excessive electric voltage through the bearing

Under certain conditions, electric current will pass through a bearing seeking ground. For example, when repairing a shaft, excessive voltage potentials can result from improperly grounding the welding equipment. As electricity arcs from one bearing ring to the rolling elements and from there to the other ring, severe damage occurs. **Fig. 31** shows excessive electric voltage damage on the outer ring raceway and roller surface of a large spherical roller bearing.

The damage can occur at standstill but usually occurs during operation. Nevertheless, this type of damage is classified as pre-operational.

Fig. 31

Damage to a large spherical roller bearing due to passage of excessive electric voltage. Left: damage to the outer ring raceway; right: corresponding damage to the roller.
ISO classification: Excessive voltage



Transportation and storage damage

Damage typically associated with transportation includes true brinelling (overload) from shock loading or false brinelling from vibration.

True brinelling is the result of an impact. Impact can occur as a result of improper bearing handling or shock loads in an application. Depending on the severity of the damage, true brinelling will increase noise and vibration levels and reduce bearing service life. To identify true brinelling, check that the distance between the damaged areas matches the distance between the rolling elements. Since true brinelling is the result of an impact, the original grinding lines can be visible under magnification. **Fig. 32** shows a 100 × magnification of the damage due to an (overload) impact.

False brinelling damage also matches the distance between the rolling elements. However, since it is caused by vibration, the grinding marks have disappeared, as shown in **fig. 33**. False brinelling will also lead to increased noise and vibration levels, depending upon the severity.

When in storage, the bearing packaging should remain in good condition, otherwise the bearing condition might deteriorate. This is also valid for bearings already mounted in subassemblies (→ **fig. 34**). The bearings should be adequately protected.

Fig. 32

Impact mark from an overload (true brinelling) – 100 × magnification
ISO classification: Overload

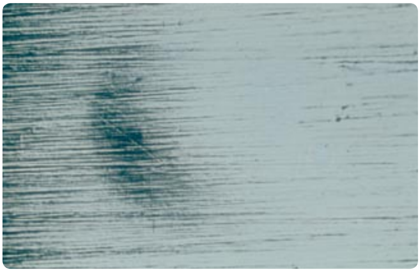


Fig. 33

Marks from false brinelling – 100 × magnification
ISO classification: False brinelling

Fig. 34

Damage from inappropriate stocking
ISO classification: Moisture corrosion

Operational causes of damage

Material fatigue (subsurface initiated)

In operation, load is transmitted from one ring to the other through the rolling elements. Every time a rolling element comes into the load zone, the load transmitted in the contact area goes from zero to a maximum and back to zero. This leads to a build-up of residual stresses in the material. Depending on the load, temperature and the number of stress cycles, these stresses will lead to structural changes in the material and result in the formation of cracks underneath the surface. These cracks will finally propagate to the surface and spalling will occur (→ **fig. 35**).

A bearing is damaged as soon as the first spall occurs. This does not mean that the bearing cannot continue to operate. Spalls will gradually increase in size (→ **fig. 36**) and number and give rise to increased noise and vibration levels in the machinery. The machine should be stopped and repaired before the bearing fails catastrophically.

To avoid premature subsurface initiated fatigue, three major conditions must exist:

- clean bearing steel – best quality bearing
- good lubrication conditions (no contamination)
- good load distribution over the rolling elements and along the rolling element contact line

Fig. 35

A spall in a bearing
ISO classification: Subsurface initiated fatigue

Fig. 36

Advanced spalling due to subsurface initiated fatigue of the material
ISO classification: Subsurface initiated fatigue

Ineffective lubrication

One of the primary assumptions made when calculating the life expectancy of a bearing, is that the bearing will be lubricated properly. This means that the correct lubricant in the right quantity will reach the bearing at the right time. All bearings require adequate lubrication for reliable operation. The lubricant separates the rolling elements, cage and raceways, in both the rolling and sliding regions of contact. Without effective lubrication, metal-to-metal contact occurs between the rolling elements and the raceways and other contact surfaces, causing damage to these surfaces.

The term “lubricant failure” is too often taken to imply that there was no oil or grease in the bearing. While this might happen occasionally, a bearing damage analysis is normally not that simple. Many damage cases are the result of insufficient lubricant viscosity, excessive lubricant viscosity, over-lubrication, inadequate lubricant quantity, contaminated lubricant or the wrong lubricant being used in the application. Therefore, a thorough examination of the lubricant properties, the amount of lubricant applied to the bearing, and the operating conditions are pertinent to any lubrication damage analysis.

