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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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ISO 15243 was prepared by Technical Committee ISO/TC 4, *Rolling bearings*.

Introduction

In practice, damage or failure of a bearing can often be the result of several mechanisms operating simultaneously. The failure can result from improper assembly 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 conditions. It is the complex combination of design, manufacture, assembly, operation and maintenance that often causes difficulty in establishing the primary cause of 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 primary cause of failure. In all cases, knowledge of the actual operating conditions of the assembly and the maintenance history is of the utmost importance.

The classification of bearing failure established in this International Standard is based primarily upon the features visible on rolling element contact surfaces and other functional surfaces. Consideration of each feature is required for reliable determination of the cause of bearing failure. Since more than one process may cause similar effects to these surfaces, a description of appearance alone is occasionally inadequate for determining the reason for the failure. In such cases, the operating conditions must be considered.

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

1 Scope

This International Standard defines, describes and classifies the characteristics, changes in appearance and possible causes of failure of rolling bearings occurring in service. It will assist in the understanding of the various forms of change in appearance and the failure that has occurred.

For the purposes of this International Standard the term "failure of rolling bearings" means the result of a defect or damage that prevents the bearing meeting the intended design performance.

Consideration is restricted to characteristic forms of change in appearance and failure, which have a 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 diagrams, and the most frequent causes are indicated.

The failure mode designations shown in the subclause titles are recommended for general use, but similar expressions or synonyms are given within parentheses below the titles.

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

2 Normative references

The following referenced documents are indispensable for the application 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 5593:1997, *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.

3.1
characteristics
visual appearance resulting from service performance

NOTE Surface defects and types of geometrical change that occur during wear (appearance of wear) are partly defined in ISO 6601 and ISO 8785.

4 Classification of failure modes occurring in rolling bearings

Rolling bearing failures are classified strictly according to their primary causes. However, it is not always 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).

The evolution of tribological research during recent decades has led to a remarkable increase of new knowledge describing failure mechanisms and failure modes. In this International Standard, failure modes are classified in six main groups and various sub-groups (see Figure 1).

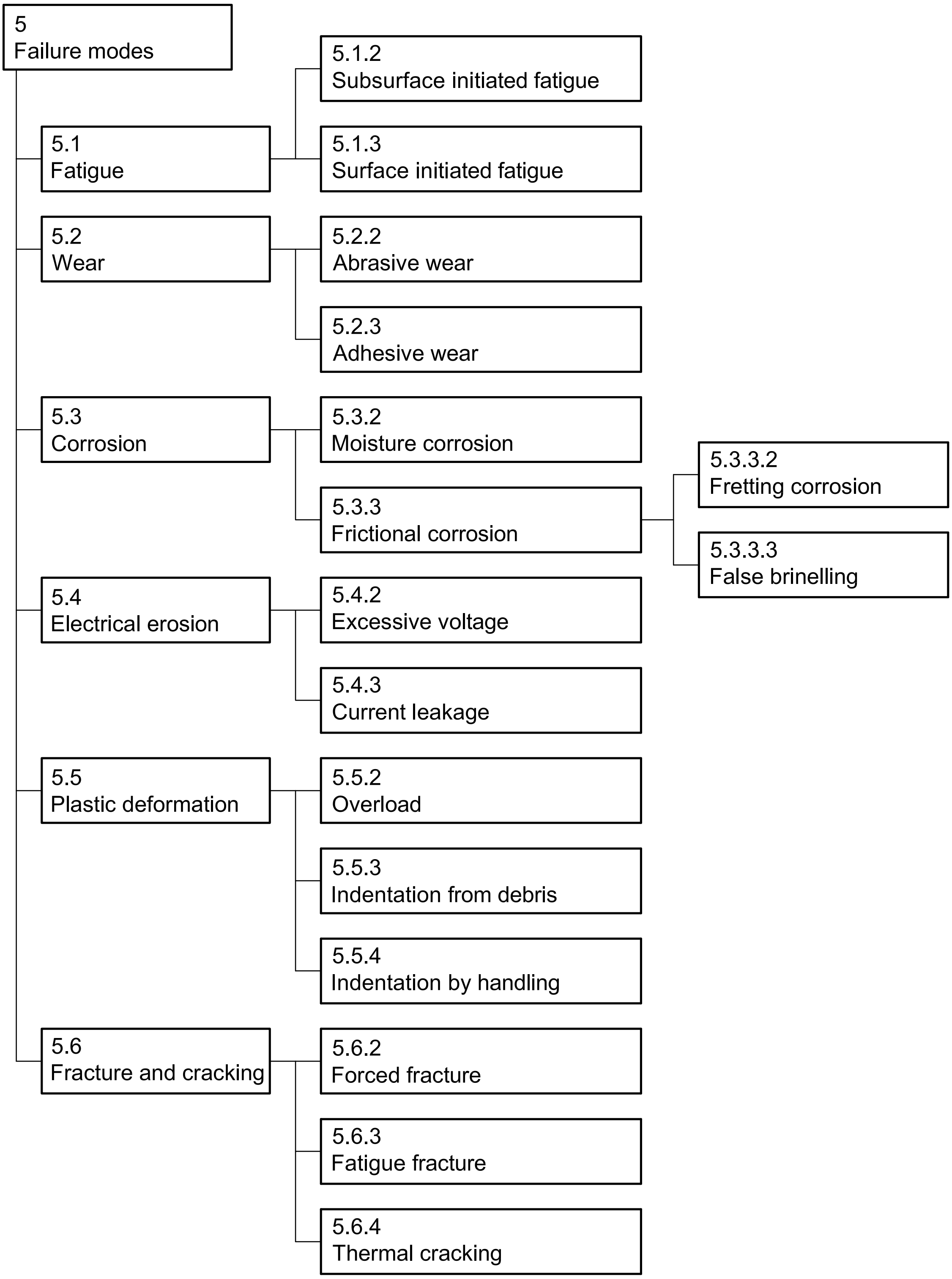


Figure 1 — Classification of failure modes

5 Failure modes

5.1 Fatigue

5.1.1 General definition

The change in the structure, which is caused by the repeated stresses developed in the contacts between the rolling elements and the raceways, is described as fatigue. Fatigue is manifested visibly as a flaking of particles from the surface.

5.1.2 Subsurface initiated fatigue

Under the influence of loads in rolling contacts, described by the Hertzian Theory, structural changes will occur and microcracks will be initiated at a certain depth under the surface, i.e. subsurface. The initiation of the microcracks is often caused by inclusions in the bearing steel (see Figure 2). The microcracks, which are observed at the edge of the white etched areas (butterflies), will normally propagate to the rolling contact surface producing flaking, spalling (pitting) and then peeling (see Figure 3).

NOTE The bearing life calculation in accordance with ISO 281 and ISO 281/Amd. 2 is based on subsurface initiated fatigue.

5.1.3 Surface initiated fatigue

Fatigue initiated from the surface is, among other things, caused by surface distress.

Surface distress is the damage to the rolling contact metal surface asperities under a reduced lubrication regime and a certain percentage of sliding motion, causing the formation of

- asperity microcracks, see Figure 4;
- asperity microspalls, see Figure 5;
- microspalled areas (grey stained), see Figure 6.

Indentations in the raceways caused either by contaminant particles or by handling can also lead to surface initiated fatigue (see 5.5.3 and 5.5.4). Surface initiated fatigue caused by indentation arising from plastic deformation is shown in A.2.6.1 and A.2.6.3.

NOTE ISO 281/Amd. 2 includes surface related calculation parameters that are known to have an influence on the bearing life, such as material, lubrication, environment, contaminant particles and bearing load.

Figure 2 — Subsurface microcrack with the "butterfly phenomenon" (white etched area) (Scale 500:1)

