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Rolling bearings — Damage and failures — Terms, characteristics and causes

Roulements — Détérioration et défaillance — Termes, caractéristiques et causes

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Foreword

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The procedures used to develop this document and those intended for its further maintenance are described in the ISO/IEC Directives, Part 1. In particular the different approval criteria needed for the different types of ISO documents should be noted. This document was drafted in accordance with the editorial rules of the ISO/IEC Directives, Part 2 (see www.iso.org/directives).

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. ISO shall not be held responsible for identifying any or all such patent rights. Details of any patent rights identified during the development of the document will be in the Introduction and/or on the ISO list of patent declarations received (see www.iso.org/patents).

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For an explanation on the meaning of ISO specific terms and expressions related to conformity assessment, as well as information about ISO's adherence to the World Trade Organization (WTO) principles in the Technical Barriers to Trade (TBT) see the following URL: www.iso.org/iso/foreword.html.

The committee responsible for this document is ISO/TC 4, *Rolling bearings*.

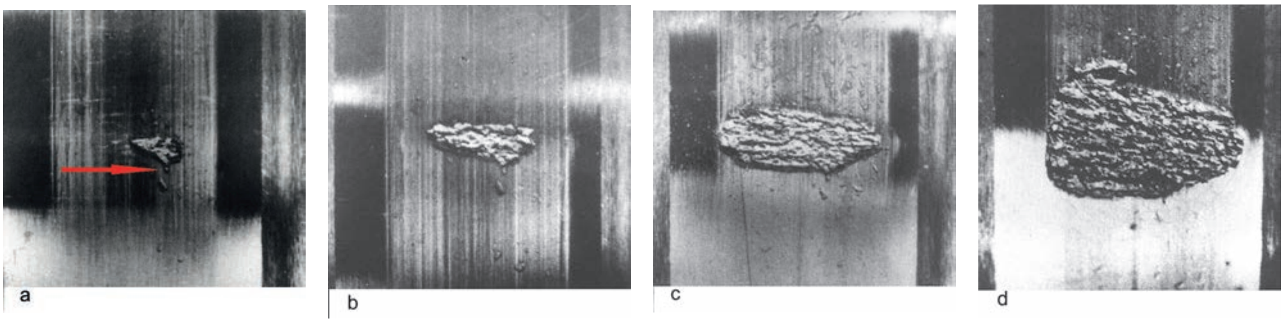
This second edition cancels and replaces the first edition (ISO 15243:2004), which has been technically revised.

Introduction

In practice, damage and/or failure of a rolling bearing can often be the result of several mechanisms operating simultaneously. The failure can result from improper transport, handling, mounting or maintenance or from faulty manufacture of the bearing or its adjacent parts. In some instances, failure is due to a design compromise made in the interests of economy or from unforeseen operating and environmental conditions. It is the complex combination of design, manufacture, mounting, operation and maintenance that often causes difficulty in establishing the root cause of failure.

NOTE Be aware that counterfeit bearings are circulated in the market. They might look as original bearings, but their use often lead to very early damage or failure.

In the event of extensive damage to or catastrophic failure of the bearing, the evidence is likely to be lost and it will then be impossible to identify the root cause of failure. It is therefore important to stop equipment in time to enable appropriate bearing damage analysis (see Figure 1). In all cases, knowledge of the actual operating conditions of the assembly and the maintenance history is of utmost importance.



NOTE The spall started just behind the dent in the raceway [a)]. Over a period of time, the spalling becomes more severe [b) and c)]. If not stopped in time, the proof of the root cause disappears [d)].

Figure 1 — Progression of bearing damage

The classification of bearing failure established in this document is based primarily upon the features visible on rolling contact surfaces and other functional surfaces. Consideration of each feature is required for reliable determination of the root cause of bearing failure. Since more than one failure mechanism may cause similar effects to these surfaces, a description of appearance alone is often inadequate for determining the cause of the failure. In such cases, the operating conditions need to be considered. In some cases, the analysed damage is too advanced, and can be originated from different primary causes. In these cases, it is interesting to look for simultaneous presence of indications to determine the primary cause of the failure.

This document covers rolling bearings having steel rings and rolling elements. Damage to the rings of bearings with ceramic rolling elements shows similar failure modes.

In this document, bearing life is as described in ISO 281[1], which provides formulae to calculate bearing life taking a number of factors into consideration, such as bearing load carrying capacity, bearing load, type of bearing, material, bearing fatigue load limit, lubrication conditions and degree of contamination.

Rolling bearings — Damage and failures — Terms, characteristics and causes

1 Scope

This document classifies different modes of failure occurring in service for rolling bearings made of standard bearing steels. For each failure mode, it defines and describes the characteristics, appearance and possible root causes of failure. It will assist in the identification of failure modes based on appearance.

For the purposes of this document, the following terms are explained:

— failure of a rolling bearing: the result of a damage that prevents the bearing meeting the intended design performance or marks the end of service life;

— in service: as soon as the bearing has left the manufacturer's factory;

— visible features: those that are possible to observe directly or with magnifiers or optical microscopes, also those from pictures, but only with the use of non-destructive methods.

Consideration is restricted to characteristic forms of change in appearance and failure that have well-defined appearance and which can be attributed to particular causes with a high degree of certainty. The features of particular interest for explaining changes and failures are described. The various forms are illustrated with photographs and the most frequent causes are indicated.

If the root cause cannot be reliably assessed by the examination and characterization of visual features against the information in this document, then additional investigations are to be considered. These methods are summarized in A.3 and may involve, for example, the use of invasive methods possibly including taking of cross sections, metallurgical structural analysis by visual and electronic microscopes, chemical and spectrographic analysis. These specialized methods are outside the scope of this document.

The failure mode terms shown in the subclause titles are recommended for general use. Where appropriate, alternative expressions or synonyms used to describe the submodes are given and explained in A.4.

Examples of rolling bearing failures are given in A.2, together with a description of the causes of failure and proposed corrective actions.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO 5593, *Rolling bearings — Vocabulary*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO 5593 and the following apply.

NOTE Explanations for terms for damage and failures are listed in A.4.

ISO and IEC maintain terminological databases for use in standardization at the following addresses:

— IEC Electropedia: available at http://www.electropedia.org/

— ISO Online browsing platform: available at http://www.iso.org/obp

3.1
characteristics
visual appearance that results from service performance

Note 1 to entry: Surface defects and types of geometrical change are defined in ISO 8785[3] and partly in ISO 6601[2] (related to abrasive wear).

3.2
damage
any visible deterioration of the bearing operating surfaces or structures

3.3
event sequences
sequence of events leading to bearing *failure* (3.4) starting with initial *damage* (3.2) to the bearing

Note 1 to entry: At an early stage, this damage can result in loss of function or failure. In many cases, however, the initial damage does not result in failure and the bearing continues to operate. This continued operation most often leads to secondary damage which eventually results in failure. Secondary damage can introduce competing modes of failure, which can make root cause analysis difficult.

3.4
failure
any condition where the bearing can no longer deliver its designed function

Note 1 to entry: This will include degradation of important rotational properties and warning of imminent more extensive or complete failure, but may not be so advanced as to prevent rotation or support of the subject machine elements.

Note 2 to entry: The extent of *damage* (3.2) required to cause a declaration of operational failure will depend on the application. Applications requiring accurate smooth rotation will tolerate only very minor loss of properties. Applications not sensitive to increased vibration, increased noise or reduced rotational accuracy may be able to continue to deliver their performance for a restricted period.

3.5
failure mode
manner in which a bearing fails

4 Classification of failure modes occurring in rolling bearings

Preferably, one would classify rolling bearing damage and failures according to the root cause. However, it is often not easy to distinguish between causes and characteristics (symptoms) or, in other words, between failure mechanisms and failure modes. The large number of articles and books written on the subject confirms this (see Bibliography). Therefore, in this document, failure modes are classified in six main groups and various sub-groups (see Figure 2), based on their visible distinctive characteristic appearance in service.

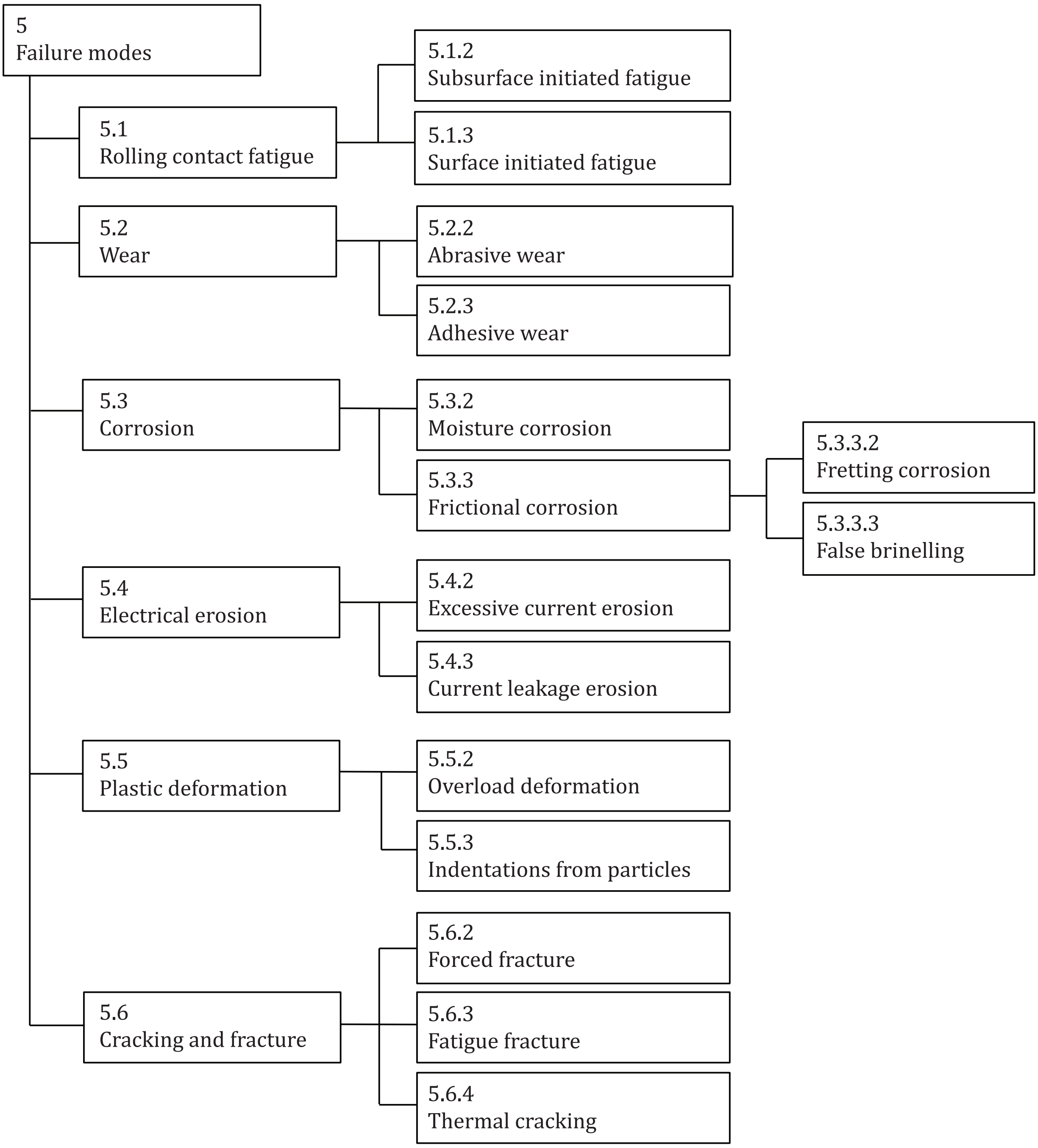


Figure 2 — Classification of failure modes

5 Failure modes

5.1 Rolling contact fatigue

5.1.1 General description of rolling contact fatigue

Rolling contact fatigue is caused by the repeated stresses developed in the contacts between the rolling elements and the raceways. Fatigue is manifested visibly as a change in the structure (microstructure) and as spalling of material from the surface (macrostructure) that, in most of the cases, could be consequential to a change in microstructure.

NOTE Spalling and flaking are synonyms (see A.4).

5.1.2 Subsurface initiated fatigue

Under the influence of cyclic loading in the rolling contacts described by the Hertzian theory, stresses and material structural changes occur and microcracks are initiated at a location and depth which depend on the applied load, the operating temperature, the material and its cleanliness and microstructure. The initiation of the microcracks is often caused by inclusions in the bearing steel.

The changes might appear at metallurgical investigation (see A.3). These cracks propagate and when they come to the surface, spalling occurs (see Figures 3 and 4).

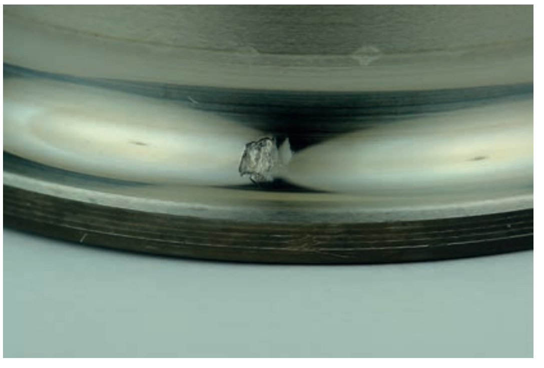


Figure 3 — Initial subsurface spalling in a deep groove ball bearing — Rotating inner ring

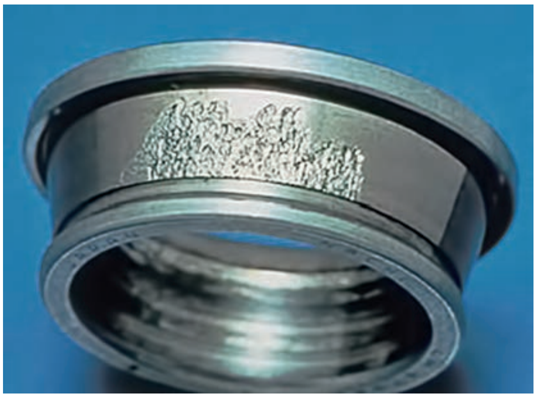


Figure 4 — Advanced subsurface spalling in a tapered roller bearing — Stationary inner ring

5.1.3 Surface initiated fatigue

Fatigue initiated from the surface is typically caused by surface distress.