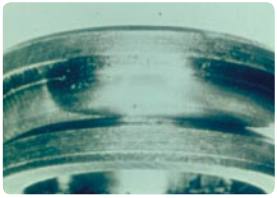
When lubrication is ineffective, damage in the form of surface fatigue will result. This damage might progress rapidly to failures that are often difficult to differentiate from failures due to material fatigue or spalling. Spalling will occur and often destroy the evidence of ineffective lubrication. However, if found early enough, indications that pinpoint the real cause of damage will be visible.

Stages of damage due to inadequate lubrication (surface distress) are shown in **fig. 37**. The first visible indication of trouble is usually a fine roughening or waviness on the surface. Later, fine cracks develop, followed by spalling.

Fig. 37

Progressive stages of spalling (surface distress) caused by ineffective lubrication
ISO classification: Surface initiated fatigue

Stage 1: Fine roughening or waviness develops on the surface.



Stage 2: Surface distress and small cracks develop. Then microspalling occurs.

Stage 3: The debris is over-rolled; real surface spalling develops.

Stage 4: If run too long, the whole raceway is spalled; initial damage can no longer be observed.

Fig. 38 shows an inner ring raceway of a large spherical roller bearing. Due to inadequate lubrication, fatigue of the surface has occurred. Spalling has already started on the outer sides of the raceway contact. **Fig. 39** shows an outer ring of a spherical roller bearing. Here, spalling is advanced.

Fig. 38

Surface distress on the outer sides of the inner ring raceway contact in a large spherical roller bearing
ISO classification: Surface initiated fatigue

Fig. 39

Advanced spalling resulting from surface distress in the outer ring of a spherical roller bearing
ISO classification: Surface initiated fatigue

Another form of surface damage is called smearing (adhesive wear). Smearing (skidding) can occur under any of the following conditions:

- relatively high speeds
- insufficient load
- lubricant too stiff
- excessive clearance
- insufficient lubricant in the load zone

When the rolling elements are subjected to severe accelerations on their re-entry into the load zone, sliding can occur. The heat generated by these sliding contacts may be so high that the two surfaces melt together at the points of metal-to-metal contact. This welding process causes material to be transferred from one surface to the other, which also leads to higher friction, and local stress concentrations with a high risk that cracks will occur and the bearing will fail prematurely. **Fig. 40** shows the outer ring of a spherical roller bearing. Each row exhibits a patch of smearing. Notice the two wear patterns in the load zone. Another example of smearing is shown in **fig. 41**.

Smearing can also occur in applications where the load is too light relative to the speed of rotation. Sliding of the rolling elements leads to a rapid increase in temperature, which can cause local melting, and the transfer of material from one surface to the other (→ **fig. 42**).

Smearing can also occur in areas such as locating flanges and roller side faces in cylindrical and tapered roller bearings, guide ring and roller side faces in spherical roller bearings and the thrust side of rollers and raceways of spherical roller thrust bearings (→ **fig. 42**).

Fig. 40

Smearing in the re-entry side of the load zone in the outer ring of a spherical roller bearing
ISO classification: Adhesive wear

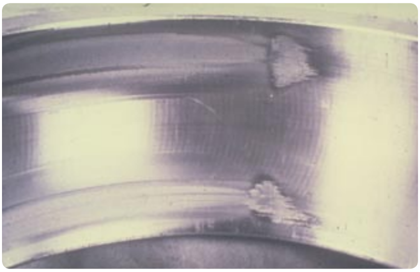


Fig. 41

Smearing on one raceway of the stationary inner ring of a spherical roller bearing
ISO classification: Adhesive wear

Fig. 42

Smearing on the thrust side of a roller of a spherical roller thrust bearing
ISO classification: Adhesive wear

Wear in a bearing as a whole also results from ineffective lubrication. **Fig. 43** illustrates this type of damage.

Most metallic cages are not hardened. With ineffective lubrication, wear often starts in the cage pockets (→ **figs. 44** and **45**).

Fig. 43

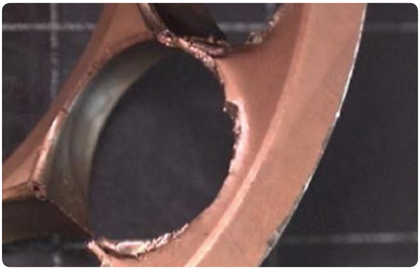
Wear due to ineffective lubrication in a spherical roller bearing
ISO classification: Abrasive wear

Fig. 44

Wear due to ineffective lubrication: solid brass cage of a cylindrical roller bearing
ISO classification: Abrasive wear

Fig. 45

Advanced wear due to ineffective lubrication: solid steel cage of a single row angular contact ball bearing
ISO classification: Abrasive wear



Ineffective sealing

This section deals with damage to bearings due to ineffective sealing arrangements.