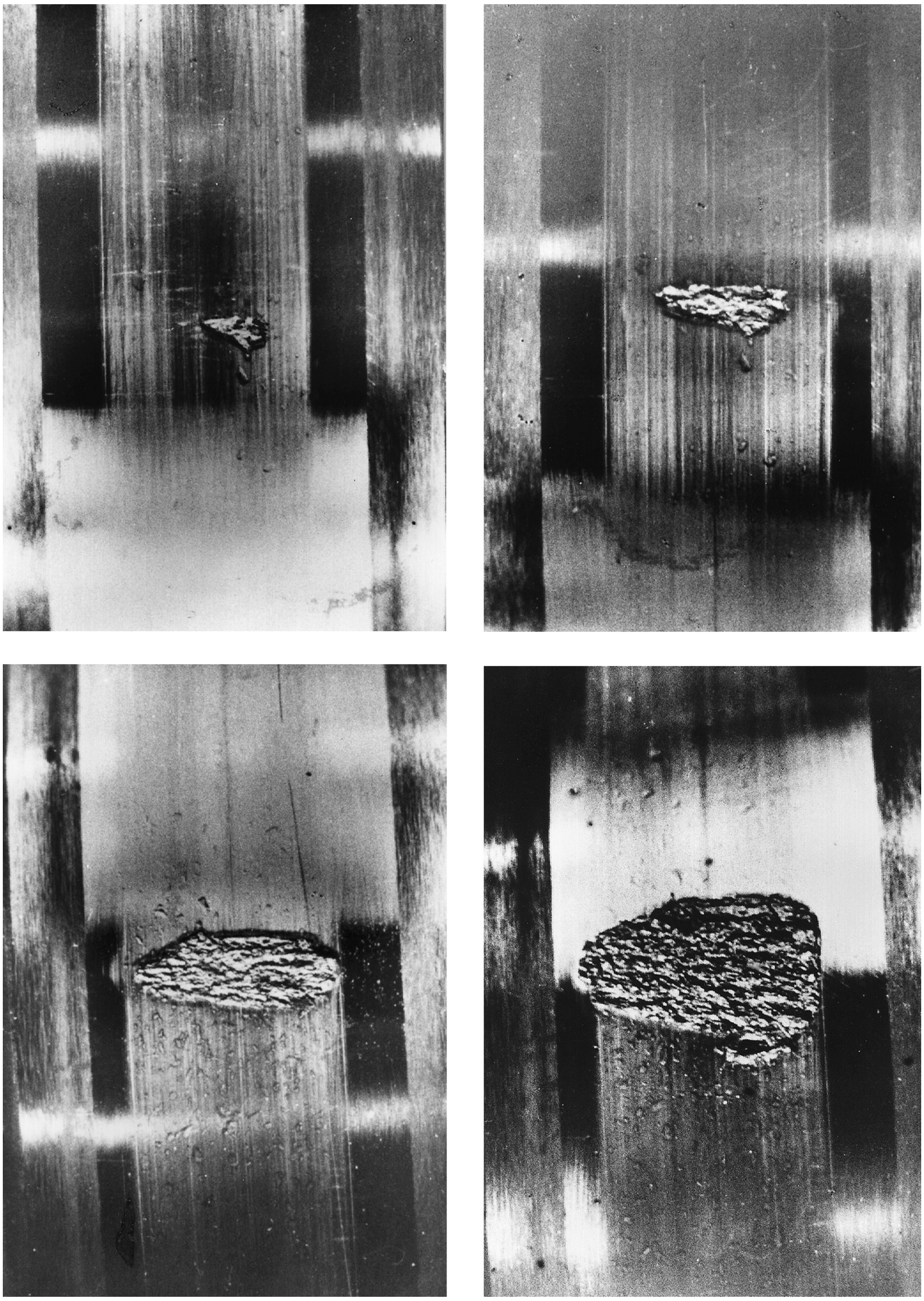


Figure 3 — Progression of subsurface fatigue

5.2 Wear

5.2.1 General definition

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

5.2.2 Abrasive wear

(particle wear; three body wear)

Abrasive wear is the result of inadequate lubrication or 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 Figure 7). These particles gradually increase in number as material is worn away from the running surfaces and cage. Finally, the wear becomes an accelerating process that results in a failed bearing.

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.

5.2.3 Adhesive wear

(smearing; skidding; galling)

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

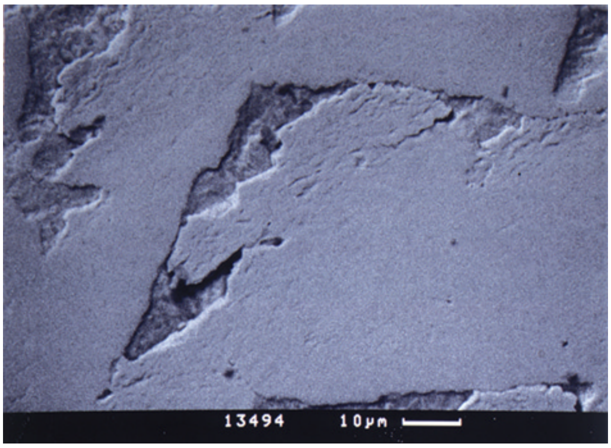


Figure 4 — Microcracks forming a “fish-scale” appearance

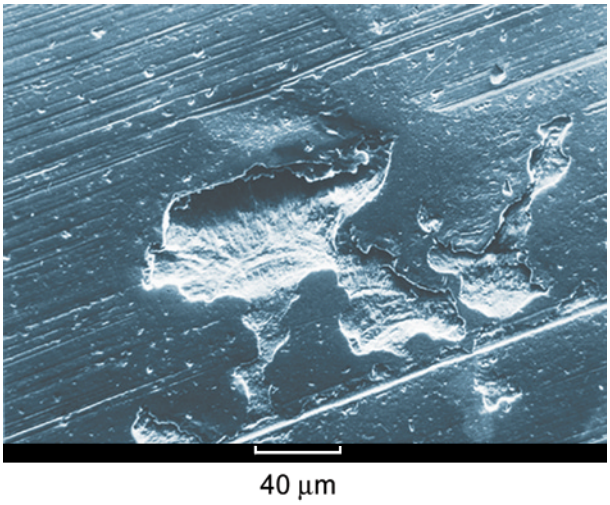


Figure 5 — Microspalls

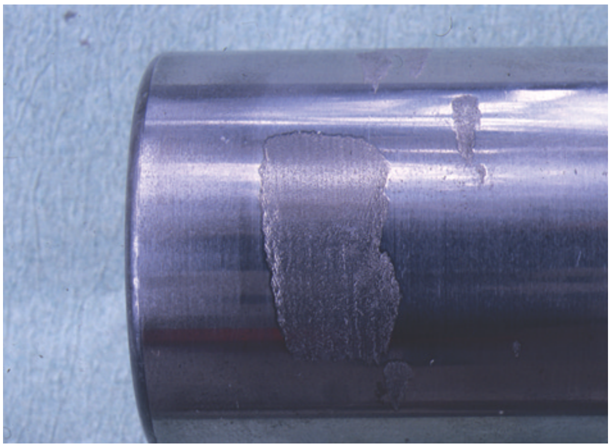


Figure 6 — Heavy grey stained areas
(Scale 1,25:1)

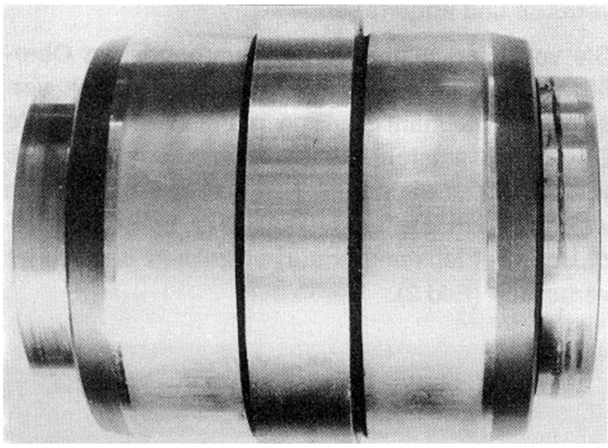


Figure 7 — Abrasive wear on the inner ring raceways of a double-row cylindrical roller bearing with central rib

Smearing (skidding) can occur between rolling elements and raceways due to the fact that the rolling elements are lightly loaded and subjected to severe acceleration on their re-entry into the load zone (see Figure 8). Smearing can also occur between rolling elements and raceways when the load is too light in relation to the speed of rotation.

Smearing can occur on the guiding flange faces and on the ends of the rollers due to insufficient lubrication (see Figure 9). In full complement bearings (cageless), smearing can also occur in the contacts between rolling elements depending on lubrication and rotation conditions.

If a bearing ring "rotates" relative to its seating, i.e. mounting shaft or housing, then smearing can occur in the contact between the ring end face and its axial abutment, which can also cause cracking of the ring as shown in Figure 10. This type of damage generally occurs when the radial load on the bearing rotates relative to the bearing ring and the bearing ring is mounted with a very small clearance (loose fit) to its seating. 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 one point by the radial load, 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/seating contact region are over-rolled, which can cause the surface of the ring to take on a shiny appearance (see A.2.4.7). The over-rolling during creeping is often, but not necessarily, accompanied by sliding in the ring/seating contact, and then other damage will also be visible, e.g. scratches, fretting corrosion and wear. Under certain loading conditions and when the ring/seating interference fit is insufficiently tight, then fretting corrosion will predominate (see A.2.4.5).

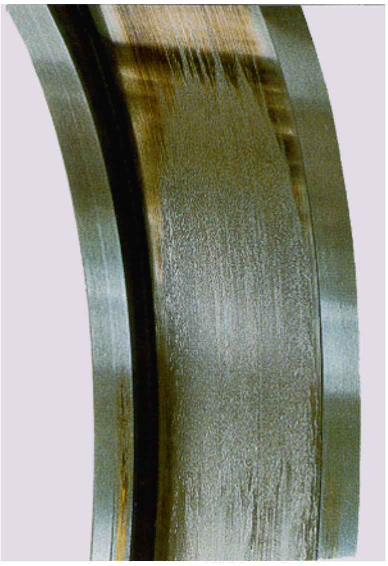


Figure 8 — Smearing on raceway surfaces

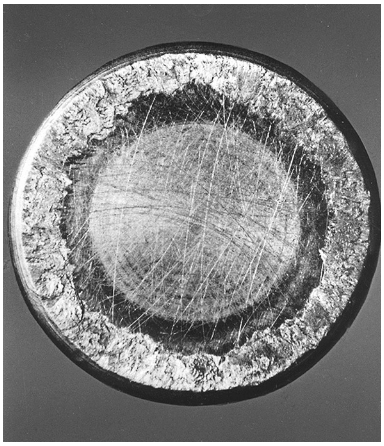


Figure 9 — Smearing of roller end

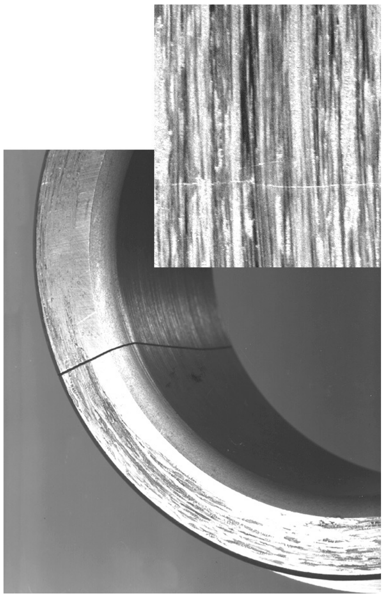


Figure 10 — Smearing on ring end face (ring is also fractured)

5.3 Corrosion

5.3.1 General definition

Corrosion is a chemical reaction on metal surfaces.

5.3.2 Moisture corrosion

(oxidation; rust)

When steel, used for rolling bearing components, is in contact with moisture, e.g. water or acid, oxidation of surfaces takes place. Subsequently the formation of corrosion pits occurs and finally flaking of the surface (see Figure 11).

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. The advanced stage will result in dark discolouration of the contact areas at intervals corresponding to the ball/roller pitch, eventually producing corrosion pits (see Figures 12 and 13).