Surface distress is damage initiated at the rolling contact surfaces due to plastic deformation of the surface asperities (smoothing, burnishing, glazing). Contact between the asperities of the rolling element and bearing raceway is most often the result of inadequate lubrication conditions (insufficient lubricant film thickness). This contact may be caused by insufficient lubrication flow/availability, improper lubricant for the application, operating temperatures beyond the expected level or rough surface finishes. Contact and plastic deformation of the surface asperities can lead to

— asperity microcracks (see Figure 5),

— asperity microspalls (see Figure 6), and

— microspalled areas (grey stained) (see Figure 7).

Sliding motion under low lubricant film conditions can significantly accelerate the surface damage.

For cases where film thickness is sufficient for normal operating conditions, surface-initiated fatigue may still occur. This can happen when particles are introduced into the contact area (see 5.5.3), extreme loads plastically deform the surface or handling nicks are present. All three conditions result in indentations in the raceways. Protrusions around the indentation exceed the height of the oil film, resulting in deformation of surface asperities. Surface initiated fatigue caused by indentation arising from plastic deformation is shown in A.2.6.2.

NOTE ISO 281[1] includes surface related calculation parameters that are known to have an influence on the bearing life such as material, lubrication, environment, contamination particles and bearing load.

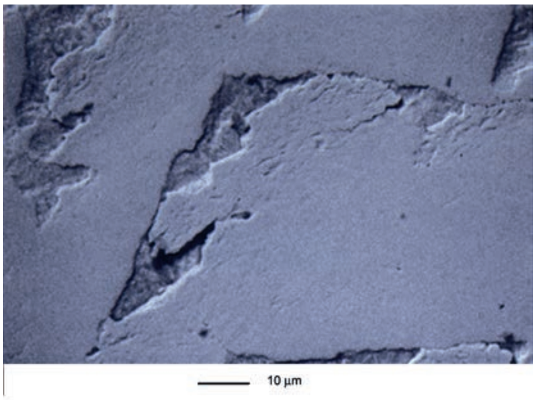


Figure 5 — Asperity microcracks and microspalls on a raceway

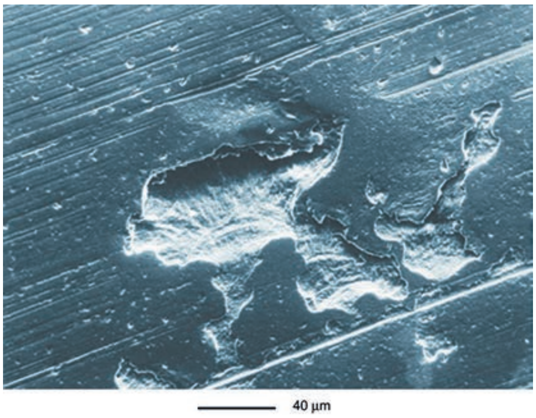


Figure 6 — Surface initiated microspalls on a raceway

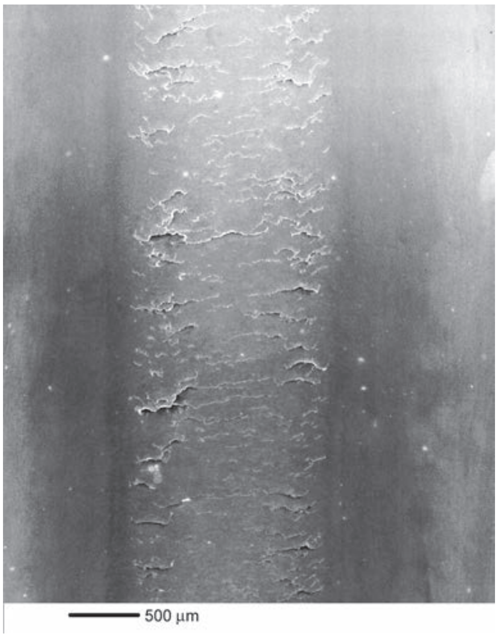


Figure 7 — Microspalled areas on a raceway

5.2 Wear

5.2.1 General description of wear

Wear is the progressive removal of material from the surface, resulting from the interaction of two sliding or rolling/sliding contacting surfaces during service.

5.2.2 Abrasive wear

Abrasive wear (particle wear, three-body wear) is the removal of material due to sliding in presence of hard particles. It is the result of a hard surface or particle removing material from another surface through a cutting or ploughing action when sliding across it. The surfaces become dull to a degree, which varies according to the coarseness and nature of the abrasive particles (see Figure 8). These particles gradually increase in number as material is worn away from the running surfaces and, possibly, the cage (see Figure 9). Finally, the wear becomes an accelerating process that results in a failed bearing.

Although the surfaces normally become dull to a certain extent, when the abrasive particles are very fine, a polishing effect might occur, resulting in very shiny surfaces (see Figure 10).

NOTE The “running-in” of a rolling bearing is a natural short process after which the running behaviour, e.g. noise or operating temperature, stabilizes or even improves. As a consequence, the running path or running track becomes visible; however this is not indicating that the bearing is damaged.

Figure 8 — Abrasive wear on the inner ring of a spherical roller bearing

Figure 9 — Advanced abrasive wear on the cage pockets of a solid metal cage

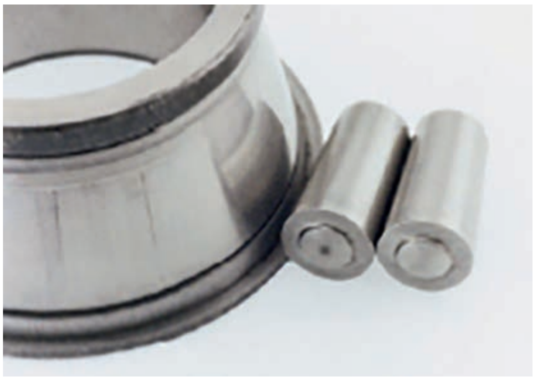


Figure 10 — Abrasive wear on the raceway of the large rib surface of the inner ring and on the large end face of rollers in a tapered roller bearing

5.2.3 Adhesive wear

Adhesive wear is characterized by a transfer of material from one surface to another with frictional heat and, sometimes, tempering or rehardening of the surface. This produces localized stress concentrations with the potential for cracking or spalling of the contact areas.

Smearing (skidding, galling, scoring, frosting) occurs because of inadequate lubrication conditions when sliding occurs and localized temperature rises from friction cause adhesion of the contacting surfaces, resulting in material transfer. This typically happens between rolling elements and raceways if the rolling elements are too lightly loaded and subjected to severe acceleration on their re-entry into the load zone (see Figures 11 and 12). In severe cases of smearing, seizing may result. Smearing is usually a sudden occurrence as opposed to an accumulated wear process.

Smearing can also occur on the rib faces and on the ends of the rollers due to inadequate lubrication (see Figure 13). In full complement (cageless) bearings, smearing can also occur in the contacts between rolling elements, depending on lubrication and rotation conditions.

If a bearing ring moves (creeps) relative to its seat because of inadequate retention on the shaft or in the housing, then smearing (also called scuffing) can occur in the bearing bore, the outside diameter or on the shaft or in the housing seat. Because of the minute difference in the diameters of the two components, they will have a minute difference in their circumferences and, consequently, when brought into contact at successive points by the radial load rotating with respect to the ring, will rotate at minutely different speeds. This rolling motion of the ring against its seating with a minute difference in the rotational speeds is termed “creep”.

When creep occurs, the asperities in the ring/seat contact region are over-rolled, which can cause the surface of the ring to take on a shiny appearance. The over-rolling during creeping is often, but not always, accompanied by sliding in the ring/seat contact, and then other damage will also be visible, e.g. score marks, fretting corrosion and wear. Under certain loading conditions and when the ring/seating interference fit is insufficiently tight, fretting corrosion will predominate (see A.2.4.2.1 and A.2.4.2.2).

Furthermore, with a loose radial fit, creep can also occur between the face of a ring and its axial abutment. In severe cases, this can lead to transverse thermal cracks and finally cause cracking of the ring (see 5.6.4).

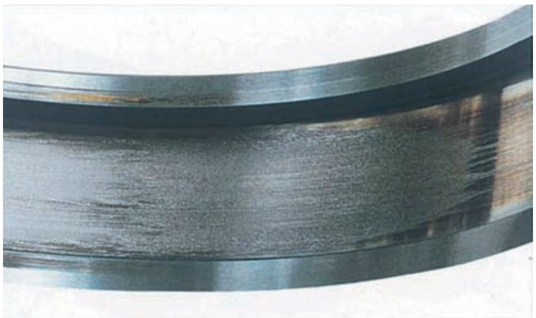


Figure 11 — Smearing on the outer ring raceway of a cylindrical roller bearing

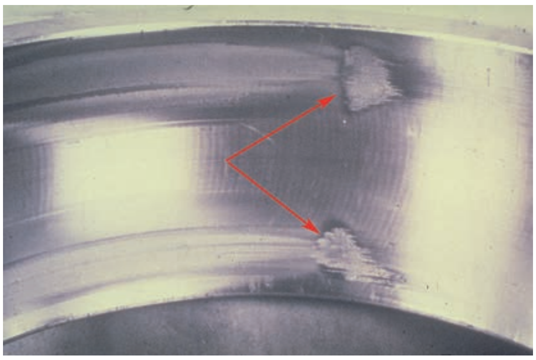


Figure 12 — Smearing on the outer ring raceways of a spherical roller bearing

Figure 13 — Smearing on the side face of rollers of a cylindrical roller bearing

5.3 Corrosion

5.3.1 General description of corrosion

Corrosion is the result of a chemical reaction on metal surfaces.

5.3.2 Moisture corrosion

When bearing components are in contact with moisture or aggressive media (e.g. water or acids), oxidation or corrosion (rust) of surfaces takes place (see Figure 14). Subsequently, the formation of corrosion pits occurs and finally spalling of the surface occurs (see Figure 15).

A specific form of moisture corrosion can be observed in the contact areas between rolling elements and bearing rings where the water content in the lubricant or the degraded lubricant reacts with the surfaces of the adjacent bearing elements. During static periods, the advanced stage will result in dark discolouration of the contact areas at intervals corresponding to the ball/roller pitch (see Figure 16); eventually producing corrosion pits.

Figure 14 — Moisture corrosion on the cage and rollers of a needle roller thrust bearing

Figure 15 — Moisture corrosion on the outer ring raceway of a cylindrical roller bearing

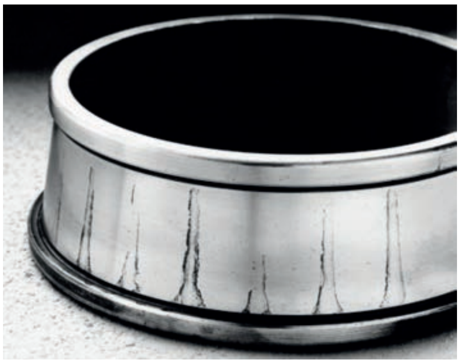


Figure 16 — Contact corrosion at roller pitch on the inner ring raceway of a tapered roller bearing

5.3.3 Frictional corrosion

5.3.3.1 General description of frictional corrosion

Frictional corrosion (tribo-corrosion, tribo-oxidation) is a chemical reaction activated by relative micromovements between mating surfaces under certain friction and load conditions. These micromovements lead to oxidation of the surfaces and released material becoming visible as powdery rust and/or loss of material from one or both mating surfaces.

5.3.3.2 Fretting corrosion

Fretting corrosion occurs in fit interfaces between components that are transmitting loads under oscillating contact surface micromovements. Surface asperities oxidize and are rubbed off and vice versa; powdery rust develops (fretting rust, iron oxide). The bearing surface becomes discoloured blackish red (see Figure 17). Typically, the damage develops when loads and/or vibrations overcome the radial clamping given by the mounting fits. Excessively rough and/or wavy surface finish of bearing, shaft and housing surfaces can also reduce the effective mounting fit and induce fretting corrosion (see Figure 18).

NOTE 1 Some abrasive wear might occur as a resultant effect of the presence of the corrosion products (iron oxide) and micromovements.

NOTE 2 In this document, fretting corrosion is classified under corrosion. In other documents, it is sometimes classified as fretting wear.

Figure 17 — Fretting corrosion in the inner ring bore of a deep groove ball bearing

Figure 18 — Fretting corrosion on the outer diameter of a roller bearing

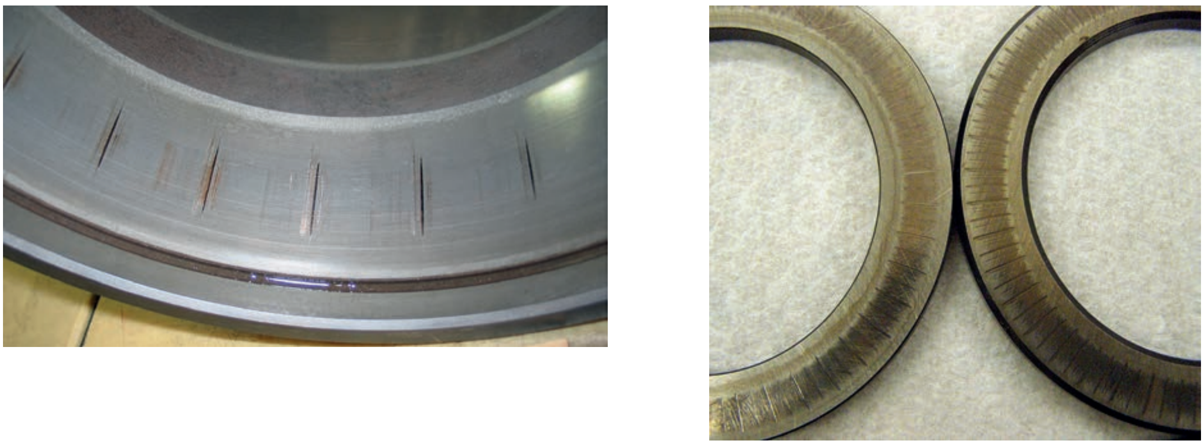
5.3.3.3 False brinelling

False brinelling (vibration corrosion) most commonly occurs in rolling element/raceway contact areas of non-rotating bearings due to micromovements and/or resilience of the elastic contacts under cyclic vibrations. Depending on the intensity of the vibrations, the load and lubrication conditions, depressions are formed on the raceways, mostly also leading to corrosion (due to lack of protective lubricant) and resultantly abrasive wear.