When contaminants enter the bearing cavity, bearing service life will be reduced. It is therefore extremely important to protect the bearings with either integral seals or shields or external seals. In severely contaminated environments, it can be advantageous to use both sealing solutions.

When solid contaminants enter a bearing, the lubricant can lose its effectiveness and wear can occur. This is an accelerating process, because the lubricant will continue to deteriorate and the wear will destroy the microgeometry of the bearing. The speed of this process depends largely on the type of contaminant and whether the wear particles remain in the bearing, or are removed (relubrication). Most of the time, wear results in dull surfaces (→ **figs. 46** to **48**).

Fig. 46 shows the outer ring of a spherical roller bearing with two wear bands in the load zone. Some waviness, due to vibration during operation, is also visible. **Fig. 47** shows the inner ring of a spherical roller bearing in an application with outer ring rotation. The wear is advanced in both raceways and spalling has started. **Fig. 48** shows the inner ring of a large spherical roller bearing in an application with outer ring rotation. The wear is very advanced and spalling has started. Each raceway has two wear zones. Wear occurred in one zone. Then, due to inner ring creep (turn), wear started in the second zone.

Fig. 46

Wear in a spherical roller bearing outer ring
ISO classification: Abrasive wear

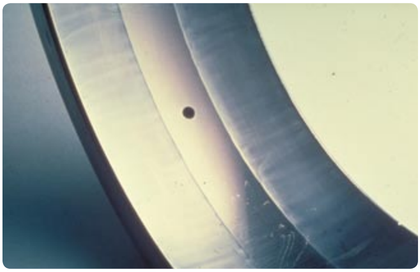


Fig. 47

Advanced wear on a stationary inner ring of a spherical roller bearing
ISO classification: Abrasive wear

Fig. 48

Very advanced wear on the stationary inner ring of a large spherical roller bearing
ISO classification: Abrasive wear

Sometimes, wear particles or other solid contaminants will act as a polishing agent and the contact surfaces become extremely shiny. The extent of this depends on the size of the particles, their hardness and time (→ **figs. 49** and **50**).

Fig. 49

Polishing wear in a spherical roller bearing
ISO classification: Abrasive wear

Fig. 50

Polishing wear on the inner ring of a large spherical roller bearing
ISO classification: Abrasive wear

Solid contaminants that enter into the bearing cavity cause indentations when over-rolled in the raceways by the rolling elements. The damage done to the raceways depends on the type of contaminant. Very hard particles, such as Al_2O_3 (material from a grinding stone), produce indentations with sharp corners, which cause high stresses in the damaged area. Soft contaminants like a thin piece of paper or the thread from a cotton cloth can also cause harmful indentations.

Every indentation has the potential to initiate premature fatigue.

Fig. 51 shows an indentation from an over-rolled piece of metal wire in a very large spherical roller bearing.

Fig. 52 shows indentations in a very large spherical roller bearing. The large number of indentations would significantly reduce bearing service life.

Fig. 53 shows a deep groove ball bearing with indentations due to contaminants. Spalling started at the two points indicated by the circles and continued on from there.

Fig. 51

An indentation from a piece of metal wire in a very large spherical roller bearing
ISO classification: Indentation from debris

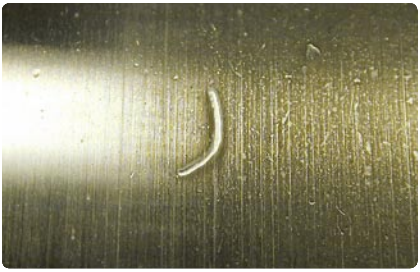


Fig. 52

Indentations from debris in a large spherical roller bearing
ISO classification: Indentation from debris

Fig. 53

Spalling in a deep groove ball bearing due to indentations
ISO classification: Indentation from debris

Corrosion is another problem that occurs as a result of an ineffective sealing arrangement, mostly at standstill.

Water, acid, and many cleaning agents deteriorate lubricants, resulting in corrosion.

When water, acid or cleaning agents enter an application, it negatively affects the ability of the lubricant to protect steel surfaces from oxidation. As a result, when a machine is at a standstill, deep-seated rust forms easily.

Over time, the excessive moisture will form an acid in the lubricant and etch the surface black, as shown in **fig. 54**.

In the presence of water and due to capillary action, the area next to the rolling element contact zone might become corroded (→ **fig. 55**). This corrosion appears as greyish black streaks across the raceways, which usually coincide with the distance between the rolling elements (→ **fig. 56**).