5.3.3 Frictional corrosion

(tribocorrosion; tribo-oxidation)

5.3.3.1 General definition

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

Figure 11 — Corrosion on a roller bearing outer ring

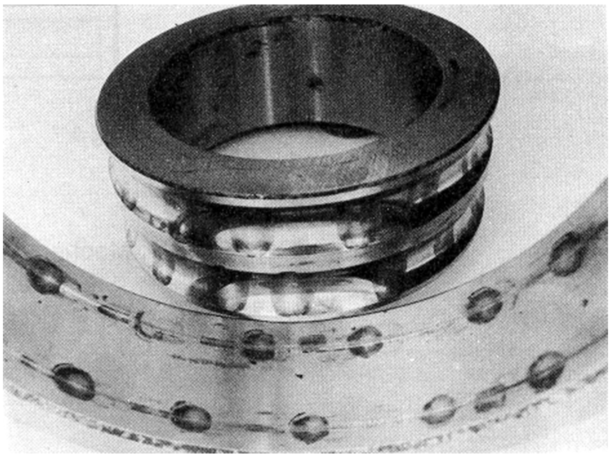


Figure 12 — Contact corrosion on a ball bearing inner ring and outer ring raceways

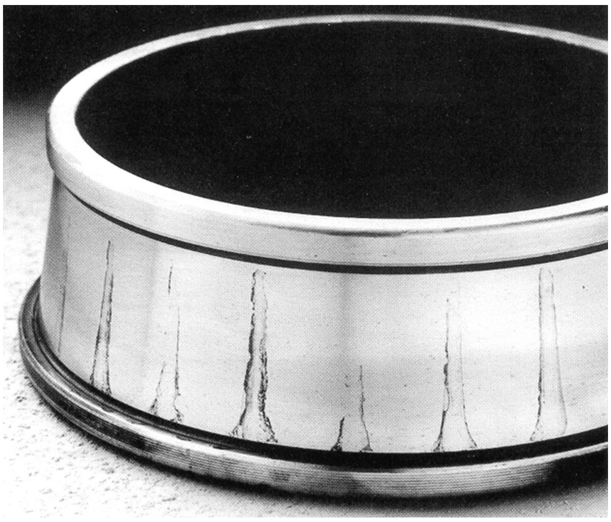


Figure 13 — Contact corrosion on a bearing raceway

5.3.3.2 Fretting corrosion
(fretting rust)

Fretting corrosion occurs in fit interfaces that are transmitting loads under oscillating contact surface micromovements. Surface asperities oxidize and are rubbed off and vice versa; powdery rust develops (iron oxide). The bearing surface becomes shiny or a discoloured blackish red (see Figure 14). Typically, the failure develops in incorrect fits, either too light an interference fit or too high a surface roughness, in combination with loads and/or vibrations.

5.3.3.3 False brinelling
(vibration corrosion)

False brinelling occurs in rolling element/raceway contact areas due to micromovements and/or resilience of the elastic contacts under cyclic vibrations. Depending on the intensity of the vibrations, the lubrication conditions and load, a combination of corrosion and wear occurs, forming shallow depressions in the raceways.

In the case of a stationary bearing, the depressions appear at rolling element pitch and can often be discoloured reddish or shiny (see Figure 15).

False brinelling caused by vibrations occurring during rotation shows itself in closely spaced flutes (see Figure 16). These should not be mistakenr for electrically caused flutes (see 5.4.3 and Figure 19). 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 in colour. The damage caused by electric current is also distinguishable by the fact that the rolling elements are also marked.

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

5.4 Electrical erosion

5.4.1 General definition

Electrical erosion is the removal of material from the contact surfaces caused by the passage of electric current.

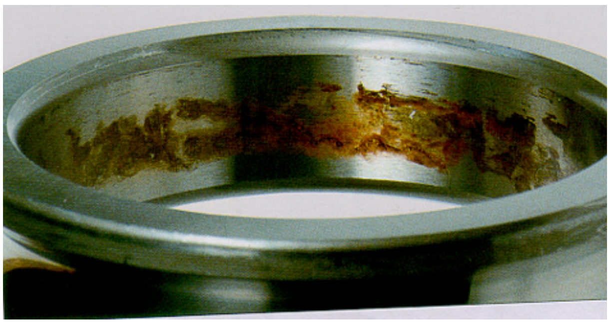


Figure 14 — Fretting corrosion in inner ring bore

Figure 15 — False brinelling on inner ring raceway of cylindrical roller bearing

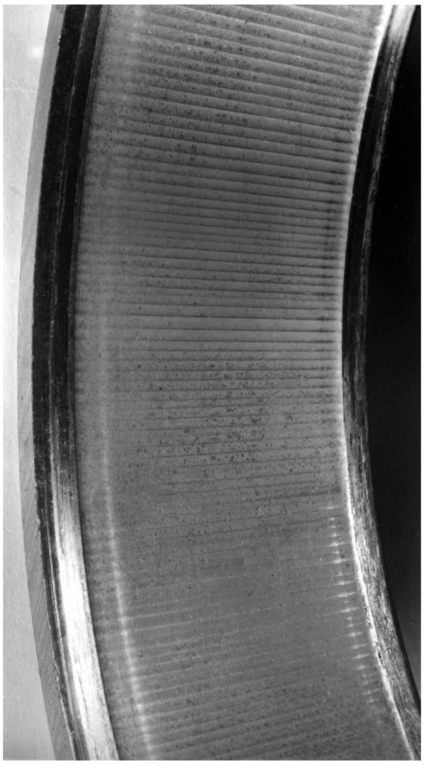


Figure 16 — False brinelling — Fluting on outer ring of tapered roller bearing

5.4.2 Excessive voltage
(electrical pitting)

When an electric current passes from one bearing ring to the other through the rolling elements and their lubricant films, sparking will occur in the contact areas because of insufficient or defective insulation. In the contact areas between rings and rolling elements, the flow lines of the current are condensed, resulting in localized heating within very short time intervals, so that the contact areas melt and weld together.

This damage may appear as a series of small craters with diameters of up to 100 µm (see Figure 17). The craters are duplicated on the rolling element and raceway contact surfaces in bead-like procession in the rolling direction (see Figure 18).

5.4.3 Current leakage
(electrical fluting)

Initially the surface damage takes the shape of shallow craters, which are closely positioned to one another and small in size. This happens even if the intensity of the current is comparatively low. Flutes will develop from the craters in time, as shown in Figure 19. They can be found on roller and ring raceway contact surfaces, but not on balls, which have dark colouration only (see Figure 20). The flutes are equally spaced. The raceways are dark in the bottoms of the depressions (see Figures 20 and 21). Eroded patches, next to the flutes on Figure 21, indicated by the pencil point, were caused by contact of the cage ribs with the inner ring.

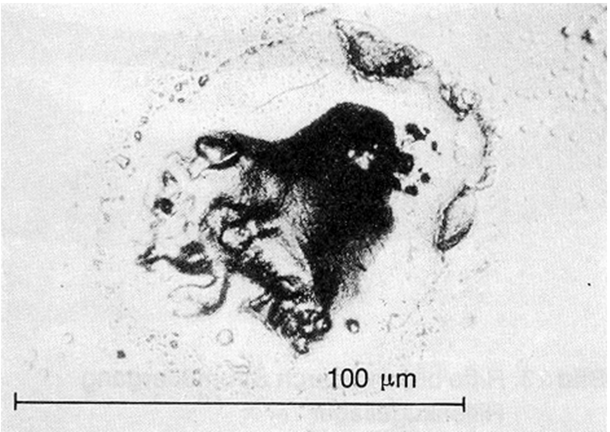


Figure 17 — Craters formed by the passage of electric current

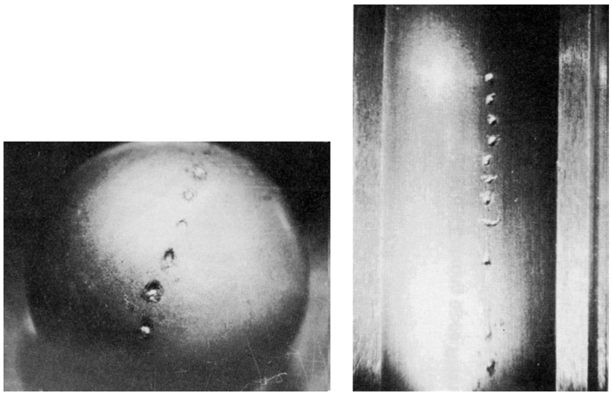


Figure 18 — Craters in bead-like procession on ball and raceway

Figure 19 — Craters formed by current leakage resulting in fluting

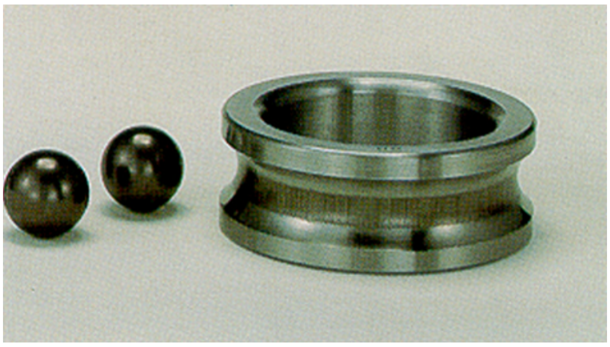


Figure 20 — Fluting on inner ring raceway — Dark coloured balls

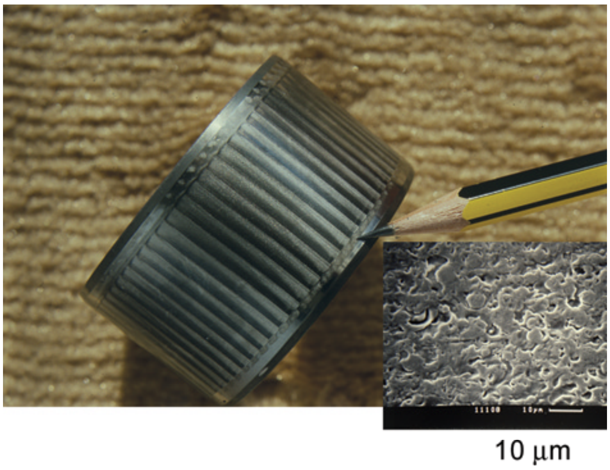


Figure 21 — Fluting on a needle roller bearing inner ring
(Enlarged surface detail is seen behind the bearing ring and an enlarged view using scanning electron microscopy is in the lower right corner.)