In the case of a stationary bearing, the depressions appear at rolling element pitch and may be discoloured reddish or shiny (see Figures 19 and 20).

False brinelling occurring in stand-by equipment, when long stopped periods in the presence of vibrations from nearby operating equipment are alternated with rather short running sessions, could result in closely spaced flutes. These should not be mistaken for electrically caused flutes (see 5.4.3 and Figures 23, 24 and 25). The fluting resulting from vibration has bright or fretted bottoms to the depressions compared to fluting produced by the passage of electric current, where the bottoms of the depressions are dark greyish in colour. The damage caused by electric current is distinguishable by the fact that the rolling elements show corresponding marks, but normally in a less advanced stage.

NOTE In this document, false brinelling is classified under corrosion. In other documents, it is sometimes classified as wear.



a) Outer ring of a tapered roller bearing **b) Washer raceways of a needle roller thrust bearing**

Figure 19 — False brinelling

Figure 20 — False brinelling on the outer ring raceway of a self-aligning ball bearing

5.4 Electrical erosion

5.4.1 General description of electrical erosion

Electrical erosion is the localized microstructural change and removal of material at the contact surfaces caused by the passage of damaging electric current.

5.4.2 Excessive current erosion

When an electric voltage between bearing rings and rolling element(s) exceeds the insulation breakdown threshold value, an electrical current passes from one bearing ring to the other through the rolling elements and their lubricant films. In the contact areas between raceways and rolling elements, a concentrated discharge takes place resulting in localized heating within very short time intervals, so that the contact areas melt and weld together.

This damage (electrical pitting) may appear as a series of craters with diameters of up to 500 µm (see Figures 21 and 22). The craters are duplicated on the rolling element and raceway contact surfaces, typically in bead-like procession in the rolling direction (see Figure 21).

Figure 21 — Roller of a spherical roller bearing — Craters formed by the passage of excessive electric current

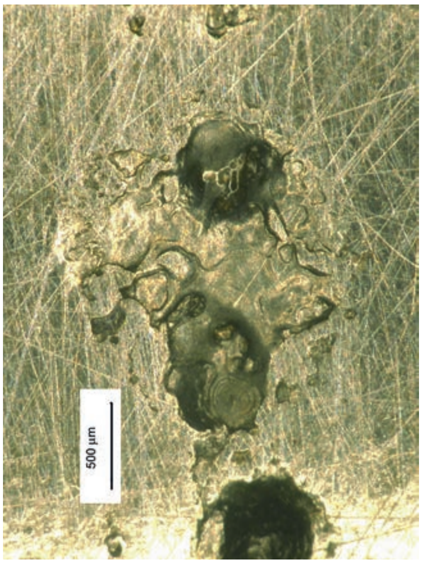


Figure 22 — Enlargement of Figure 21 showing craters and molten material

5.4.3 Current leakage erosion

When a damaging (capacitive or inductive) electric current becomes continually established, the erosion takes on a different appearance as to 5.4.2. Initially, the surface damage may take the shape of shallow craters, which are closely positioned to one another and very small in size, in the order of micrometres. This happens even if the intensity of the current is relatively low. Flutes may develop due to current passing through the whole contact ellipse (ball bearing) or line (roller bearing), as shown in Figures 23, 24 and 25 (electrical fluting). Flutes can be found on roller and ring raceway contact surfaces, but not on balls, which have dark colouration only. The visual appearance of balls is mostly dull varying from light to dark grey (see Figure 24). Inspection on microscale usually shows craters.

Additionally, the lubricant can also deteriorate by the electric current passage. The damaged grease exhibits black discolouring and hardened consistency.

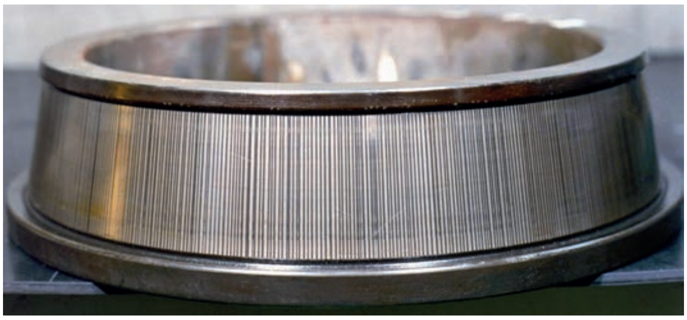


Figure 23 — Fluting (washboarding) as a result of current leakage on the inner ring raceway of a tapered roller bearing

Figure 24 — Fluting on the inner ring raceway and matt dark grey coloured balls of a deep groove ball bearing

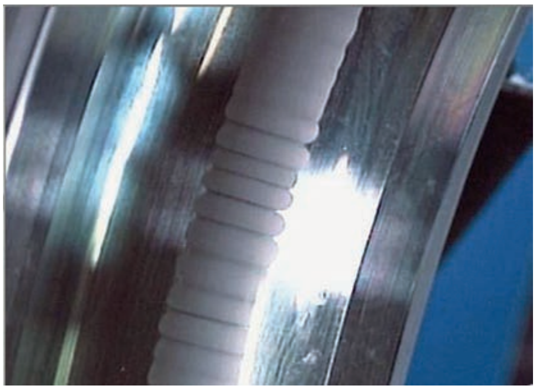


Figure 25 — Fluting on the outer ring raceway of a deep groove ball bearing

5.5 Plastic deformation

5.5.1 General description of plastic deformation

This is a permanent deformation that occurs whenever the yield strength of the material is exceeded.

Typically, this can occur in two different ways:

— on a macroscale, where the contact load between a rolling element and the raceway causes yielding over a substantial portion of the contact footprint;

— on a microscale, where a foreign object is over-rolled between a rolling element and the raceway and yielding occurs over only a small part of the contact footprint.

5.5.2 Overload deformation

Overload deformation can occur while the bearing is stationary (most common), or while rotating (uncommon).

Overloading of a stationary bearing by static load or shock load leads to plastic deformation at the rolling element/raceway contacts (true brinelling), i.e. the formation of shallow depressions or flutes on the bearing raceways in positions corresponding to the pitch of the rolling elements (see Figures 26 and 27).

Overload can be distinguished from false brinelling or electrical fluting by the visibility of surface finish or residual machining marks at the bottom of the depression or flute. Furthermore, overloading can occur by excessive preloading or due to incorrect handling during mounting (see Figure 26).

Inappropriate handling can also cause overloading and deformation of other bearing components, e.g. shields, washers and cages (see Figure 28). Raceways and rolling elements can incur indentations and nicks caused by hard, possibly sharp objects or by incorrect assembly (see Figure 29).

Overload of a rotating bearing can take different aspects depending on the type of overload.

— Instantaneous overload can lead to fluting (washboarding) with individual, non-symmetrical marks that are more or less extended.

— Instantaneous overload can lead to depressions at rolling element pitch.

— Permanent overload can result in lamination and macroscopic plastic deformation of the whole circumference of the overloaded part of the raceway.

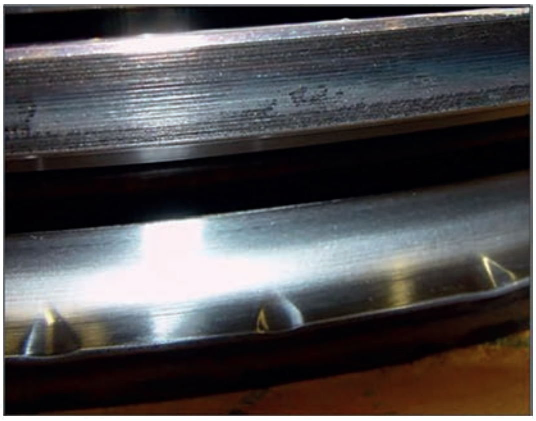


Figure 26 — Overload on a stationary inner ring of an angular contact ball bearing

Figure 27 — Spalling as a result of shock load deformation on the inner ring raceway of an angular contact ball bearing, resulting from impacts in radial direction, which further developed in spalling

Figure 28 — Cage deformation of an angular contact ball bearing caused by a shock load during handling

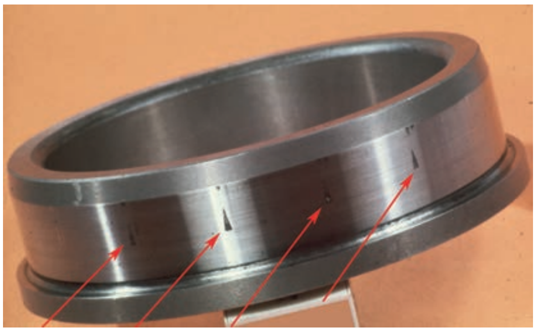


Figure 29 — Indentations on the inner ring raceway of a cylindrical roller bearing caused by incorrect assembly

5.5.3 Indentations from particles

When particles are over-rolled, indentations are formed on raceways of rings (see Figure 30) and rolling elements (see Figure 31). The size and shape of the indentations will depend on the nature of the particles. Figure 32 depicts the following types of indentation:

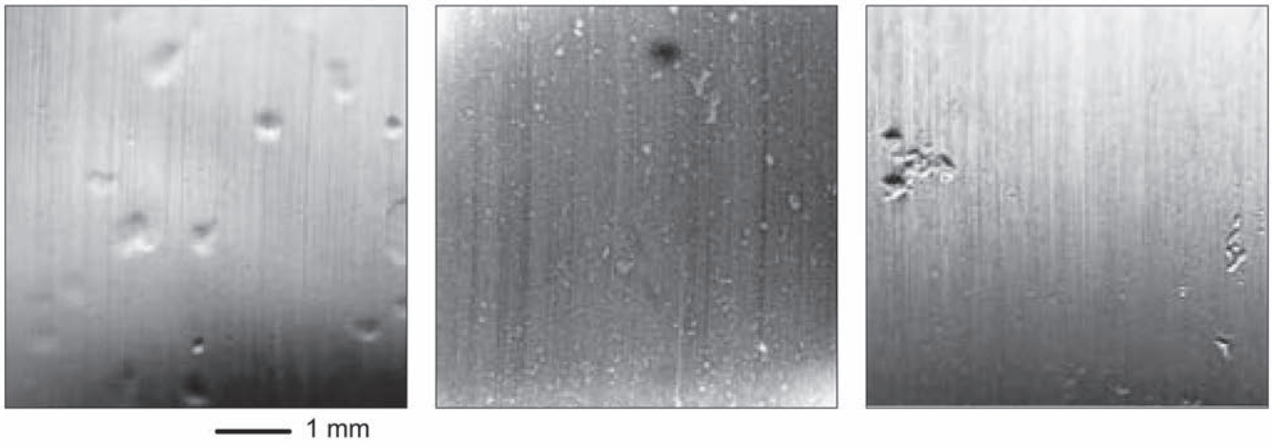
a) from soft particles, e.g. fibres, elastomers, plastics and wood [see Figure 32 a)];

b) from hardened steel particles, e.g. from gears and bearings [see Figure 32 b)];

c) from hard mineral particles, e.g. from sand particles (silica) in the oil [see Figure 32 c)].

Figure 30 — Indentations from particles on the inner ring raceway of a tapered roller bearing

Figure 31 — Indentations from particles on tapered rollers



a b c

Figure 32 — Enlargements of indentations on raceways resulting from over-rolled particles

5.6 Cracking and fracture

5.6.1 General description of cracking and fracture

Cracks are initiated and propagate when the ultimate tensile strength of the material is locally exceeded.

Fracture is the result of a crack propagating completely through a section of the component or propagating such that a portion of the component is completely separated from the original component.

5.6.2 Forced fracture

Forced fracture is due to a stress concentration in excess of the material (tensile) strength and is caused by local over-stressing, e.g. from impact (see Figure 33), or by over-stressing due to an excessive interference fit, e.g. too high hoop stress (see Figure 34).

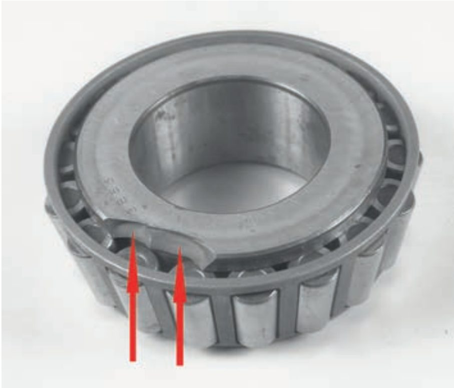
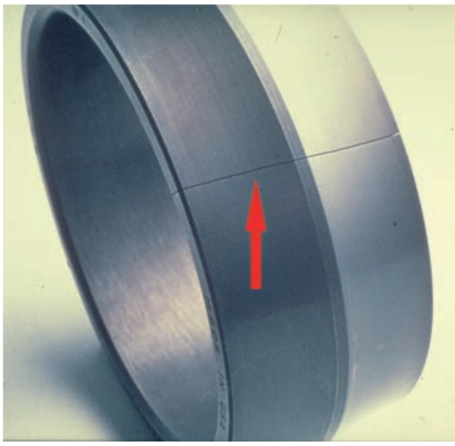


Figure 33 — Forced fracture of a tapered roller bearing inner ring shoulder, caused by an impact load during assembly procedures

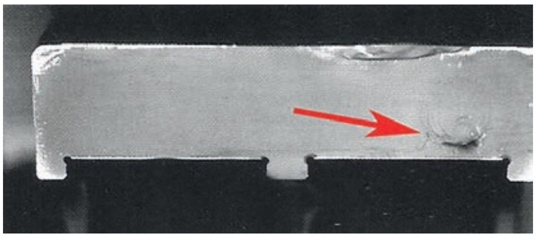


NOTE Fracture caused by an excessive interference fit during mounting, for example, by driving a tapered bore inner ring too far up the shaft taper.