Fig. 54

Moisture acids in a spherical roller bearing
ISO classification: Moisture corrosion

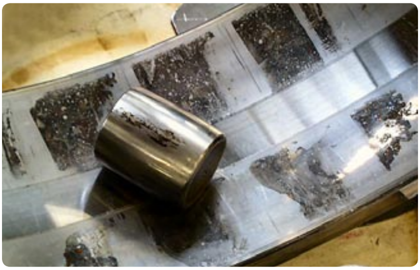


Fig. 55

Due to capillary action, the area next to the rolling element contact zone might become corroded.
ISO classification: Moisture corrosion

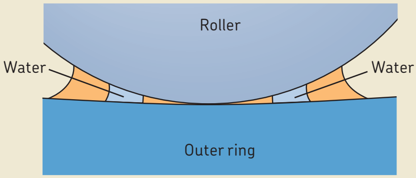


Fig. 56

Corrosion streaks caused by water in the lubricant
ISO classification: Moisture corrosion

When water, acid, or cleaning agents have compromised the lubricant's ability to protect steel surfaces, and the standstill is prolonged, the entire surface of the rings and rolling elements can become corroded (→ **figs. 57** and **58**).

Fig. 57

Rust on an outer ring of a spherical roller bearing caused by moisture during prolonged standstill
ISO classification: Moisture corrosion

Fig. 58

Rust on a roller of a spherical roller bearing caused by moisture during prolonged standstill
ISO classification: Moisture corrosion

Vibration (false brinelling)

Vibration, mostly during standstill, is another cause of bearing damage. As in the case of auxiliary and standby equipment, vibration damage can be caused by nearby machinery that is in operation. Depending on the proximity of the idle unit to the operating one(s), vibration created from the running equipment causes the rolling elements in the bearing of the static machine to vibrate. Depending on the intensity and frequency of the vibration, the condition of the lubricant and the load, a combination of corrosion and wear occurs, forming shallow depressions in the raceway.

The depressions, which have the same spacing as the rolling elements, are often discoloured (reddish) or shiny (sphered depressions for ball bearings, lines for roller bearings).

The magnitude and duration of the vibration and the bearing internal clearance can influence the damage. Roller bearings seem more susceptible to this type of damage than ball bearings.

Fig. 59 shows the result of vibration damage in a self-aligning ball bearing in a standby unit. **Fig. 60** shows a similar result in a CARB toroidal roller bearing due to prolonged standstill. **Fig. 61** shows false brinelling in the outer ring of a cylindrical roller bearing. The bearing was fitted to the electric motor of an auxiliary piece of equipment. There were several stops and starts. At every standstill, vibration damage occurred. Several sets of "flutes" at roller spacing can be observed. The three arrows show the heaviest damage – at roller spacing – during a prolonged standstill.

Fig. 59

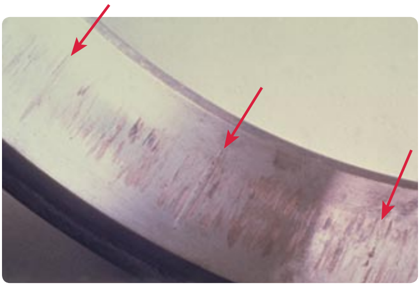
Vibration damage in a self-aligning ball bearing in a standby unit
ISO classification: False brinelling

Fig. 60

Vibration damage in a CARB toroidal roller bearing due to prolonged standstill
ISO classification: False brinelling

Fig. 61

Vibration damage in a cylindrical roller bearing in an auxiliary piece of equipment
ISO classification: False brinelling

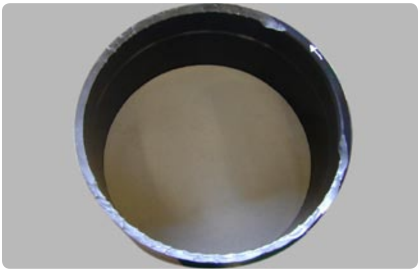


Operational misalignment

Causes of operational misalignment include shaft deflections caused by heavy loads or load amplitude changes during operation (imbalanced load). When operational misalignment is present, load zones are not parallel to the raceway grooves (→ **fig. 9** on **page 297**). The result is induced axial loads, which can be dangerous, because they can lead to fatigue fracture. **Fig. 62** shows the outer ring of a NNCF double row full complement cylindrical roller bearing. The outer ring flange is almost completely broken off, due to fatigue from induced axial loads resulting from shaft deflection.

Fig. 62

Fatigue fracture of the outer ring flange in a double row full complement cylindrical roller bearing
ISO classification: Fatigue fracture



Passage of electric current through the bearing

For damage due to excessive voltage, refer to the section *Passage of excessive electric voltage through the bearing* on **page 307**.