5.5 Plastic deformation

5.5.1 General definition

Permanent deformation occurring 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
(true brinelling)

Overloading of a stationary bearing by static load or shock load leads to plastic deformation at the rolling element/raceway contacts, i.e. the formation of shallow depressions or flutes on the bearing raceways in positions corresponding to the pitch of the rolling elements (see Figure 22). Furthermore, overloading can occur by excessive preloading or due to incorrect handling during mounting (see Figure 23).

Inappropriate handling can also cause overloading and deformation of other bearing components, e.g. shields, washers and cages (see Figure 24).

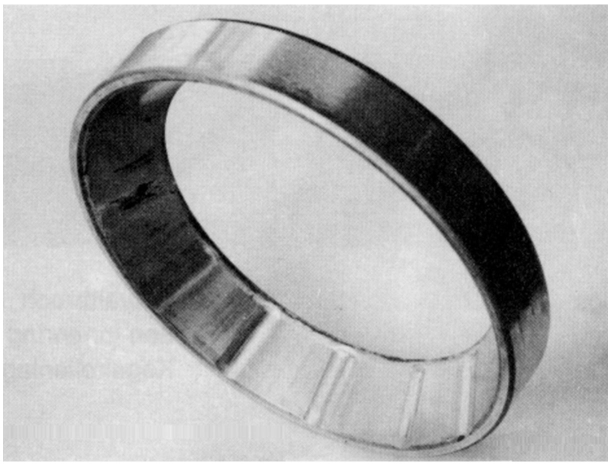


Figure 22 — Plastic deformation on a tapered roller bearing raceway produced by overloading

Figure 23 — Overloading during mounting

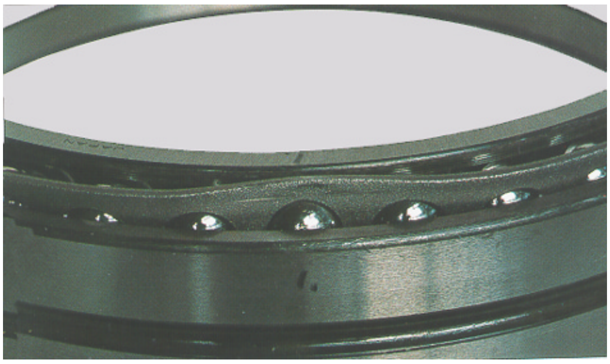


Figure 24 — Cage deformed by incorrect handling

5.5.3 Indentation from debris

When particles are over-rolled, indentations are formed on raceways and rolling elements. The size and shape of the indentations depend on the nature of the particles. See Figures 25 a), b) and c), which depict the following types of indentation:

a) from soft particles, e.g. fibres and wood;

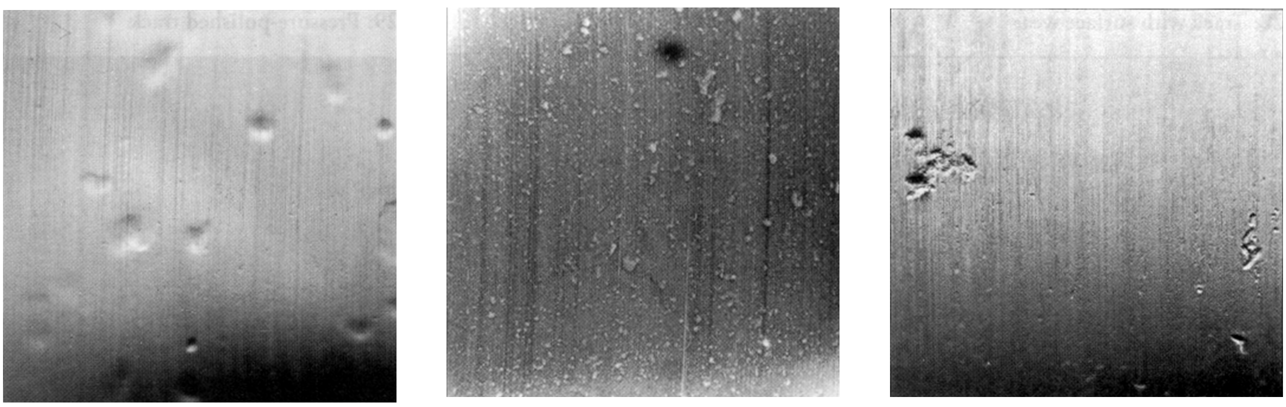
b) from hardened steel particles, e.g. from gears and bearings;

c) from hard mineral particles, e.g. from grinding wheels.

NOTE ISO 281/Amd. 2 describes the reduction of the bearing life by particle indentation.

5.5.4 Indentation by handling

Raceways and rolling elements can incur indentations and nicks caused by hard, possibly sharp, objects (see Figure 26).



a) b) c)

Figure 25 — Indentations caused by over-rolled particles

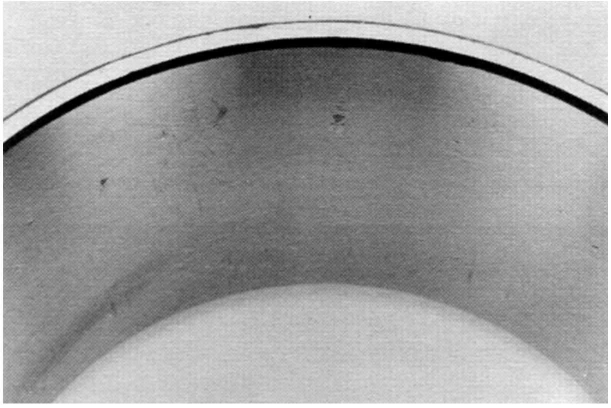


Figure 26 — Nicks (gouges)

5.6 Fracture and cracking

5.6.1 General

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

Fracture is the result of a crack propagating to the point of complete separation of a part of the 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 27), or by over-stressing due to an excessive interference fit (see Figure 28).

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 and cages (see Figures 29 and 30). The fatigue crack striations are clearly visible in the fractured surface of the cage bar in the enlarged (lower) image in Figure 30.

Fatigue fracture is sometimes caused by insufficient support of the bearing ring in the housing or on the shaft (see Figure 31).

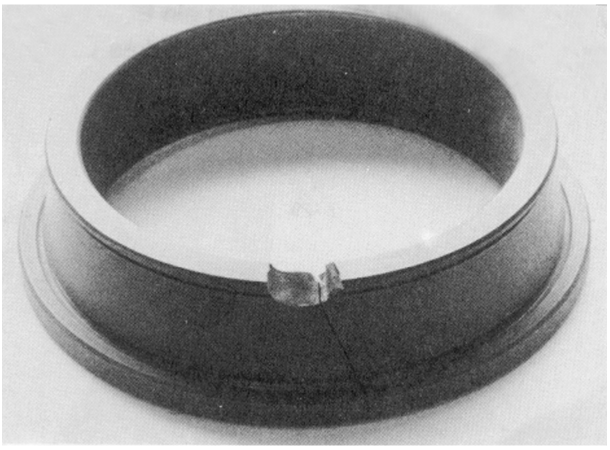


Figure 27 — Forced fracture caused by a direct hammer blow

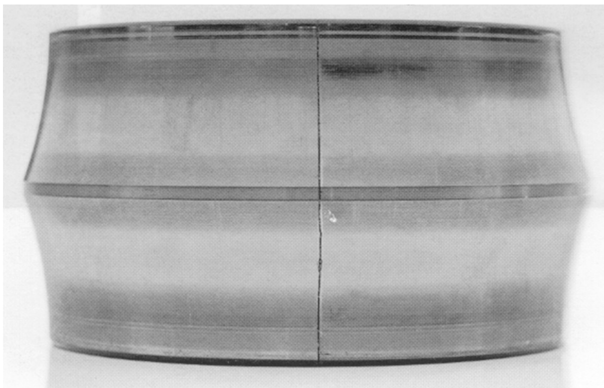


Figure 28 — Spherical roller bearing inner ring with forced fracture caused by excessive interference fit

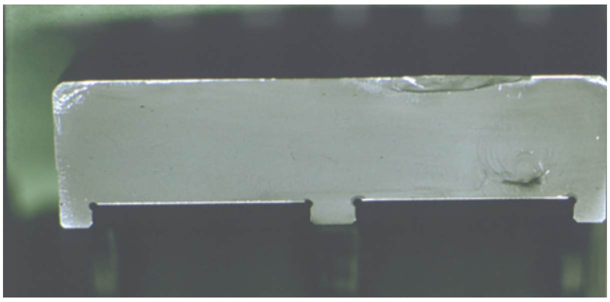


Figure 29 — Fatigue fracture of a back-up roll outer ring caused by bending
(The damage at the outside surface is secondary and occurred when the ring fractured.)