Figure 34 — Forced fracture of a spherical roller bearing inner ring

5.6.3 Fatigue fracture

Frequent exceeding of the fatigue strength limit under bending, tension or torsion conditions results in fatigue cracking. A crack is initiated at a stress raiser and propagates in steps over a part of the component cross-section, ultimately resulting in a forced fracture. Fatigue fracture occurs mainly on rings (see Figure 35) and cages (see Figure 36).



NOTE The origination of fracture is near the right raceway, centred in the characteristic sea shell signature left by a progressing fatigue crack (the damage above the outside surface is secondary and occurred when the ring fractured).

Figure 35 — Section of fatigue fracture of a cam roller outer ring caused by bending

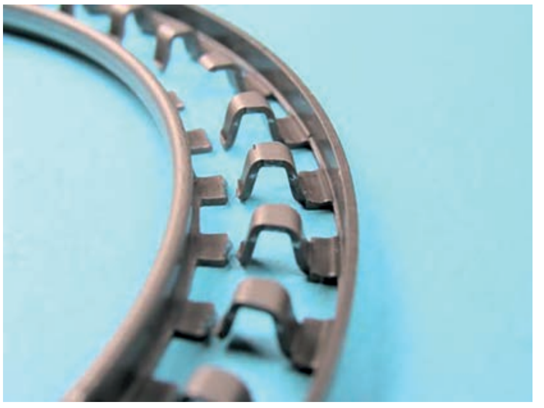


Figure 36 — Fatigue fracture of cage bars of a needle roller thrust bearing

5.6.4 Thermal cracking

Thermal cracking (heat cracking) is caused by high frictional heating due to sliding motion. Cracks usually appear at right angles to the direction of sliding (see Figure 37). Hardened steel components are generally sensitive to thermal cracking due to local rehardening of the surfaces in combination with the development of high residual tensile stress.

Figure 37 — Thermal cracks on the small end of the inner ring of a tapered roller bearing

Annex A
(informative)

Failure analysis — Illustrations of damage — Other investigations — Explanation of terms used

A.1 Failure analysis

A.1.1 General

— The purpose of this document is to promote and assist in a logical objective investigation of bearing failure to identify possible causes.

— Careful identification of the most probable causes and modes of a failure can be an important input to development of a long term preventive solution.

— Targeted countermeasures can be devised to guard against the identified causes.

— An open objective approach by all participants is essential to successful application of this document.

A.1.2 Securing evidence before and after removal

A.1.2.1 Important points

— When a bearing fails, it is vital to collect as much evidence as possible before attempting a diagnosis of the causes.

— An impartial enquiring approach is required.

A.1.2.2 Conserving evidence

— Equipment operator/owner to disturb as little evidence as possible prior to investigation.

— The different interested parties need to devise a logical investigation procedure.

— Avoid destroying or compromising some evidence before it can be assessed and recorded.

— Gather as much recent operational data as possible from operator and other involved organizations and persons.

— Instant diagnoses and conclusions should be treated as preliminary.

— Note these initial possible diagnoses, but put them to one side until evidence has been gathered and assessed.

— When a plan has been devised and agreed, dismantling of the equipment to reach the bearing can commence.

The matrix in Table A.1 provides a guide to making a plan.

A.1.2.3 Gathering evidence

— At each stage, be sure to make the following:

  — photographs and/or sketches;

  - notes of the condition and positions of components.
- Related parts should be kept together:
  - label, mark and put in clean plastic containers where possible.
- Be sure to obtain all evidence that needs a complete assembly or component before:
  - dismantling which is difficult or impossible to reverse;
  - cleaning including disturbing lubricant or contaminant;
  - especially cutting that destroys a circular surface.
- The bearing will contain the evidences of its own failure:
  - when removed, it would be incapable of further acceptable running;
  - it may have "failed" more than once already;
  - it may, or may not, contain the original cause;
  - other components may have important evidence:
    - investigate them in parallel as far as possible;
  - record any available design, system, service and operational history;
  - bearing designation and manufacturer to be recorded:
    - if still visible or deducible from physical features;
    - check manufacturer's specification if possible;
  - the bearing may be unsuitable:
    - inappropriate service replacement for an originally installed bearing;
    - not a valid equivalent;
    - does not meet the equipment manufacturer's specification.

NOTE Lubricants and contaminants are to be considered as parts just as much as the solid metallic and any polymeric or rubber components.

A.1.2.4 Interpreting the evidence

It is important to bear in mind that, depending on the time between damage initiation and its detection, the damage can be more or less advanced when the mechanical system is dismounted and inspected.

If the detection of the damage occurred comparatively late after its initiation, the clues on the initial cause may have been suppressed, hidden or worn off, so that it can be difficult to determine the real cause for damage or failure.

It is very important that to observe and analyse all indications on the bearing(s) and surrounding parts, to establish the probable sequence of damage.

For example, propagated spalling can be originated from a surface spall initiated on a dent that resulted from lubricant contamination, but also by surface defects such as nicks produced by plastic deformation during mounting, corrosion, craters formed by excessive electric current, etc.

If in this case spalling is observed in conjunction with another initial damage indication on other areas of a bearing component, all these indications worked out together can lead to a plausible scenario of damage and original cause.

— Complete the agreed structured examination plan.

— Now, apply value judgement to all evidence.

— Do not approach conclusions yet.

— Strong evidence will be readily categorized.

— Any evidence that cannot be confidently matched against the examples in this document should be treated with caution and labelled “probable”.

— The assessed evidence may then be studied to try to establish a most likely sequence of events.

— Trial theories about the cause can be developed and tested against the evidence:

  — make trial estimates of sequences causes and effects;

  — repeat the iteration until a convincing match is achieved:

    — no verified evidence elements can be left in conflict;

    — list doubtful evidence and rank it for possible irrelevance.

— It is vital not to reverse the process and attempt to force the evidence to fit a theory.

— If the causes of failure cannot be reliably determined:

  — seek further specialist help as described in A.3.

Table A.1 is provided to help the logical collection of initial information.

Once the starting point for a comprehensive analysis of visible features has been established, the detailed matrices and illustrations which follow are to be used in assessing and categorizing the bearing condition and hence, to deduce the most probable cause or causes of failure.

Table A.2 is provided to give a general view of possible modes and causes, based on the assessment.

If, at the conclusion of this visual assessment, the cause of failure cannot be reliably determined, then further specialist tests, possibly requiring cutting of parts, may be necessary. See A.3 for further advice.

Table A.1 — Systematic procedure when securing evidence before, during and after removal

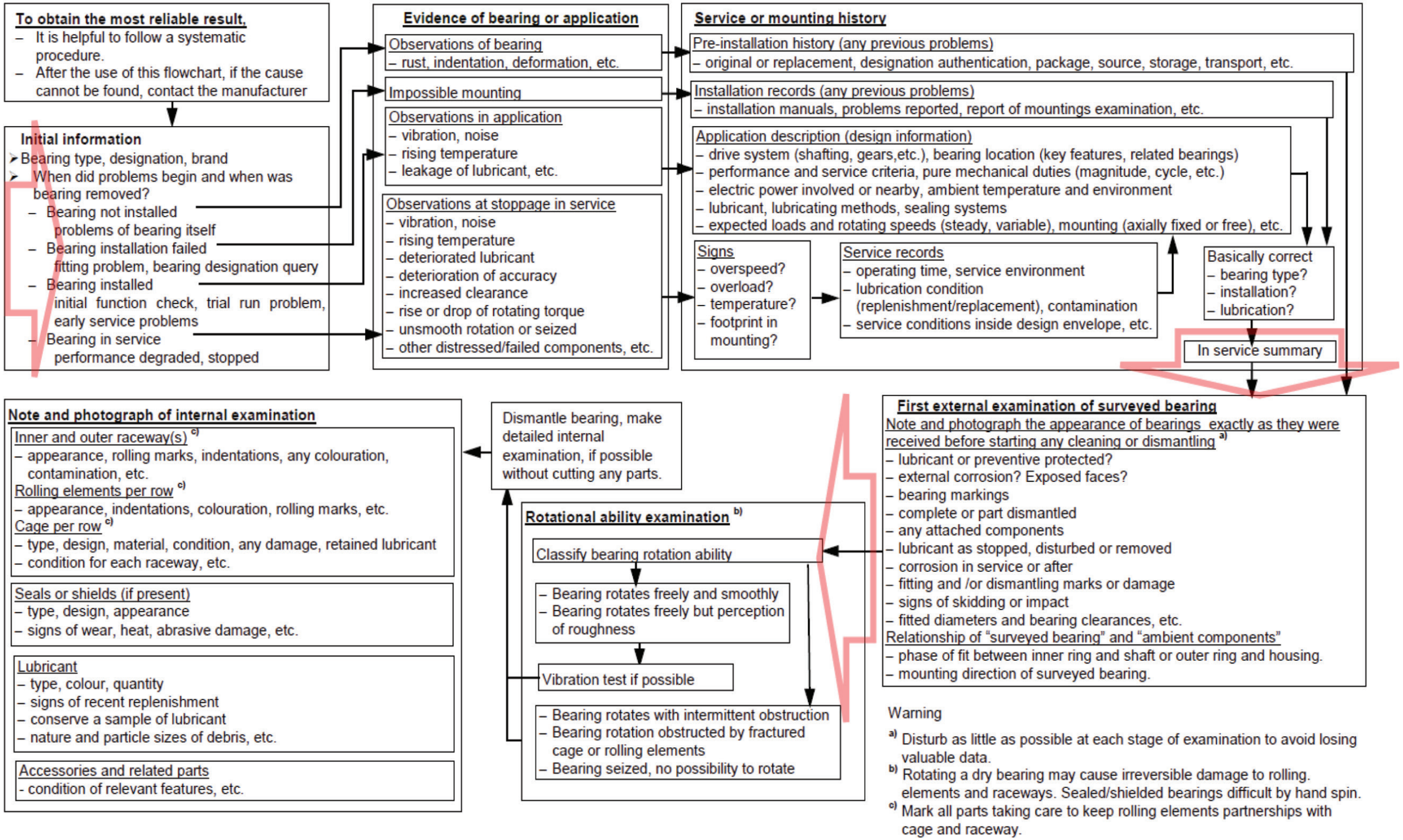


Table A.2 — Bearing failure modes and causes

Which part is damaged ?	Which surfaces of parts show change?	Which one of these below changes?	Possible cause																																Related ISO failure modes
			Lubricant, lubrication							Operating conditions and maintenance											Handling and mounting						Design and adjacent parts					Bearing making			
			not enough lubricant	too much lubricant	inappropriate viscosity	wrong lubricant	oxidized lubricant	solid contamination	liquid contamination	too high static or dynamic load	insufficient load	too high speed	too low speed	rapid acceleration/deceleration	variable load/rotation	vibration excitations	current passage	external heat/insufficient cooling	poor maintenance	oil filter clogged	inappropriate storing condition	transportation vibrations	wrong clearance/preload setting	inappropriate radial/axial preload	misalignment	improper mounting method	shaft and housing size or shape	rigidity non-uniform ring support	inappropriate fits and tolerances	inappropriate or failed sealing	insufficient heat removal	material, heat treatment	machining and assembly	handling, package, transport	
rings		spalls, subsurface fatigue	•			•	•			•									•				•	•	•							•	•		5.1.2
		microspalls, surface initiated fatigue	•		•	•	•		•	•									•	•					•							•	•		5.1.3
		surface removal by wear, abrasive wear	•			•	•		•										•	•															5.2.2
		score marks																								•									5.5.2
		smearing, seizing mark	•		•	•	•				•	•		•	•			•													•				5.2.3
		nicks																	•	•															5.5.2
		rust, corrosion							•										•		•									•					5.3.2
		false brinelling			•											•						•													5.3.3.3
		craters, fluting															•																		5.4.2/5.4.3
		plastic deformation								•																•									5.5.2
		indentation by particles																	•	•										•					5.5.3
		true brinelling								•															•	•						•			5.5.2
		hit marks, scratches																								•						•		•	5.5.2
		forced fracture																								•		•							5.6.2
		fatigue fracture								•																	•		•						5.6.3
		forced running bands	•		•	•	•		•	•										•					•							•			5.2.2
		shiny polished appearance	•		•	•	•		•																										5.2.2
		discolouration (overheating)	•	•		•	•			•									•				•	•	•										5.2.3
	on ribs	smearing, seizing mark	•		•	•	•		•			•						•	•				•	•	•										5.2.3
		rust, corrosion							•										•		•									•				•	5.3.2
		forced fracture																								•		•							5.6.2
	on mating surfaces and faces	fretting corrosion, reddish surface								•					•	•									•		•		•						5.3.3.2
		creep, polished surface													•														•						5.2.2
		rust, corrosion							•										•		•									•				•	5.3.2
		heat cracking													•																•				5.6.4
rolling elements	on rolling contact surfaces	spalls, subsurface initiated fatigue	•			•	•			•									•				•	•	•							•			5.1.2
		microspalls, surface initiated fatigue	•			•	•		•	•									•	•												•			5.1.3
		surface removal by wear, abrasive wear	•			•	•		•										•	•												•			5.2.2
		smearing, seizing mark	•		•	•	•				•	•		•	•			•													•				5.2.3
		craters, fluting															•																		5.4.2/5.4.3
		rust, corrosion							•										•		•									•					5.3.2
	on end faces	smearing, seizing mark, scuffing	•		•	•	•		•			•						•					•	•	•										5.2.3
		abrasive wear	•		•	•	•												•	•			•	•								•			5.2.2
cages	on rings	fatigue fracture																																	5.6.3
		wear on guiding surface	•		•	•	•		•			•										•								•		•			5.2.2
	in pockets or on bars	abrasive wear	•		•	•	•		•										•	•															5.2.2
		fatigue fracture												•	•								•		•							•	•		5.6.3
	rivets	fatigue fracture												•	•								•		•							•	•		5.6.3
seals or shields	bodies	deformation																								•								•	5.5.2
	lips	abrasive wear								•										•															5.2.2

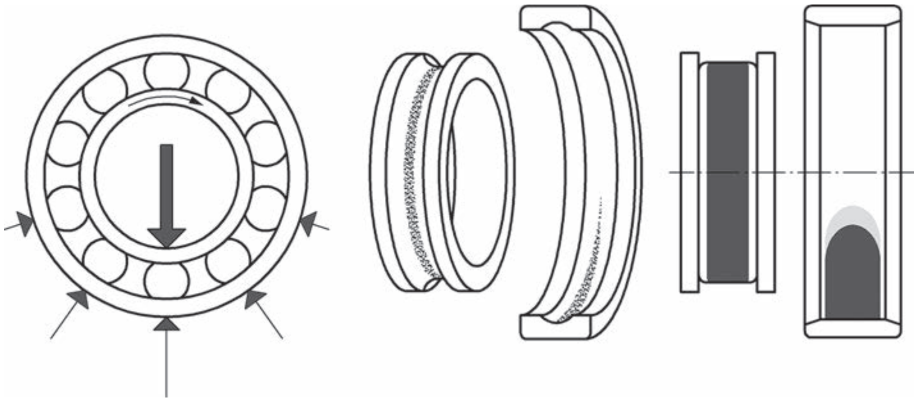
A.1.3 Contact traces

A.1.3.1 General

The interpretation of contact traces and, in particular, the running path patterns on the raceways for given applications is very important for the practical analysis of a failure. The types of load, operating clearance and possible misalignment may be clearly revealed. In Figures A.1 to A.11, typical running path patterns for the most common applications and bearing types are shown.