However, current damage can occur even if the intensity of the current is relatively low. Stray electric currents can be caused by any one of the following: frequency inverters, flux asymmetries, motor design, unsymmetrical cabling, grounding and driven machinery. Initially, the surface is damaged by shallow craters, which are closely positioned to one another and so small that magnification is necessary (→ **figs. 63** and **64**).

Cutting through the material and enlarging to approximately 500 × magnification shows the material change (→ **fig. 65**). The white area shows that the metal has been rehardened, typically 66 to 68 HRC. This material is very hard and brittle. Below the hardened area is a black layer, annealed by the heat, which is softer than the surrounding bearing material (56 to 57 HRC).

Fig. 63

Current leakage: Small craters can be observed at 500 × magnification.
ISO classification: Current leakage

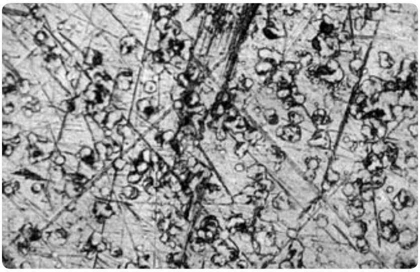


Fig. 64

Craters (1 000 × magnification)
ISO classification: Current leakage

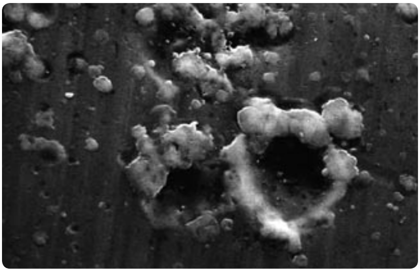
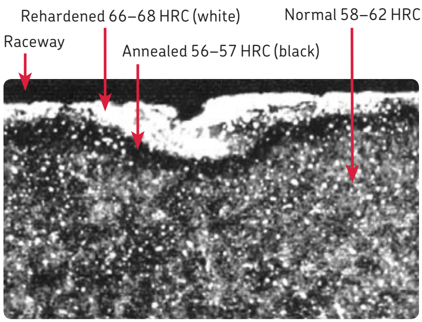


Fig. 65

Material change: Bearing ring cross section at 500 × magnification
ISO classification: Current leakage



The extent of damage depends on a number of factors: bearing type, the intensity of the current (Amperes), duration, bearing load, bearing clearance, speed and lubricant. Over a period of time, flutes (also called washboarding effect) will develop from the craters (→ **figs. 66** and **67**), parallel to the rolling axis. They can be considerable in depth, producing noise and vibration during operation. Eventually, the bearing will fail due to metal fatigue. Apart from the fluting pattern on the rings and rollers of the bearings, there are two more signs that can indicate damage from stray electric currents: a darkened grey dull discoloration of the rolling elements (→ **fig. 68**), together with a very fine darkened grey matt discoloured load zone. The grease on or near the cage bars will be (carbonized) black (→ **fig. 69**).

Current damage can also happen from static electricity emanating from charged belts or from manufacturing processes involving leather, paper, cloth or rubber. These stray currents pass through the shaft and bearing to ground. When the current bridges the lubricant film between the rolling elements and raceways, microscopic arcing occurs.

NOTE: To avoid problems with damage from current leakage, SKF recommends using bearings that provide insulation: hybrid or INSOCOAT bearings. Electrical discharge detector pens from SKF can help detect the presence of electrical discharge currents in rolling bearings.

Fig. 66

Flutes (washboarding) in an early stage in a spherical roller bearing
ISO classification: Current leakage

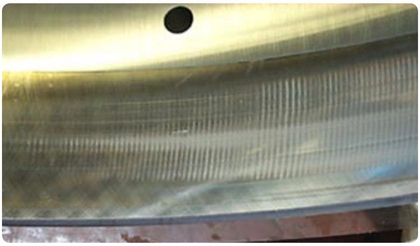


Fig. 67

Flutes in an advanced stage in a deep groove ball bearing
ISO classification: Current leakage

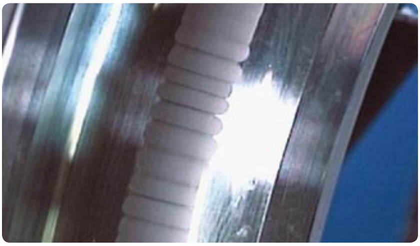


Fig. 68

Left: ball with dull colour caused by current leakage
Right: normal ball
ISO classification: Current leakage

Fig. 69

Burnt grease on the cage bars
ISO classification: Current leakage