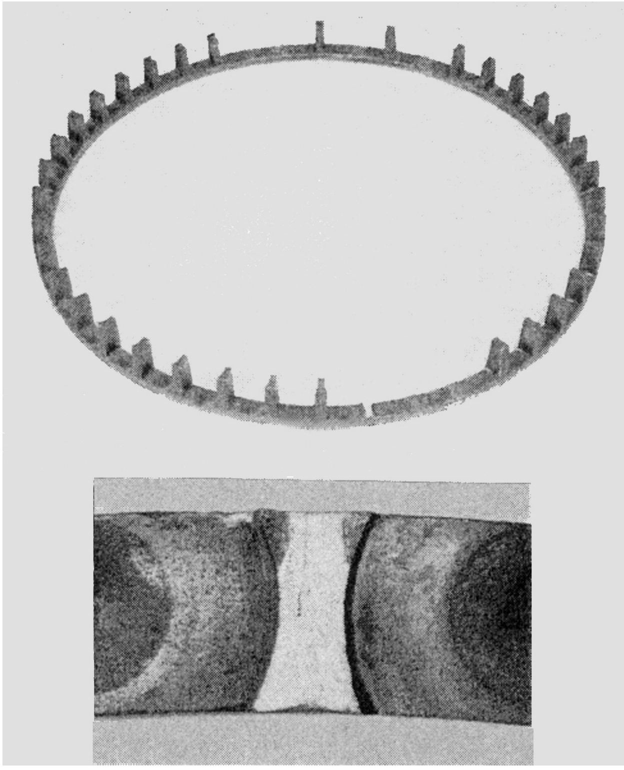


Figure 30 — Fatigue fractures of cage bars

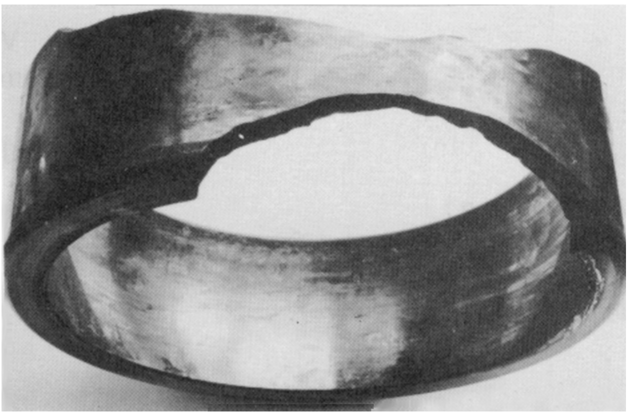


Figure 31 — Fatigue fracture of an outer ring caused by insufficient support in the housing

5.6.4 Thermal cracking
(heat cracking)

Thermal cracking is caused by high frictional heating due to sliding motion. Cracks usually appear at right angles to the direction of sliding (see Figure 32). Hardened steel components are sensitive to thermal cracking due to rehardening of the surfaces in combination with the development of high residual tensile stress.

Figure 32 — Thermal cracking on an inner ring face

Annex A
(informative)

Failure analysis — Illustrations of damage — Terms

A.1 Failure analysis

A.1.1 Securing evidence before and after removal

When, due to failure, a bearing is removed from a machine, the cause of the failure should be classified as well as the means of avoiding future failures. To obtain the most reliable result, it is helpful to follow a systematic procedure when securing evidence and inspecting the bearing. The matrix given in Table A.1 shows the most probable correlation of visual characteristics of frequent failures and their possible causes.

The following items should be considered when investigating bearings:

- obtain operating data, analyse records and charts from bearing monitoring devices;
- extract lubricant samples to determine lubrication conditions;
- check bearing environment for external influences, including equipment problems;
- assess bearing in mounted condition;
- mark mounting position;
- remove bearing and parts;
- mark bearing and parts;
- check bearing seats;
- assess bearing;
- examine individual bearing/bearing parts;
- consult experts, or despatch bearings to experts[1], together with full results from the above check points as required.

Important factors necessary to find the causes of failure may be lost if the procedure selected is incorrect.

A.1.2 Contact traces

A.1.2.1 General

The interpretation of the 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 the following illustrations, typical running path patterns for the most common applications and bearing types are shown.

1) In this case the failed bearing should be kept in the as-failed condition.

Table A.1 — Matrix of defects

Possible causes		Characteristic features of defects																					
		Wear								Fatigue		Corrosion			Fractures			Deformation			Cracks		
		Increased wear	Tracks	Scores	Seizing marks, smearing	Scratches, scuffing marks	Fluting, washboarding	Chatter marks	Hot running	Pitting	Flaking, spalling	General corrosion (rust)	Fretting corrosion (rust)	Electrical craters, fluting	Through crack, fracture	Cage fractures	Local spalling, chipping	Deformation	Indentations	Marking	Thermal cracks	Heat treatment cracks	Grinding cracks
Lubricant	Insufficient lubricant	●			●	●			●	●	●					●					●		
Lubricant	Excessive lubricant								●														
Lubricant	Incorrect viscosity	●			●	●			●	●	●					●					●		
Lubricant	Inadequate quality	●			●	●			●	●	●	●									●		
Lubricant	Contamination	●	●	●						●	●	●							●				
Operating condition	Excessive speed	●			●	●			●	●	●					●		●					
Operating condition	Excessive load	●			●				●	●	●				●			●	●		●		
Operating condition	Frequently fluctuating loads	●		●	●	●				●	●					●							
Operating condition	Vibration	●			●	●		●		●	●		●		●	●							
Operating condition	Passage of electrical current						●			●	●			●									
Mounting	Faulty electrical insulation						●		●	●	●			●									
Mounting	Incorrect mounting					●				●	●				●	●	●	●	●	●			
Mounting	Incorrect heating	●																●			●		
Mounting	Misalignment	●				●				●	●							●					
Mounting	Undesirable preloading	●	●						●	●	●				●	●		●			●		
Mounting	Impact	●	●													●		●					
Mounting	Inadequate fixing	●	●		●					●	●				●		●	●			●		
Mounting	Uneven seating surface	●	●							●	●		●		●			●					
Mounting	Incorrect seating fit	●	●						●	●	●		●				●	●			●		
Design	Incorrect bearing selection				●	●			●				●		●	●	●						
Design	Unsuitable adjacent components				●	●			●				●		●	●	●						
Handling	Incorrect storage											●											
Handling	Vibration during transportation					●		●					●						●	●			
Manufacture	Incorrect heat treatment	●							●	●	●											●	
Manufacture	Incorrect grinding																						●
Manufacture	Inadequate surface finish	●	●							●	●												
Manufacture	Inaccurate application component	●	●						●	●	●				●		●						
Material	Structural defects									●	●				●								
Material	Combination of incompatible materials	●			●	●			●									●					

A.1.2.2 Radial bearings

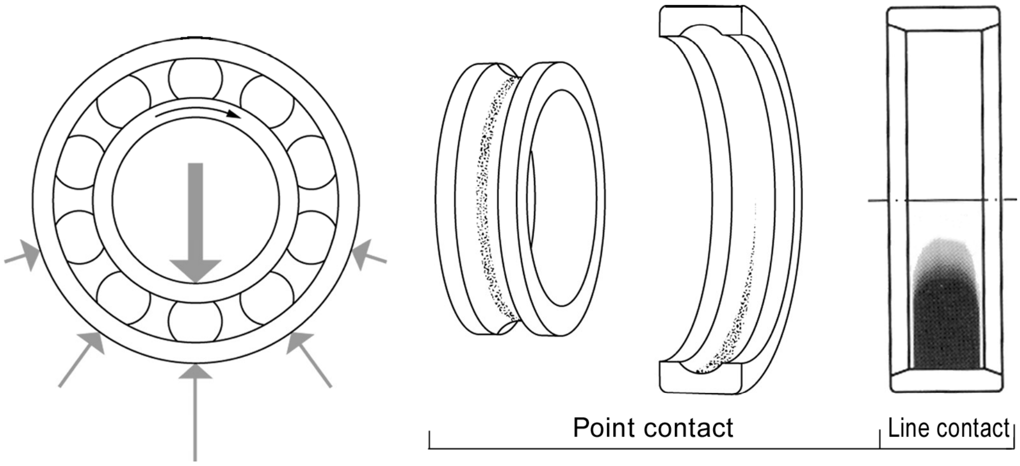


Figure A.1 — Uni-directional radial load — Rotating inner ring – Stationary outer ring

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 widest in the load direction, tapering towards the ends and 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.

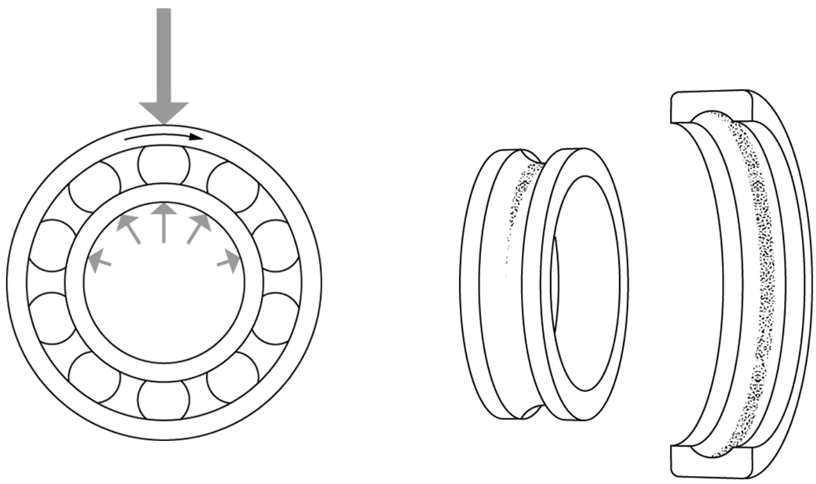


Figure A.2 — Uni-directional radial load — Stationary inner ring – Rotating outer ring

Inner ring: Running path pattern widest in the load direction, tapering towards the ends and 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.

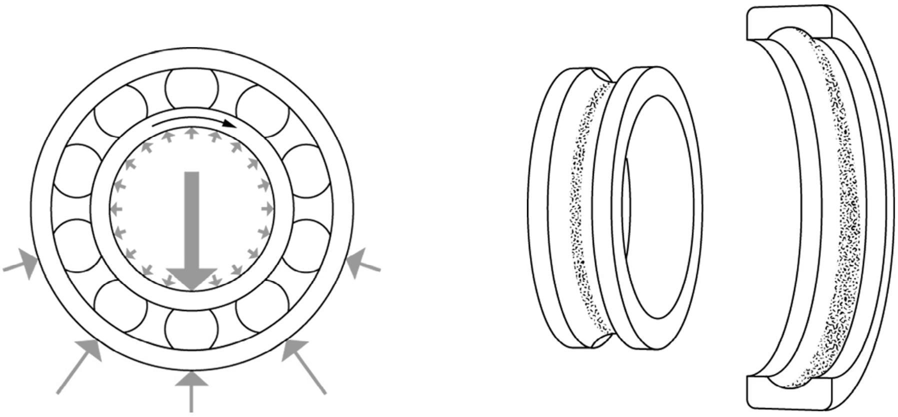


Figure A.3 — Radial preloading with uni-directional radial load — Rotating inner ring – Stationary outer ring

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 in the direction of radial loading.