In the illustrations, point contact refers to ball bearings and line contact to roller bearings.

A.1.3.2 Radial bearings

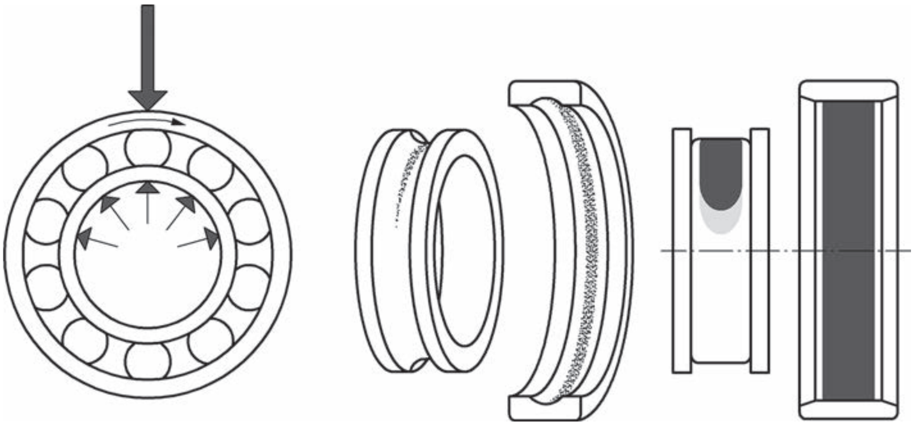


Inner ring: Running path pattern uniform in width, positioned in the middle of the raceway and extending around its entire circumference.

Outer ring: Running path pattern widest at the point of the applied load and tapers circumferentially depending on the load zone, positioned in the middle of the raceway. With normal fits and normal internal clearance, the running path pattern extends to less than half of the circumference of the raceway.

NOTE Normal running path.

Figure A.1 — Uni-directional radial load — Rotating inner ring — Stationary outer ring

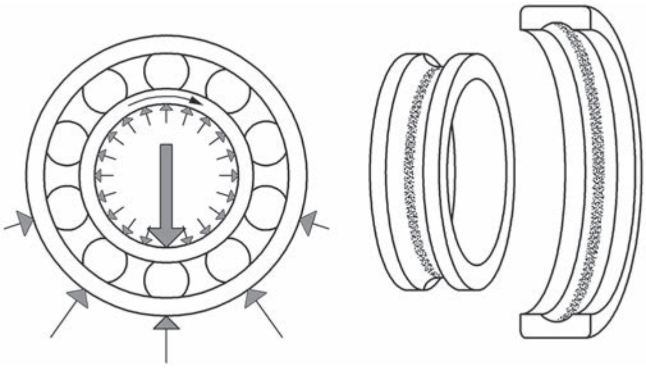


Inner ring: Running path pattern widest at the point of the applied load and tapers circumferentially depending on the load zone, positioned in the middle of the raceway. With normal fits and normal internal clearance, the running path pattern extends to less than half of the circumference of the raceway.

Outer ring: Running path pattern uniform in width, positioned in the middle of the raceway and extending around its entire circumference.

NOTE Normal running path.

Figure A.2 — Uni-directional radial load — Stationary inner ring — Rotating outer ring

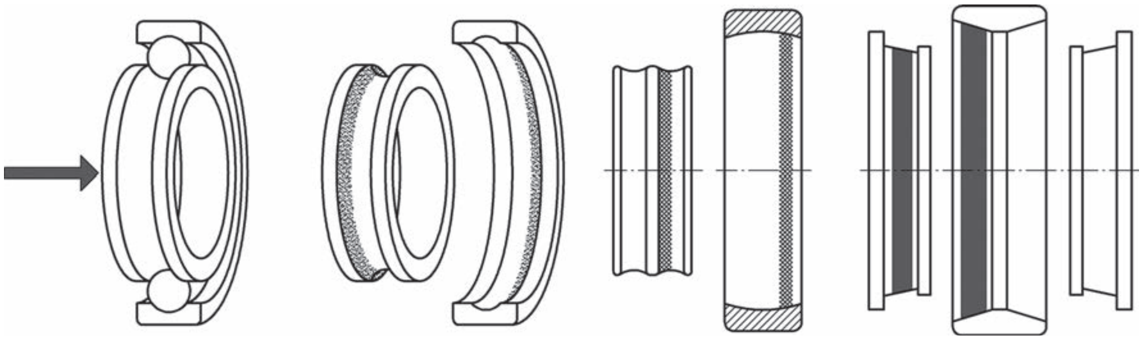


Inner ring: Running path pattern uniform in width, positioned in the middle of the raceway and extending around its entire circumference.

Outer ring: Running path pattern positioned in the middle of the raceway and may, or may not, extend around its entire circumference. The running path pattern is widest at the point of the applied load.

NOTE Normal running path.

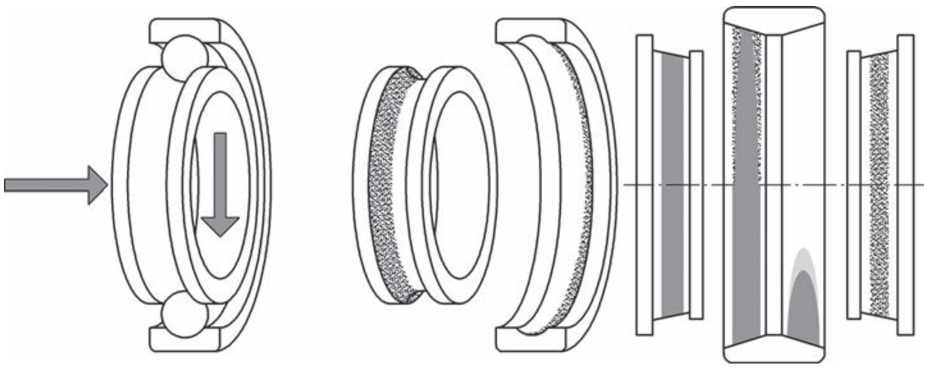
Figure A.3 — Radial preloading with uni-directional radial load — Rotating inner ring — Stationary outer ring



Inner and outer rings: Running path pattern uniform in width, axially displaced and may, or may not, extend around the entire circumference of the raceways of both rings.

NOTE Normal running path.

Figure A.4 — Uni-directional axial load — Rotating inner ring and/or outer ring

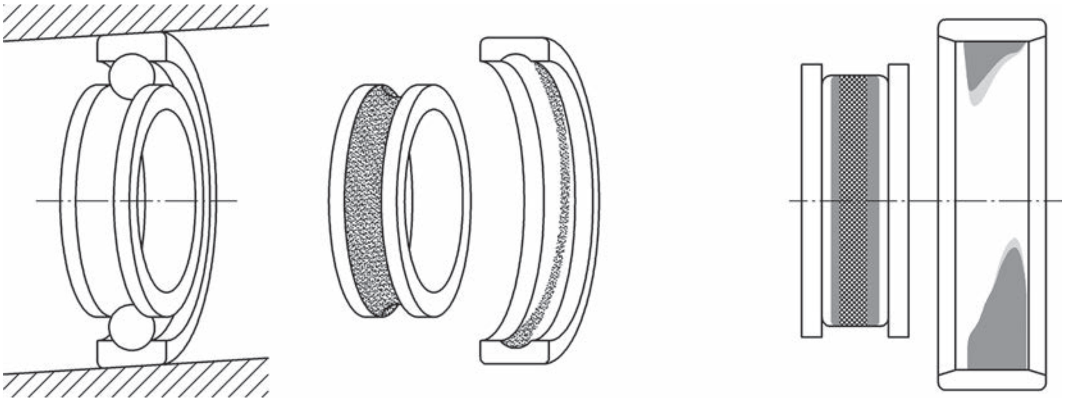


Inner ring: Running path pattern uniform in width, extending around the entire circumference of the raceway and axially displaced.

Outer ring: Running path pattern axially displaced and may, or may not, extend around the entire circumference. The running path pattern is widest at the point of the applied radial load.

NOTE Normal running path.

Figure A.5 — Combination of uni-directional radial and axial load — Rotating inner ring — Stationary outer ring

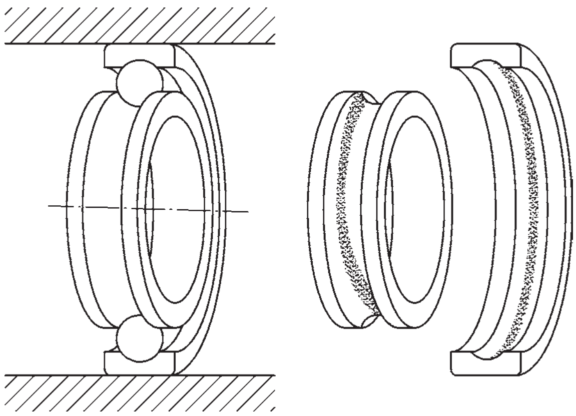


Inner ring: Running path pattern uniform in width, wider than in Figure A.1, positioned in the middle of the raceway and extending around its entire circumference.

Outer ring: Running path pattern varying in width and in two diametrically opposed sections, displaced diagonally in relation to each other.

NOTE Faulty running path.

Figure A.6 — Outer ring misaligned in the housing — Rotating inner ring — Stationary outer ring

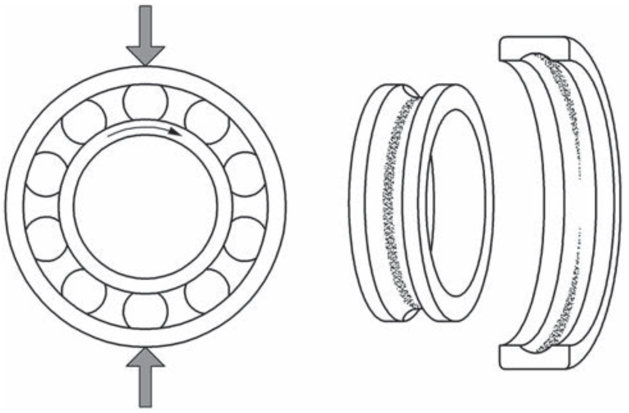


Inner ring: Running path pattern varying in width and in two diametrically opposed sections, displaced diagonally in relation to each other.

Outer ring: Running path pattern uniform in width, wider than in Figure A.2, positioned in the middle of the raceway and extending around its entire circumference.

NOTE Faulty running path.

Figure A.7 — Inner ring misaligned on the shaft — Stationary inner ring — Rotating outer ring



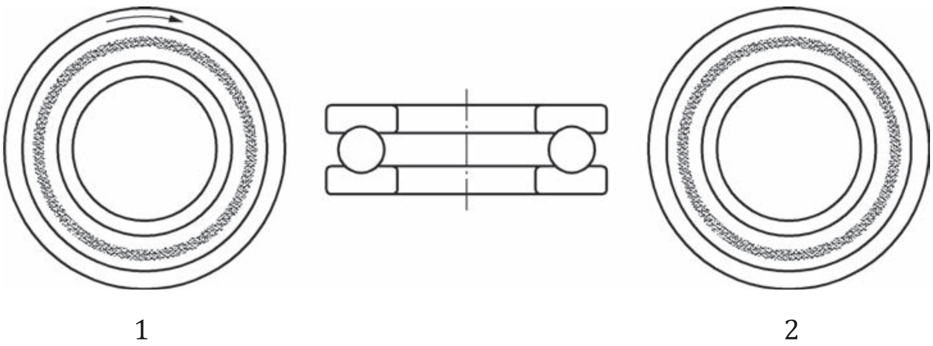
Inner ring: Running path pattern uniform in width, wider than in Figure A.1, positioned in the middle of the raceway and extending around its entire circumference.

Outer ring: Running path pattern widest where the compression has occurred and positioned in two diametrically opposed sections of the raceway. The length of the pattern depends upon the magnitude of the compression and the initial radial internal clearance in the bearing.

NOTE Faulty running path.

Figure A.8 — Oval compression of outer ring — Rotating inner ring — Stationary outer ring

A.1.3.3 Thrust bearings



Key

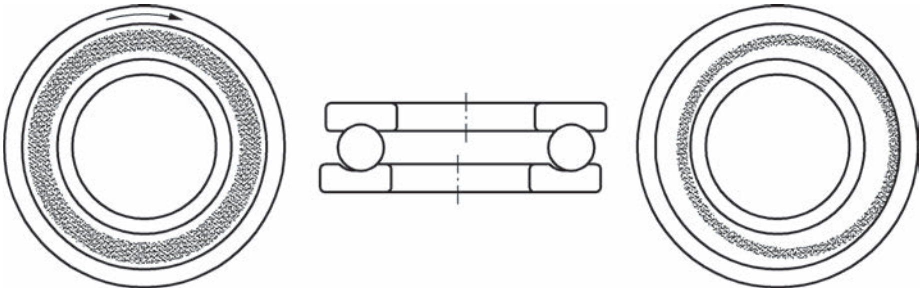
1 shaft washer

2 housing washer

Shaft and housing washers: Running path patterns uniform in width, positioned in the middle of the raceways and extending around the entire circumference of the raceways

NOTE Normal running path.