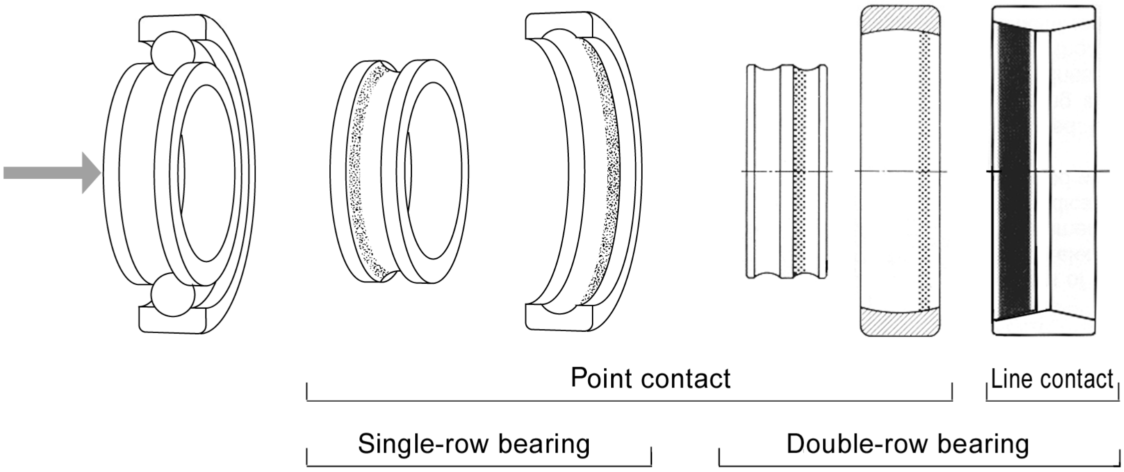


Figure A.4 — Uni-directional axial load — Rotating inner ring and/or outer ring

Inner and outer rings: Running path pattern uniform in width, axially displaced and extending around the entire circumference of the raceways of both rings.

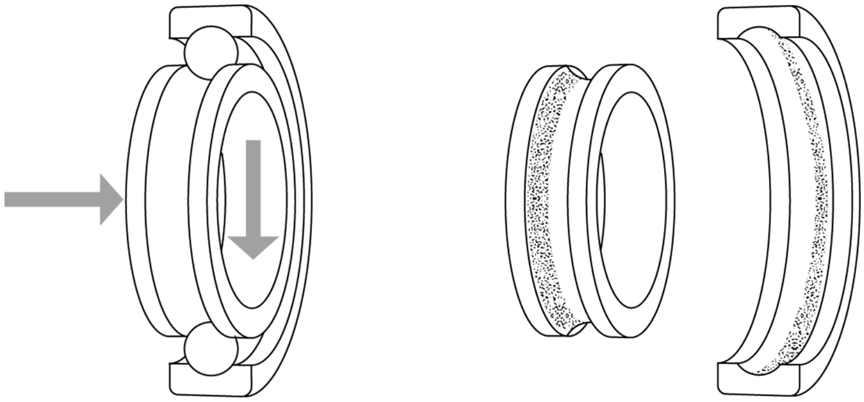


Figure A.5 — Combination of uni-directional radial and axial loads — Rotating inner ring – Stationary outer ring

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 in the direction of the radial loading.

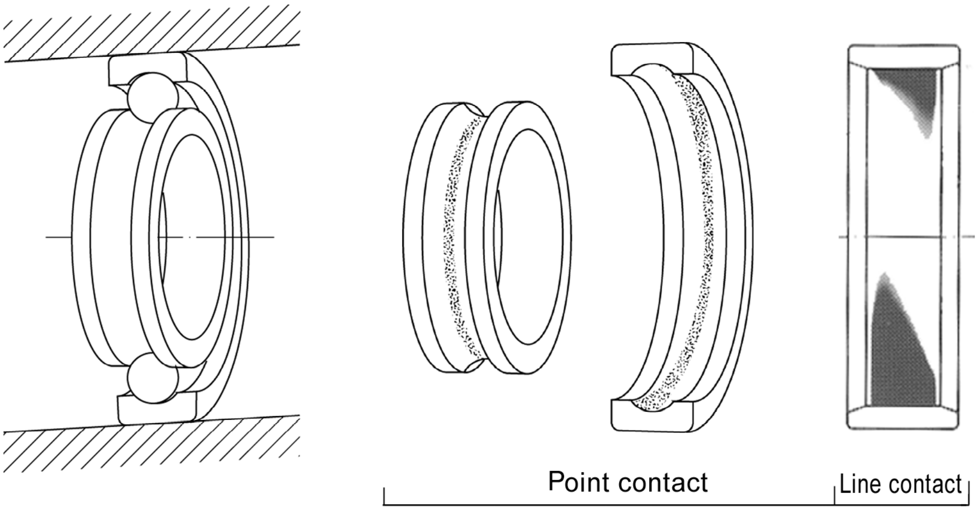


Figure A.6 — Outer ring misaligned in housing — Rotating inner ring – Stationary outer ring

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.

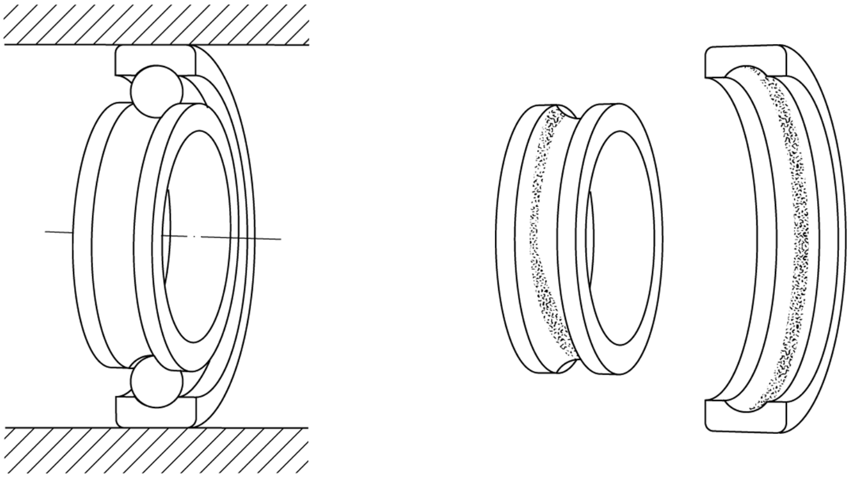


Figure A.7 — Inner ring misaligned on shaft — Rotating inner ring – Stationary outer ring

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.

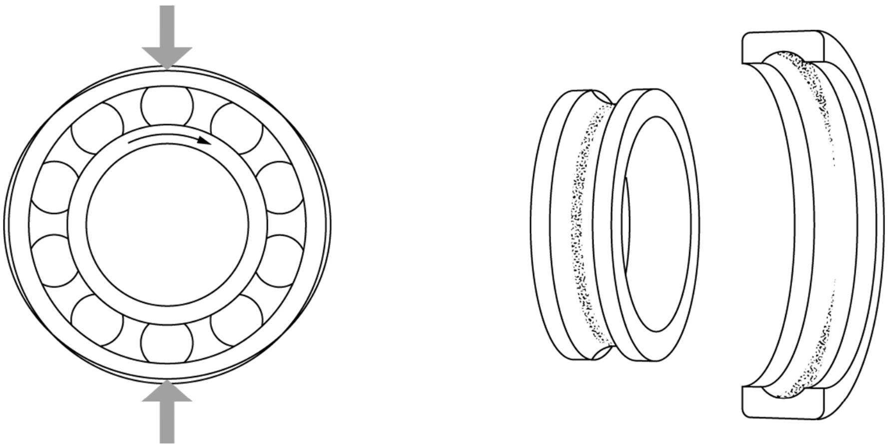


Figure A.8 — Oval compression of outer ring — Rotating inner ring – Stationary outer ring

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 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.

A.1.2.3 Thrust bearings

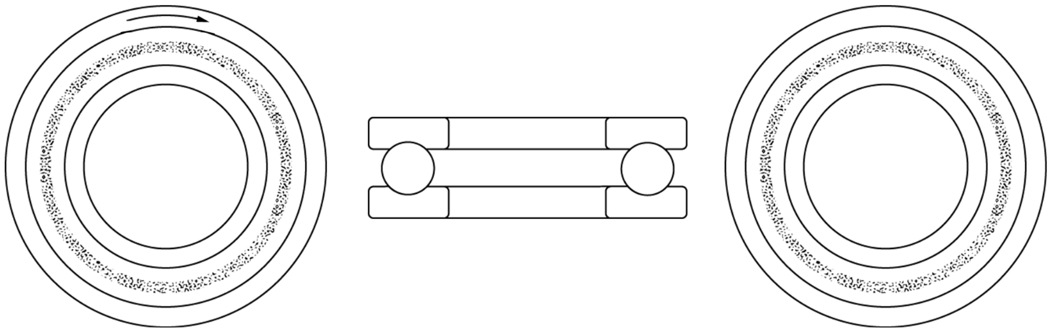


Figure A.9 — Uni-directional axial load — Rotating shaft washer – Stationary housing washer

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.

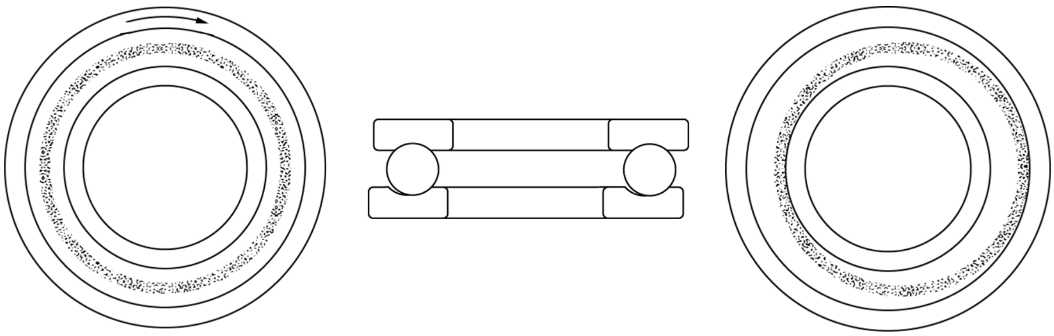


Figure A.10 — Uni-directional axial load on eccentrically positioned housing washer relative to shaft washer — Rotating shaft washer – Stationary housing washer

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.

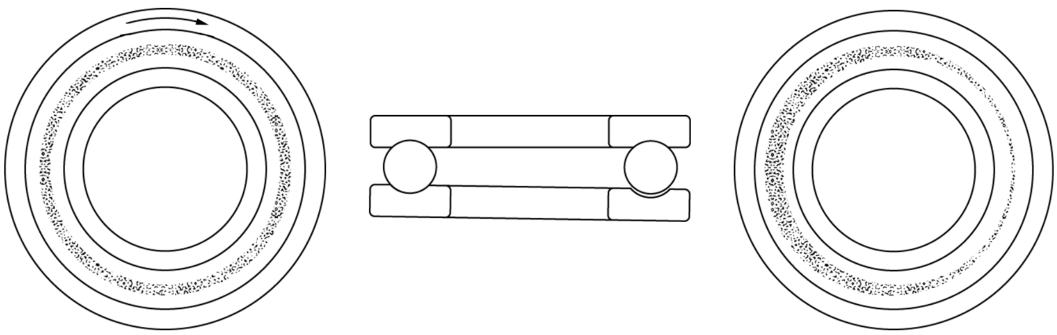


Figure A.11 — Misaligned housing washer — Rotating shaft washer – Stationary housing washer

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.

A.2 Illustrated failures catalogue — Causes 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 1. 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.

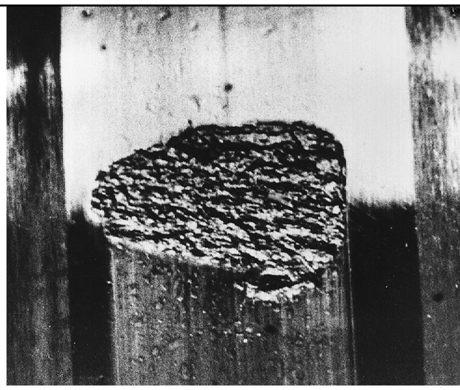
For each illustration, there are also proposed countermeasures or corrective actions to avoid failures, given in the paragraph headed “Countermeasure”.

A.2.2 Fatigue

A.2.2.1 Flaking

Cause of failure
Subsurface initiated material fatigue. The accumulation of load cycles leads to structural changes and fatigue cracks, originating in the loaded zone.

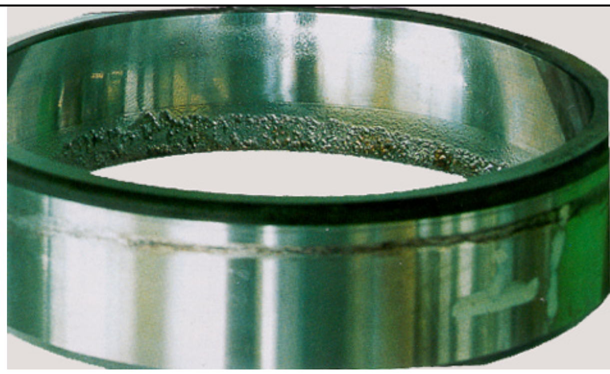
Countermeasure
Use a bearing with higher load-carrying capacity if longer life is required.



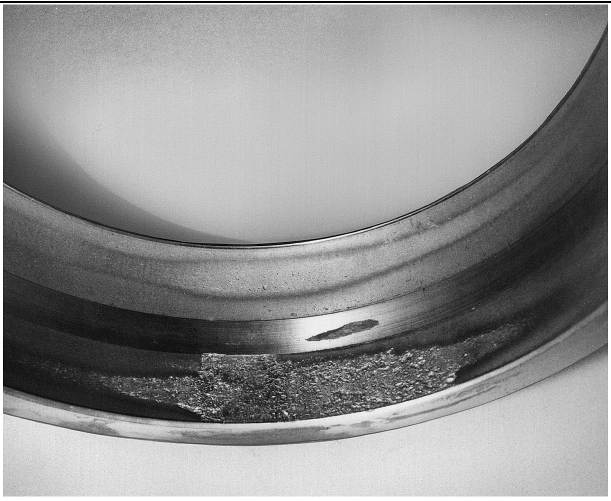
A.2.2.2 Flaking of only one raceway of spherical roller bearing

Cause of failure
Excessive axial load on a spherical roller bearing caused premature fatigue and flaking over the entire circumference of one of the raceways.

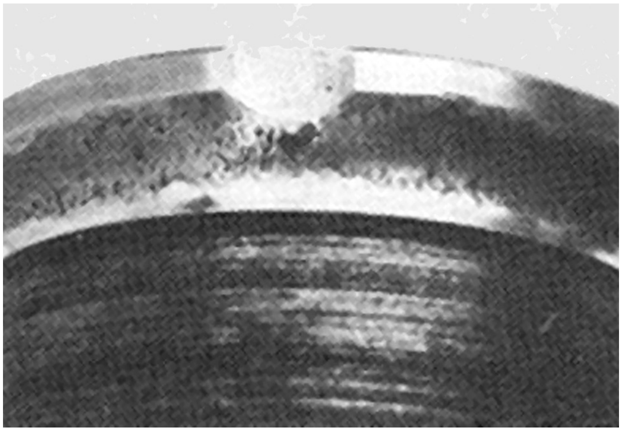
Countermeasure
If appropriate, select a bearing with higher axial load-carrying capacity. Control axial load on the bearing.



A.2.2.3 Raceway fatigue at two diametrically opposite locations

Cause of failure Flaking on the outer ring of a spherical roller bearing due to ovality of the housing. Similar damage can occur if split housings are wrongly assembled or if debris is embedded in the housing seating. **Countermeasure** Check form accuracy of adjacent parts and improve them, if necessary. Assemble split housings properly. Observe utmost cleanliness during mounting. NOTE The running path patterns on the raceways will indicate if outer ring or inner ring is out-of-round.	

A.2.2.4 Flaking (spalling) originating at filling slot, e.g. in double-row angular contact ball bearing

Cause of failure Incorrect bearing selection; faulty mounting; axial load directed towards filling slot. **Countermeasure** In the case of double-row bearings with filling slots only on one row, consider the direction of the axial load during operation when mounting the bearing. In the case of alternating axial loads use a bearing without the filling slot or, at least, apply only light axial loads in the direction of the filling slot. For single-row bearings with filling slots, axial loads should be kept low in relation to the radial load.	

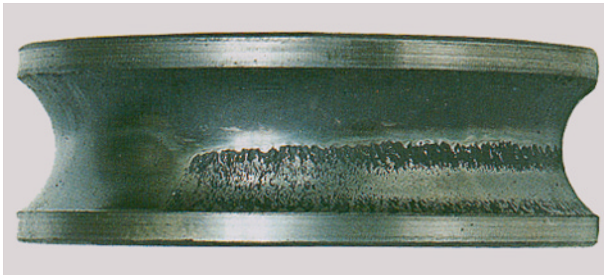
A.2.2.5 Flaking (spalling) of raceway at intervals corresponding to rolling element pitch

Cause of failure Faulty mounting and/or handling producing indentations in the raceway at rolling element pitch. Subsequent over-rolling leading to flaking. **Countermeasure** Mount bearing correctly by using suitable tools. Do not transmit mounting forces through the rolling elements. In the case of cylindrical roller bearings, rotate shaft slowly during mounting, if possible.	

A.2.2.6 Full running path pattern around entire raceway circumference of stationary outer ring of self-aligning ball bearing with rotating inner ring

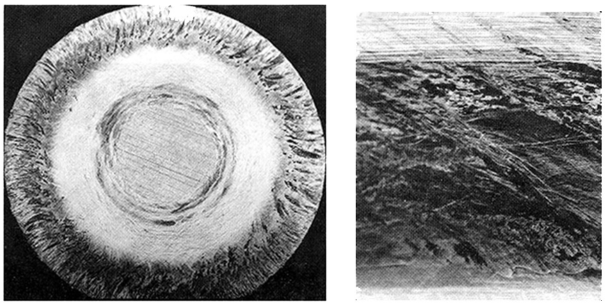
Cause of failure Temperature difference between shaft and housing too large; adjacent parts not within tolerances; incorrectly selected bearing internal clearance. **Countermeasure** Check dimensions of shaft and housing. Check temperature influence on bearing clearance. Select bearing with suitable clearance. If the inner ring is mounted on tapered seating, select correct driving up distance.	

A.2.2.7 Oblique running path flaking pattern on inner ring raceway

Cause of failure Misalignment during operation; shaft deflection; abutment faces on mating part(s) out-of-square. **Countermeasure** Check that the equipment is suitable for the bearing type. Eliminate misalignment or select a bearing type suitable to accommodate the misalignment. Reduce shaft deflection. Check the squareness of the abutment faces on mating part(s).	