Figure A.9 — Uni-directional axial load — Rotating shaft washer — Stationary housing washer



Key

1 shaft washer

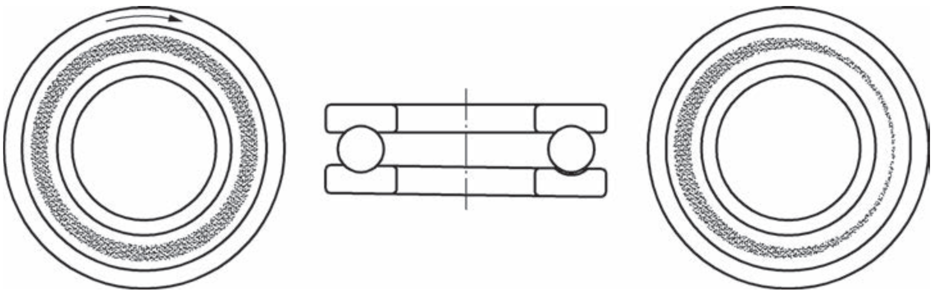
2 housing washer

Shaft washer: Running path pattern uniform in width, wider than in Figure A.9, positioned in the middle of the raceway and extending around its entire circumference.

Housing washer: Running path pattern varying in width, extending around the entire circumference of the raceway and eccentric to the raceway.

NOTE Faulty running path.

Figure A.10 — Uni-directional axial load on eccentrically positioned housing washer relative to shaft washer — Rotating shaft washer — Stationary housing washer



Key

1 shaft washer

2 housing washer

Shaft washer: Running path pattern uniform in width, positioned in the middle of the raceway and extending around its entire circumference.

Housing washer: Running path pattern in the middle of the raceway, but varying in width and may, or may not, extend around the entire circumference of the raceway.

NOTE Faulty running path.

Figure A.11 — Misaligned housing washer — Rotating shaft washer — Stationary housing washer

A.2 Illustrated failures compendium — Cause of failure and countermeasures

A.2.1 General

Each bearing failure is the result of a primary cause that in practice is often hidden by subsequent damage.

The order of the following illustrations follows the classification of failure modes shown in Figure 2. The classification of the failures is based on the observed appearance.

Each illustration is provided with an explanation of the failure in a paragraph that is given the heading “Cause of failure”. The explanation can include a description of the failure, probable (primary) cause of the failure and comments.

For each illustration, there are also proposed countermeasures or corrective actions to avoid reoccurrence of failures, given in the paragraph headed “Countermeasure”.

A.2.2 Rolling contact fatigue

A.2.2.1 Subsurface initiated fatigue

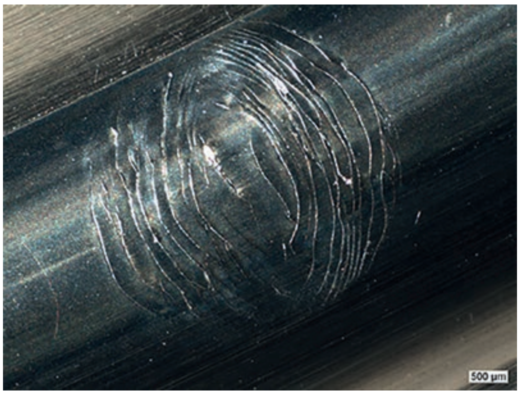
A.2.2.1.1 Cracks resulting from subsurface initiated fatigue in the early stage, before spalling, on the outer ring raceway of an angular contact ball bearing

Cause of failure

— Fatigue cracks due to heavy load in combination with accumulation of load cycles.

Countermeasure

— Use a bearing with higher load-carrying capacity.



A.2.2.1.2 Spalling in an early stage on the outer ring raceway of an angular contact ball bearing

Cause of failure

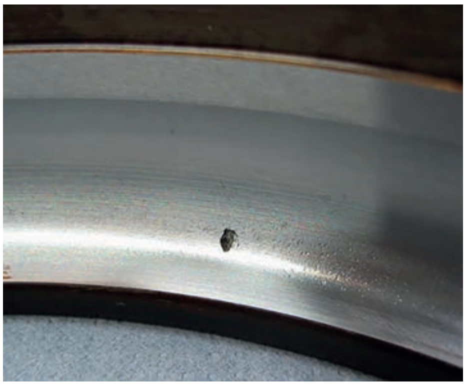
— Fatigue cracks and initial spalling due to:

— heavy load in combination with accumulation of load cycles;

— further operation after fatigue cracks started.

Countermeasure

— Use a bearing with higher load-carrying capacity.



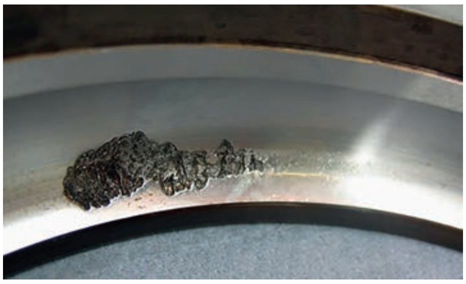
A.2.2.1.3 Spalling in a more advanced stage on an outer ring raceway of an angular contact ball bearing

Cause of failure

— Fatigue cracks and propagated spalling due to:

— heavy load in combination with accumulation of load cycles;

— further operation after fatigue cracks at the raceway surface.



Countermeasure

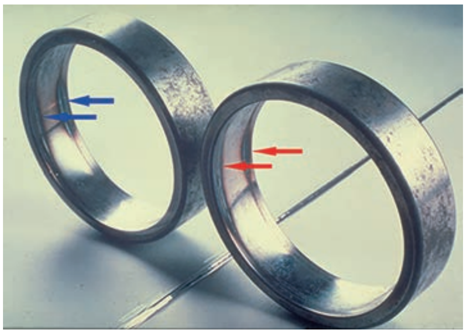
— Use a bearing with higher load-carrying capacity.

A.2.2.1.4 Spalling resulting from subsurface initiated fatigue at two diametrically opposite locations — On the outer ring raceways of a self-aligning ball bearing

Cause of failure

— Ovality of the housing, resulting in localized higher stresses.

— Similar damage can occur if split housings are wrongly assembled or if particles are embedded in the housing seating.



Countermeasure

— Check form accuracy of adjacent parts and improve them, if necessary.

— Assemble split housings properly.

— Ensure utmost cleanliness during mounting.

NOTE Outer ring placed against a mirror to see diametrically opposed area.

A.2.2.2 Surface initiated fatigue

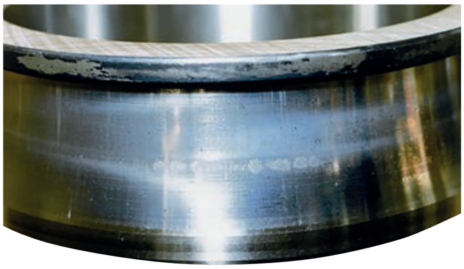
A.2.2.2.1 Microspalling on the inner ring raceway of a spherical roller bearing

Cause of failure

— Increased surface roughness of the rolling contacts due to:

— inadequate lubrication;

— particles entering the bearing.



Countermeasure

— Protect the surface finish by:

— correct lubrication;

— improved sealing;

— ensure system cleanliness.

A.2.2.2.2 Surface initiated fatigue on the inner ring raceway of a tapered roller bearing

Cause of failure

— Grey stains and microspalls at the raceway due to:

- — insufficient lubrication;
- — sliding motion;
- — insufficient preload;
- — misalignment.

Countermeasure

— Improve lubrication.

— Apply correct preload.

— Ensure alignment.

A.2.2.2.3 Surface initiated fatigue on roller raceways of a needle roller bearing

Cause of failure

— Grey stains and microspalls on rollers due to:

- — insufficient lubrication;
- — sliding motion;
- — misalignment of the shaft.

Countermeasure

— Improve lubrication.

— Realign the shaft and/or housings.

A.2.2.2.4 Surface initiated fatigue on the inner ring raceways of a double row angular contact ball bearing — Oblique running path pattern

Cause of failure

— Misalignment during operation due to:

- — shaft deflection;
- — abutment faces on mating part(s) out-of-square.

Countermeasure

— Eliminate misalignment.

— Select a bearing type suitable to accommodate the misalignment.

— Reduce shaft deflection.

— Check the squareness of the abutment faces on mating part(s).

A.2.2.2.5 Spalling on the inner ring raceway of an angular contact ball bearing

Cause of failure

— Entry of foreign particles.

— Water ingress.

— Inadequate lubrication.

Countermeasure

— Improve the sealing.

— Review the lubrication for the operating conditions.

A.2.2.2.6 Spalling (peeling) on the inner ring raceways of a tapered roller bearing

Cause of failure

— Thin lubricant film resulting from:

  — heavy loads;

  — low speed;

  — elevated temperatures.

Countermeasure

— Select proper lubricant to increase lubricant film thickness under operating conditions.

— Improve maintenance on lubrication system.

A.2.3 Wear

A.2.3.1 Abrasive wear

A.2.3.1.1 Abrasive wear on the inner ring raceways of a spherical roller bearing non-rotating inner ring

Cause of failure

— Ingress of contamination, causing very heavy abrasive wear on raceways.

Countermeasure

— Improve the sealing arrangement.

— Improve the lubrication intervals and/or grease.

— Use a sealed bearing if operating conditions permit.

A.2.3.1.2 Abrasive wear on the end face of a cylindrical roller

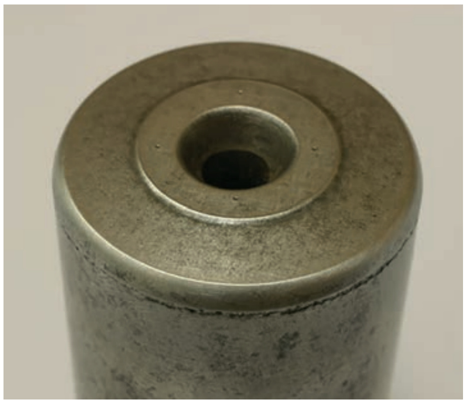
Cause of failure

— Contaminated or insufficient lubricant causing abrasive wear of the roller end face contact.

Countermeasure

— Ensure system cleanliness.

— Improve lubrication.



A.2.3.1.3 Abrasive wear on the inner ring raceway and roller of a tapered roller bearing

Cause of failure

— Particle contamination from external sources.

— Worn out or ineffective seals.

— Particles embedded into soft cage material.

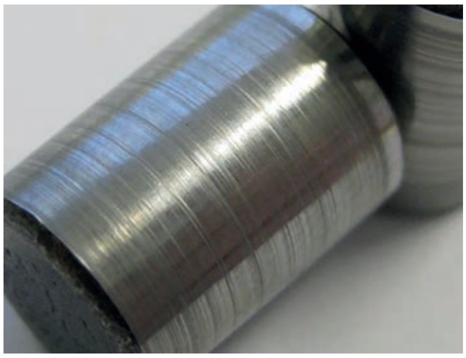
Countermeasure

— Eliminate or minimize source of contamination.

— Replace seals or upgrade sealing arrangement.

— Replace lubricant more often.

— Make sure the bearing is properly cleaned before assembly.



A.2.3.1.4 Abrasive wear on the cage pockets of a solid metal cage of an angular contact ball bearing

Cause of failure

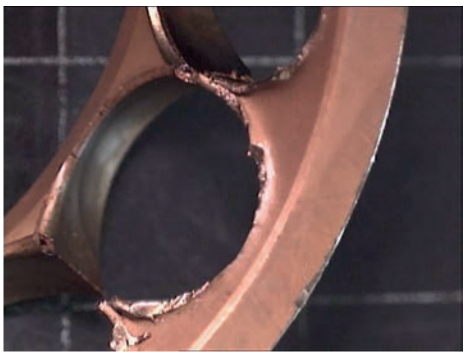
— Inadequate lubrication.

— Entrance of contaminants.

Countermeasure

— Improve lubrication.

— Review the sealing arrangement.



A.2.3.1.5 Abrasive wear, polishing of the inner and outer ring raceways of a spherical roller bearing

Cause of failure

— Ingress of very fine contaminants, resulting in shiny (heavily) worn raceways of rings and rolling elements.

— Inadequate sealing arrangement and/or lubrication.

Countermeasure

— Improve sealing arrangement.

— Improve lubrication: select proper lubricant and/or relubrication interval.

— Consider to use a sealed bearing.

A.2.3.2 Adhesive wear

A.2.3.2.1 Smearing on the inner ring raceway of a cylindrical roller bearing

Cause of failure

— Smearing (skidding) between rollers and inner ring raceway due to:

  — too light load;

  — high acceleration;

  — insufficient lubrication.

Countermeasure

— Reduce acceleration.

— Increase load.

— Use coating on surfaces.

— Improve lubrication.

A.2.3.2.2 Smearing on the large end face of a tapered roller

Cause of failure

— Inadequate lubrication resulting in metal-to-metal contact, plastic deformation, and heat damage.

Countermeasure

— Use and maintain proper lubricant to provide adequate quantity, quality, and film thickness.

— Ensure lubrication and delivery system can support the specific application’s speed and loads together with environmental requirements.

A.2.4 Corrosion

A.2.4.1 Moisture corrosion

A.2.4.1.1 Corrosion on sub-assemblies from improper storage

Cause of failure

— Rust on unused sub-assemblies, caused by:

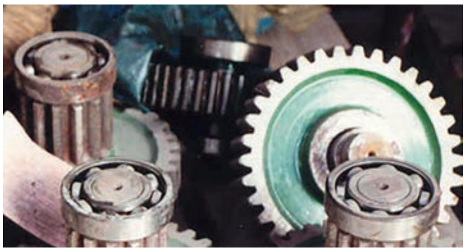
  — improper storage;

  — insufficient preservation.

Countermeasure

— Store sub-assemblies and bearings in dry places with constant temperature and low humidity.

— If possible, avoid mounting bearings on sub-assemblies, which are then left unprotected.



A.2.4.1.2 Corrosion, hand perspiration (fingerprint)

Cause of failure

— Faulty handling, bearing in the unpreserved condition touched with perspiring hands.

Countermeasure

— Avoid touching bearings with moist/perspiring hands.

— Use gloves or a barrier cream.

— Clean surfaces, apply thixotropic agent and repack properly.

A.2.4.1.3 Contact corrosion on the inner ring raceway of an angular contact ball bearing

Cause of failure

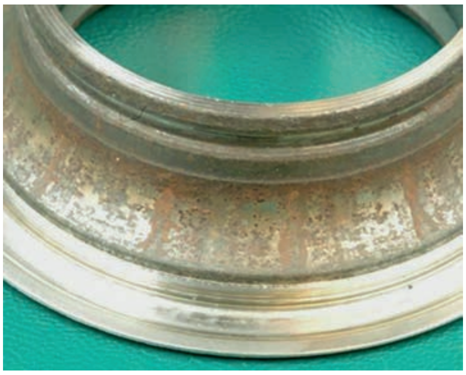
— Bearing operated with lubricant contaminated by water.

Countermeasure

— Change the bearing and contaminated lubricant.

— Check that sealing is not damaged during assembling operations.

— Replace seals, or optimize sealing arrangement, or optimize relubrication interval.



A.2.4.1.4 Contact corrosion on the inner ring raceway of a tapered roller bearing, spacing equivalent to roller pitch

Cause of failure

— Ingress of water or corrosive material (such as acid).

— Condensation of moisture contained in the air.

— Poor packaging and storing conditions.

Countermeasure

— Improve the sealing effect.

— Take measures to prevent rust when not operating for a long period of time.

A.2.4.2 Fretting corrosion

A.2.4.2.1 Fretting corrosion on the entire surface of the inner ring bore of a cylindrical roller bearing

Cause of failure

— Insufficient interference fit between the inner ring and the shaft.

Countermeasure

— Specify adequate fit with attention to the load.

— Consider the influence of surface roughness of the shaft seating.

A.2.4.2.2 Fretting corrosion on the inner ring bore of a ball bearing

Cause of failure

— Fretting corrosion due to:

  — insufficient interference fit;

  — repeated sliding between the inner ring and shaft.

Countermeasure

— Increase the shaft fit.

— Apply coating to the surfaces.

A.2.4.2.3 Fretting corrosion on the outside diameter of a spherical roller bearing

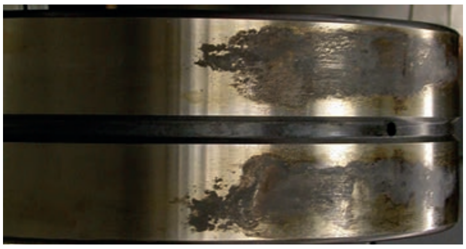
Cause of failure

— Heavily loaded, micromovements under load led to fretting corrosion.

Countermeasure

— Use special antifretting paste on the seats.

— Use a special coating.



A.2.4.2.4 Fretting corrosion on the outside diameter of a deep groove ball bearing

Cause of failure

— Heavy loads and deflections.

— Worn out housing bore.

Countermeasure

— Reduce loads or stiffen housing or system.

— Perform regular maintenance on housings.

— Repair or replace housing – follow bearing manufacturer's advice.

— Improve fitting practice.

A.2.4.2.5 Fretting corrosion on the face of a deep groove ball bearing

Cause of failure

— Micromovements between the inner ring and its counterpart (fixed on the shaft) during operation, due to vibrations.

Countermeasure

— Tighten axial clamping.

— Use anti-fretting paste.

A.2.4.3 False brinelling

A.2.4.3.1 False brinelling on the inner ring raceway of an angular contact ball bearing

Cause of failure

— Vibrations during bearing transportation causing relative movement of inner ring and outer ring.

Countermeasure

— During transportation, prevent any relative movement between inner and outer ring.

— Preload bearings (if possible).

A.2.4.3.2 False brinelling on the inner ring raceway of a deep groove ball bearing

Cause of failure

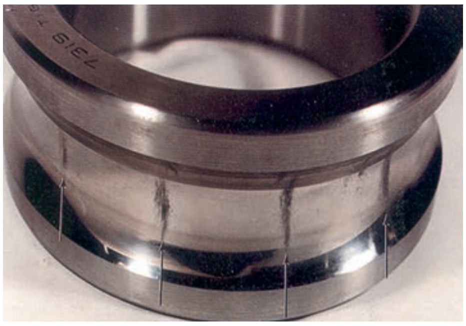
— Vibrations during standstill.

Countermeasure

— Reduce vibration.

— Apply preload.

— Apply coating.



A.2.4.3.3 False brinelling on the inner ring raceway of a needle roller bearing — Standby equipment

Cause of failure

— False brinelling at the raceway at rolling element pitch due to vibrations during standstill.

Countermeasure

— Rotate sometimes.

— Reduce vibration.

— Apply preload.

— Use a coating.

A.2.4.3.4 False brinelling on the outer ring raceway of a cylindrical roller bearing

Cause of failure

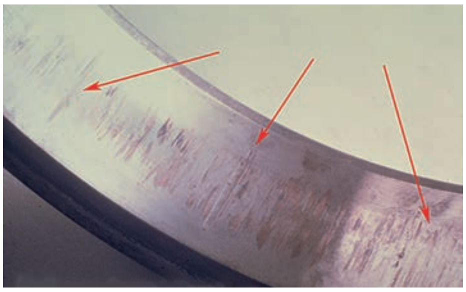
— Frequent vibrations on stand-by equipment, marks at roller pitch, several sets because of stop/go.

Countermeasure

— Counter vibrations by taking adequate design.

— Adapt lubrication.

— Consider another bearing type.



A.2.5 Electrical erosion

A.2.5.1 Excessive current erosion

A.2.5.1.1 Craters in the outer ring raceway of a deep groove ball bearing

Cause of failure

— Passage of an electric current causing craters on raceways and balls.

Countermeasure

— Verify and apply correct electrical insulation of the machine or the bearing.

— Provide proper earthing of the machine for example during electric welding operations.

A.2.5.1.2 Electrical erosion, cratering on a tapered roller

Cause of failure

— Improper electric earthing while the bearing is stationary.

Countermeasure

— Provide proper earthing during welding or electric source.

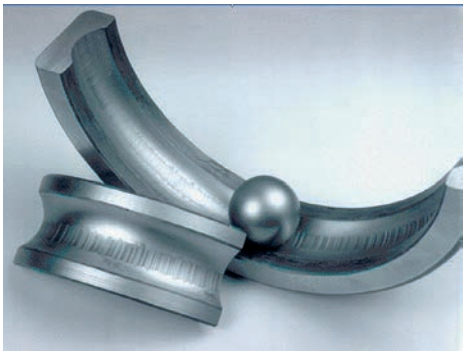
— Insulate the bearing from the welding or electric source.

A.2.5.2 Current leakage erosion

A.2.5.2.1 Fluting (washboarding) on the inner and outer ring raceways of a deep groove ball bearing

Cause of failure

— Fluting on raceway running path caused by passage of electric current of comparatively low intensity through rotating bearing, dark discolouration of the bottoms of the fluting depressions, balls are coloured dull grey.



Countermeasure

— Check insulation.

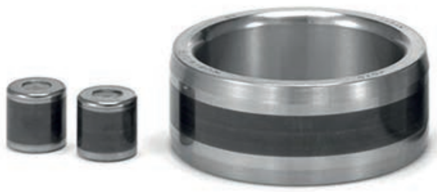
— Provide proper earthing.

— Use electrically insulated bearings or hybrid bearings.

A.2.5.2.2 Fluting due to current leakage erosion on the inner ring raceway and rollers of a cylindrical roller bearing

Cause of failure

— Arcing and burning occur through the thin oil film at points of contact between an inner ring raceway and rollers due to electrical potential difference between inner and outer rings.



Countermeasure

— Check insulation.

— Provide proper earthing.

— Use electrically insulated bearings.

A.2.5.2.3 Advanced stage of fluting due to current leakage erosion on the inner ring raceway of a cylindrical roller bearing

Cause of failure

— Progression from current leakage erosion.

Countermeasure

— Check insulation.

— Provide proper earthing.

— Use electrically insulated bearings.

A.2.5.2.4 Fluting on a spherical roller raceway, resulting from electric erosion

Cause of failure

— Flow of electric current through bearing while bearing is rotating.

Countermeasure

— Provide proper earthing.

— Insulate the bearing from the electric source.

A.2.6 Plastic deformation

A.2.6.1 Deformation by overloading

A.2.6.1.1 Overload deformation in the outer ring raceway of a deep groove ball bearing

Cause of failure

— (Axial) Overload on the outer ring of a deep groove ball bearing, due to faulty mounting procedure.

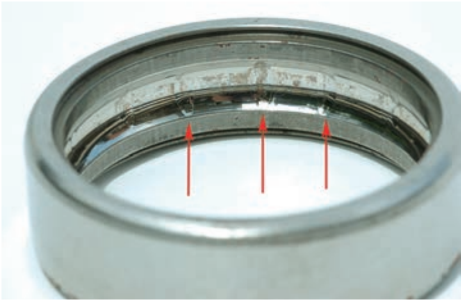
— Plastic deformation at ball distance.

Countermeasure

— Use correct mounting tools and procedures.

— Check that assembled parts are not axially preloaded.

— Confirm design does not cause axial preload.



A.2.6.1.2 Overload deformation on the inner ring raceways of a spherical roller bearing

Cause of failure

— Heavy impact load under static or rotational conditions and/or improper mounting practice.

Countermeasure

— Improve bearing installation so that rollers are not pressed into the raceways.

— Select bearing that can handle known shock loads.

— Eliminate or minimize source of shock loading.

A.2.6.1.3 Overload deformation on the inner ring raceway of a cylindrical roller bearing - deformations corresponding to rolling element pitch

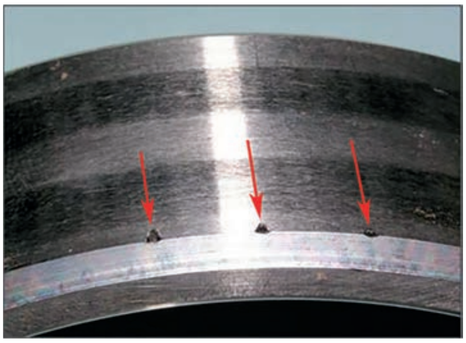
Cause of failure

— Plastic deformations at the edge of the inner ring raceway by the rollers due to misalignment during mounting operation.

Countermeasure

— Follow installation instructions to avoid misalignment.

— Use a guiding ring.



A.2.6.1.4 Spalling resulting from overload deformation on the inner ring raceway of a deep groove ball bearing, corresponding to ball pitch

Cause of failure

— Application overload.

— Shock load.

Countermeasure

— Select bearing that can handle application loads.

— Eliminate or minimize shock loading through the bearings.

A.2.6.2 Indentations from particles

A.2.6.2.1 Indentation from particles on raceways and rolling elements of a spherical roller bearing

Cause of failure

— Heavy contamination and overrolling of the particles in a large bearing, resulting in a large number of indentations.

Countermeasure

— Improve oil filtration.

— Improve sealing devices.

A.2.6.2.2 Spalling starting on an indentation on an inner ring raceway

Cause of failure

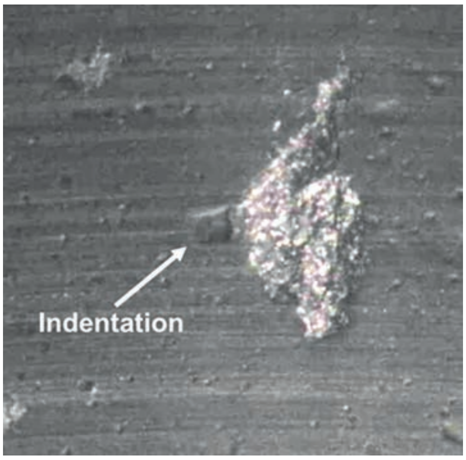
— Surface spalling initiated on dents, caused by overrolling of pollution hard particles that entered into the bearing cavity.

Countermeasure

— Work in a clean environment.

— Improve sealing system.

— Check pollution of lubricant and/or lubrication system.



A.2.6.2.3 Indentations and subsequent spalling in the inner ring of a deep groove ball bearing

Cause of failure

— Contamination and overrolling of the particles, resulting in indentations and finally spalling.

Countermeasure

— More frequent lubrication.

— Improve sealing arrangement.

— Use a sealed bearing if possible.

A.2.7 Fracture

A.2.7.1 Forced fracture

A.2.7.1.1 Forced fracture on the inner ring of a spherical roller bearing

Cause of failure

— Large fitting stress due to temperature difference between a shaft and an inner ring.

Countermeasure

— Correct the interference.

— Check the operating conditions.

A.2.7.1.2 Forced fracture of the inner ring of a deep groove ball bearing

Cause of failure

— Static overload during standstill.

Countermeasure

— Prevent overload.

— Use of bearing with higher static load capacity.

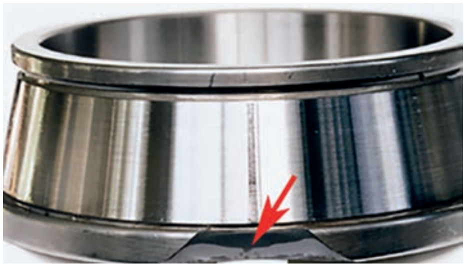
A.2.7.1.3 Forced fracture of the back face rib of the inner ring of a tapered roller bearing

Cause of failure

— Large impact during mounting.

Countermeasure

— Use appropriate mounting tools and procedures.



A.2.7.2 Fatigue fracture

A.2.7.2.1 Fatigue fracture of the cage of a deep groove ball bearing

Cause of failure

— Misalignment.

— Abnormal load action on cage in bearing operation due to misaligned mounting between an inner ring and an outer ring.

Countermeasure

— Correct alignment.

— Improve the mounting method.

— Select a suitable cage type/material.

A.2.7.2.2 Fatigue fracture of the inner ring of a tapered roller bearing

Cause of failure

— Initiation of crack on surface defect, because of shock during mounting, and fatigue propagation by bending stresses associated to axial load variation in service.

Countermeasure

— Careful mounting.

A.2.7.3 Thermal cracking

A.2.7.3.1 Thermal cracks on the outside rib of the outer ring of a cylindrical roller bearing

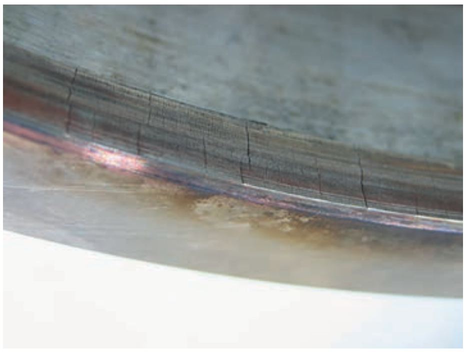
Cause of failure

— Lubrication problem – cage pockets of the cage were worn out, the outer ring guided cage rubbed heavily onto the outer ring raceway, the sliding resulted in excessive heat and thermal cracks appeared.

Countermeasure

— Make sure that the proper lubrication is used (type, viscosity, quantity).

— If possible, use a cage that is roller guided.



A.2.7.3.2 Thermal cracks on the inner ring bore of a tapered roller bearing

Cause of failure

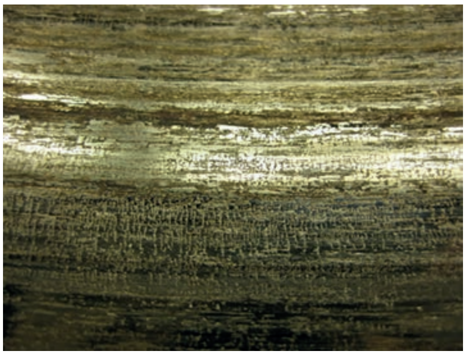
— Fit loss of the inner ring on the shaft and high heat generated from friction.

— On loose fitted inner ring poor lubrication between the bore and the shaft seat.

Countermeasure

— Follow bearing manufacturer's shaft fit recommendations.

— Ensure proper lubrication is maintained between loose-fitted bearings on shaft seats.



A.2.7.3.3 Thermal cracks on the large end face of a roller of a tapered roller bearing

Cause of failure

— Heat generation due to sliding with the inner ring rib under poor lubrication.

Countermeasure

— Improve lubrication.

— Shorter lubrication intervals.

A.3 Other investigations

If the initial investigation by visual inspection of the bearing parts and adjacent components according to the indications contained in this document does not enable relevant conclusions to be drawn as to the cause of damage or failure and possible countermeasure, it is then advised to turn to the bearing manufacturer or an independent laboratory skilled in the analysis of failed bearings to discuss the necessity and relevancy of running further analysis.

For example, the different components of a bearing can be further investigated using some of the following methods:

— dimensional measurements to account for the possible alteration of size, geometry or surface finish of the components in connection with the damage or failure;

— metallurgical investigation of the metallic components that can comprise closer inspection of the parts with adequate tools (optical microscope or non-destructive techniques) or destructive methods such as metallurgical analysis;

— physical and chemical investigation of the organic components and/or contaminants;

— care must be taken that all observations and dimensional measurements have been realized prior to the destructive step of the investigation;

— in some cases, the mode of failure will have changed the aspects and/or properties of some components such that their original conditions cannot be determined. In these circumstances deep analyses may not bring added value to the investigation.

A.4 Explanations for the terms used

A.4.1 The explanations given in A.4.2 to A.4.69 are provided to promote a better understanding of the terms used in this document.

A.4.2 Abrasive wear: progressive removal of material resulting from inadequate lubrication and the ingress of (foreign) particles. The surfaces become dull to a degree, which varies according to the coarseness and nature of the abrasive particles. See 5.2.2.

A.4.3 Adhesive wear: wear by transfer of material from one surface to another during relative motion due to a process of solid-phase welding. Particles that are removed from one surface are either permanently or temporarily attached to the other surface. See 5.2.3.

A.4.4 Burnishing: cumulative plastic deformation that leads to flattening of asperity tips, which appear progressively more polished than the topography left from the surface finish. See 5.1.3.

A.4.5 Contaminant: (unwanted) particle or water in oil or grease, or loose in the bearing cavity. See 5.1.3.

A.4.6 Corrosion: result of a chemical reaction on metal surfaces. See 5.3.

A.4.7 Crack: break within the bulk of the material without complete separation. See 5.6.

A.4.8 Cratering: formation of craters due to an electric current passing between the contacting surfaces. See 5.4.

A.4.9 Creep: unwanted motion of a bearing ring against its seating, which occurs when the bearing ring is mounted with an inadequate fit and the load rotates relative to the bearing ring. See 5.2.3.

NOTE The over-rolling during creep leads to a tiny difference in rotational speed of inner ring relative to shaft or, alternatively, outer ring relative to housing. The creeping is often, but not necessarily, accompanied by sliding in the ring/seating contact.

A.4.10 Current leakage erosion: damage to contact surfaces caused by the passage of electric current over the threshold limit. See 5.4.3.

A.4.11 Discolouration: change of appearance caused either by heat or by a chemical reaction. See 5.3.2, 5.3.3.2 and 5.3.3.3.

A.4.12 Electrical erosion: removal of material caused by the passage of a damaging electric current. See 5.4.

A.4.13 Excessive current erosion: damage caused by excessive current, which results in large craters in the raceways, possibly accompanied with discoloured lubricant through the local overheating. See 5.4.2

A.4.14 False brinelling: combination of corrosion and localized wear, arising when rolling elements of the bearing move back and forth against the raceway surface, in a stationary bearing subjected to vibrations, possibly rust coloured appearance at each location. See 5.3.3.3.

A.4.15 Fatigue: change in the structure caused by the repeated stresses developed in the contacts between the rolling elements and the raceways. See 5.1.

A.4.16 Fatigue fracture: fracture that results from frequently exceeding the fatigue strength limit, often under bending conditions or excessive interference fit. Cracks are initiated at stress raisers and propagate stepwise over a part of the ring cross-section, which finally results in complete fracture. Fatigue fracture occurs mainly on rings and cages. See 5.6.3.

A.4.17 Flaking: see spalling (preferred term) A.4.58.

A.4.18 Fluting: close (equally) spaced grooves. See washboarding A.4.68. See 5.3.3.3, 5.4.3 and 5.5.2.

A.4.19 Forced fracture: fracture caused by stress concentration in excess of material tensile strength by local overloading. See 5.6.2.

EXAMPLE 1 Impacts during mounting, or by overstressing.

EXAMPLE 2 Excessive interference fit or bending of the shaft. In the latter case, too high hoop stresses are generated.

A.4.20 Fracture: propagation of a crack to complete separation. See 5.6.

A.4.21 Fretting/fretting corrosion: chemical reaction activated by relative (sliding) micromovements between mating surfaces under certain friction conditions. This leads to oxidation of surfaces and asperities becoming visible as powdery rust and/or loss of material of one or both mating surfaces. The surfaces become shiny or discoloured (blackish red). See 5.3.3.2.

A.4.22 Fretting rust: rust caused by fretting corrosion. See 5.3.3.2.

A.4.23 Frictional corrosion: a chemical reaction activated by relative micromovements between mating surfaces under certain friction and load conditions. See 5.3.3.

A.4.24 Frosting: specific form of adhesive wear, where fine slivers of metal are pulled from the bearing raceway by the rolling elements.

NOTE The frosted area feels smooth in one direction, but has a distinct roughness in the other.

A.4.25 Galling: transfer of component surface material in macroscopic patches from a location on one contacting surface to a location on the other contacting surface, and possibly back onto the first surface, due to high tractive forces in multi-asperity dimensions. See skidding A.4.54 and smearing A.4.55. See 5.2.3.

NOTE Type of adhesive wear.

A.4.26 Glazing: burnished surface on which original finishing texture is plastically smoothed. See burnishing A.4.4.

A.4.27 Grey stain: discolouration into a grey, dull appearance. See microspalling A.4.35. See 5.1.3.

A.4.28 Hard particle: such as sand and grains from abrasive operations (e.g. grinding wheel). See 5.2.2 and 5.5.3.

A.4.29 Heat cracking: see thermal cracking A.4.64. See 5.2.3 and 5.6.4.

A.4.30 Hertzian theory: theory about contact stress related to the contact area between two bodies and to the elastic deformation properties of the materials. See 5.1.2.

A.4.31 Hoop stress: stress in bearing rings, in circumferential (tangential) direction. See 5.6.2.

A.4.32 Inclusion: particulate body of unintended foreign material included in the matrix material. See 5.1.2.

A.4.33 Indentation: local plastic depression (point, line or area) on contact surface (in service), by hard edges, or contaminants pressed into and/or rolled over the surface. See 5.5.3.

A.4.34 Microcrack: cracks formed by continued cyclic stressing, which exhausts the plasticity of the material. A heavily distressed surface is densely populated with these microcracks. See 5.1.2 and 5.1.3.

A.4.35 Microspalling: shallow spalling of asperity contacts. See spalling A.4.58. See 5.1.3.

A.4.36 Moisture corrosion: result of a moisturized chemical reaction on metallic surfaces. When steel comes in contact with moisture, e.g. water, acid, oxidation of surfaces can take place and subsequently formation of corrosion pits and spalling can occur. See 5.3.2.

A.4.37 Nick: plastic depression, caused by impressing (statically or by impact) a hard, possibly sharp object into a surface of a contact component. See 5.5.2.

A.4.38 Overload deformation: plastic deformation caused by *excessive* static or shock load, i.e. formation of shallow depressions or flutes on the bearing raceways in positions corresponding to the rolling element pitch. Overload can also happen due to excessive preloading or incorrect handling. See 5.5.2.

A.4.39 Oxidation: the combination of a substance with oxygen. See 5.3.2, 5.3.3.1 and 5.3.3.2.

A.4.40 Particle wear: see abrasive wear A.4.2 and three-body wear A.4.63.

A.4.41 Path pattern: traces (eventually discoloured) of a part of a bearing area, due to contact with another bearing part; i.e. rolling element and its raceway. See A.1.3.

A.4.42 Peeling: severe stage damage propagation of a surface provoked by rolling contact fatigue, where it looks like a small slice of metal has been peeled off. See 5.1.3.

NOTE Peeling is sometimes used as the description for microspalling of a larger surface.

A.4.43 Pitting: any removal of material resulting in the formation of surface cavities.

NOTE As this description has a general usage, it has not been used under the term of fatigue.

A.4.44 Plastic deformation: permanent deformation occurring whenever the yield strength of the material is exceeded. See 5.5.

A.4.45 Ploughing: the formation of grooves by plastic deformation of the softer of two surfaces in relative motion. See 5.2.2.

A.4.46 Polishing: smoothing action, which alters the (original manufactured) surface of a rolling bearing component to a more shiny (or brightened) appearance. See 5.2.2.

A.4.47 Rolling contact fatigue: failure due to repeated stressing of a solid surface due to rolling contact between it and another solid surface or surfaces. See 5.1.

A.4.48 Running-in: process by which machine parts improve in conformity, surface topography and frictional compatibility during the initial stage of use. See 5.2.2.

A.4.49 Rust: any of various powdery or scaly reddish-brown or reddish-yellow hydrated ferric oxides and hydroxides formed on iron and iron-containing materials by low-temperature oxidation in the presence of water or moisture. See 5.3.2, 5.3.3.1 and 5.3.3.2.

A.4.50 Scoring: severe scratching, ploughing of the surface (smearing). See scratching A.4.51. See 5.2.3.

NOTE In the USA, scoring is also used as a description for smearing.

A.4.51 Scratching: formation of fine grooves, caused by sharp edges or asperities or hard particles embedded in one surface or distributed between two surfaces. See scoring A.4.50. See 5.2.3.

A.4.52 Scuffing: type of adhesive wear or localized damage caused by occurrence of solid phase welding between sliding surfaces, without local surface melting. See 5.2.3.

NOTE The term scuffing is used in too many general and imprecise ways and should be avoided.

A.4.53 Seizing: extreme smearing, caused by inadequate lubrication, heavy load and temperature increase in the contacting surfaces, which, depending on speed and operating temperature, may lead to material softening, rehardening, cracking, friction welding and, in severe cases, jamming of bearing components. See 5.2.3.

A.4.54 Skidding: surface damage, silvery frosted in appearance, caused by high speed sliding and lubricant film rupture under rapid load changes occurring on discrete surface areas. See 5.2.3.

A.4.55 Smearing: type of adhesive wear; mechanical removal of material from a surface, usually involving plastic shear deformation, and redeposition of the material as a thin layer on one or both surfaces. See 5.2.3.

A.4.56 Smoothing: see burnishing A.4.4 and glazing A.4.26.

A.4.57 Soft particles: examples are plastic and wood chips, cotton thread. See 5.5.3.

A.4.58 Spalling: separation of particles from a surface. Loss of surface material due to subsurface or surface initiated fatigue. See 5.1.1 and 5.1.2.

A.4.59 Subsurface initiated fatigue: under the influence of loads in rolling contacts, described by the Hertzian theory, structural changes occur and microcracks are initiated at a certain depth below the surface. See 5.1.2.

A.4.60 Surface distress: see surface initiated fatigue A.4.61. See 5.1.3.

A.4.61 Surface initiated fatigue: failure of the rolling contact metal surface asperities under reduced lubrication conditions, which leads to microcracks/microspalling at the surface. All kinds of defects at the surface in combination with poor lubrication film can locally lead to an increased degree of surface defects. See 5.1.3.

A.4.62 Thermal cracking: damage (or failure) caused by high frictional heat due to sliding motion. Cracks usually appear at right angles to the direction of sliding. See 5.6.4.

A.4.63 Three-body wear: type of abrasive wear that occurs when the particles are not constrained and are free to roll and slide down a surface and interact with two contacting surfaces. See 5.2.2.

A.4.64 Tribo-corrosion: see fretting corrosion A.4.23. See 5.3.3.1.

A.4.65 Tribo-oxidation: see fretting corrosion A.4.23. See 5.3.3.1.

A.4.66 True brinelling: plastic deformation (impression) of one contacting body into the other. See 5.5.2.

A.4.67 Vibration corrosion: false brinelling with corrosion or rust. See 5.3.3.3.

A.4.68 Washboarding: see fluting A.4.18. See 5.4.3.

A.4.69 Wear: progressive removal of material from a solid surface during service, generally involving progressive loss of material due to relative motion between that surface and a contacting substance or substances. See 5.2.

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