A.2.3 Wear

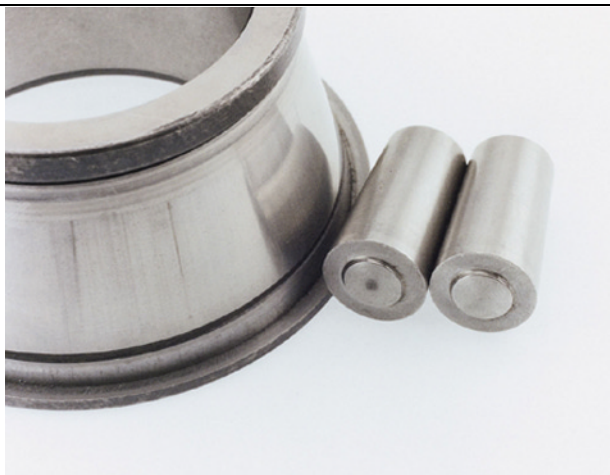
A.2.3.1 (Adhesive) Wear on roller end face

Cause of failure Axial load too high on the roller and/or inadequate lubrication causing adhesive wear in the form of seizing on the roller end face. An enlargement of the seizing is shown. (A milder form of roller end face smearing is shown in Figure 9.) **Countermeasure** Improve the lubrication. Use bearing type more suitable with regard to the pressure and lubrication conditions in the roller end face/rib contact.	

A.2.3.2 (Abrasive) Wear on tapered roller bearing

Cause of failure
Contaminated lubricant causing wear of the bearing contacting surfaces, which is clearly illustrated on the roller end faces.

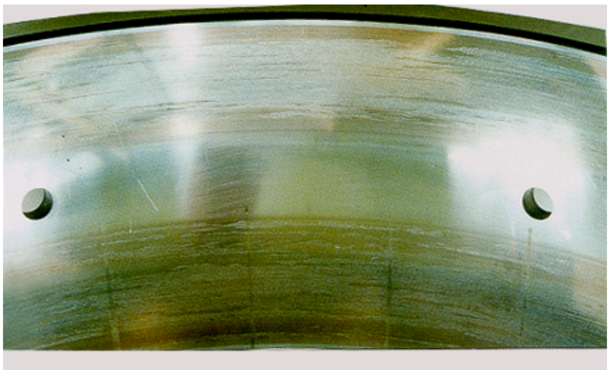
Countermeasure
Improve system cleanliness.



A.2.3.3 Smearing on raceways

Cause of failure
Incorrect design and operation. Smearing (skidding) between the rolling elements and raceways in a bearing subjected to very light load during rotation, or too high inertia of ball/roller set (high accelerations), or due to vibration (unloading). When smearing (skidding) occurs, the lubrication is inadequate or there is a shaft dynamics problem.

Countermeasure
Reconsider bearing selection (downsize). If tests without external loads are carried out, follow running-in procedures. Select suitable lubricant (viscosity, composition, additives). Provide damping.



A.2.3.4 Rib wear, smearing on roller end faces and rib

Cause of failure
Axial overloading accompanied by inadequate lubrication; excessive deflection of the shaft; wrong positioning of the bearing; out-of-squareness of mating surfaces.

Countermeasure
Check all aspects of bearing application.

A.2.3.5 Burnishing of bearing outer ring raceway

Cause of failure
Incorrect lubricant or poor lubricant supply. The raceway often gets a mirror finish.

Countermeasure
Select a lubricant with a more suitable viscosity. Provide adequate lubrication. Check relubrication interval.

A.2.3.6 Severely worn raceways, ribs and rollers

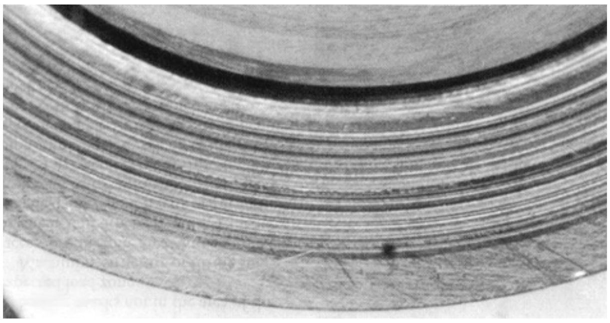
Cause of failure
Overloading and poor lubrication.

Countermeasure
Check load conditions and lubrication. Check suitability of bearing for the operating conditions.

A.2.3.7 Scratches/wear on bearing end face from rubbing against mating part

Cause of failure
Insufficient interference fit; loose mating part. The damage is circumferential scratches and wear of the contacting surfaces, caused by creeping of the inner ring. Bending of the shaft or vibration in connection with a loose mating part can, in a similar case, cause fretting corrosion type wear.

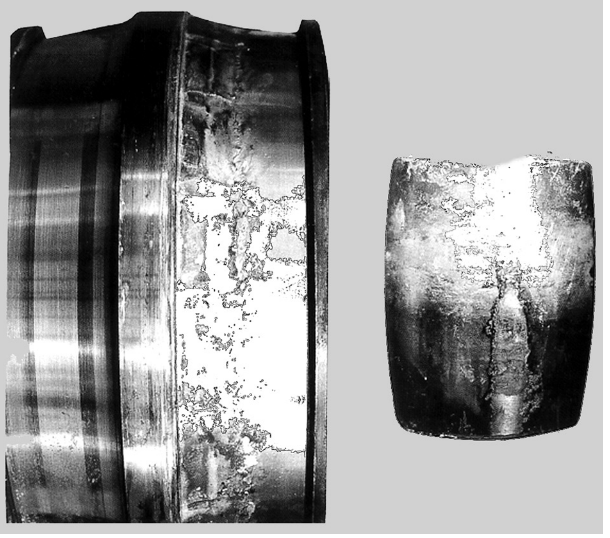
Countermeasure
Select suitable fit and use tighter clamping. Check the application conditions regarding loading and vibration.



A.2.3.8 Hot runner, running surfaces discoloured and melted

Cause of failure
Poor lubrication; operating clearance too small relative to load and speed; excessive overloading of the bearing. Resultant temperature rise causes reduction of the hardness of the surfaces. Wear particles from the cage are rolled into and become attached to the raceways. If the operation continues, there is a risk of a catastrophic failure.

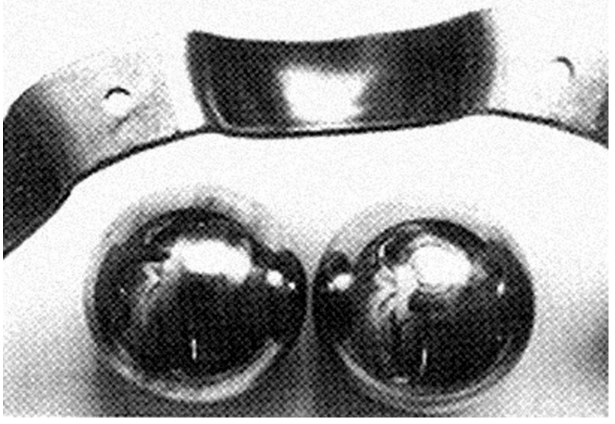
Countermeasure
Check suitability and quantity of the lubricant. Select appropriate radial internal clearance. Reconsider the bearing selection.



A.2.3.9 Wear on cage pockets and balls (polar lines)

Cause of failure
Excessive load; inadequate lubrication; undesirable preload. Polar lines can also be caused by hard particles embedded in the cage pocket.

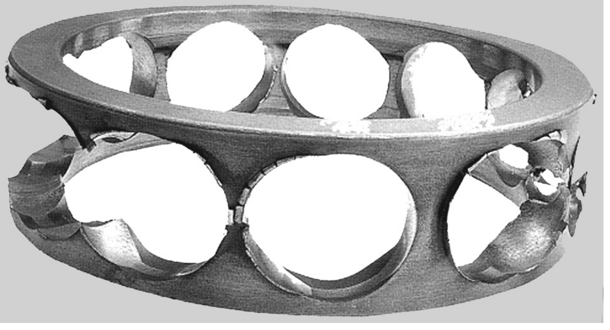
Countermeasure
Reconsider bearing selection (cage type) and radial internal clearance. Improve lubrication.



A.2.3.10 Worn cage pockets with seizing marks

Cause of failure
Constrained motion of rolling elements due to lack of clearance or misalignment; excessive vibration; inadequate lubrication; inappropriate bearing selection; badly carried out mounting.

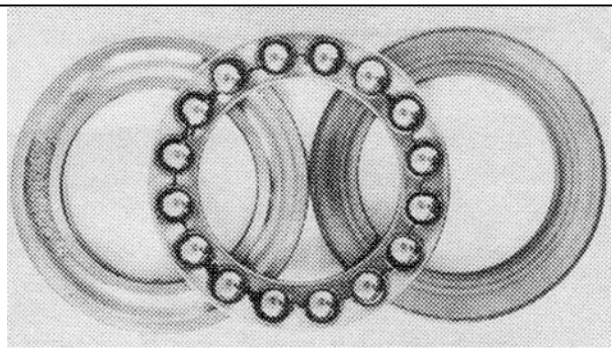
Countermeasure
Check load and mounting conditions. Select appropriate clearance and lubrication. Consider alternative bearing and cage.



A.2.3.11 Pocket wear and fracture on thrust ball bearing cage

Cause of failure
Centrifugal forces from balls too high, failure due to insufficient axial load for the high speed.

Countermeasure
Determine minimum required axial load and consider maximum speed specified by the manufacturer. Provide for (spring) preloading if suitable.



A.2.3.12 Axial scores on ring and roller raceways

Cause of failure
Scores (scratches) on ring and roller raceways caused by the cage and roller assembly misaligned and not being rotated during mounting.

Inadequate radial internal clearance can cause similar damage.

Countermeasure
Assure good alignment and, if possible, rotate slowly when entering the cage and roller assembly. Check radial internal clearance.

A.2.4 Corrosion

A.2.4.1 Corrosion, humid environment

Cause of failure
Deep seated rust on ring and raceway of cylindrical roller bearing, caused by moisture ingress or inadequate lubrication.

Countermeasure
Improve the sealing and use grease or oil with good rust-inhibiting property.

A.2.4.2 Corrosion, unused bearing

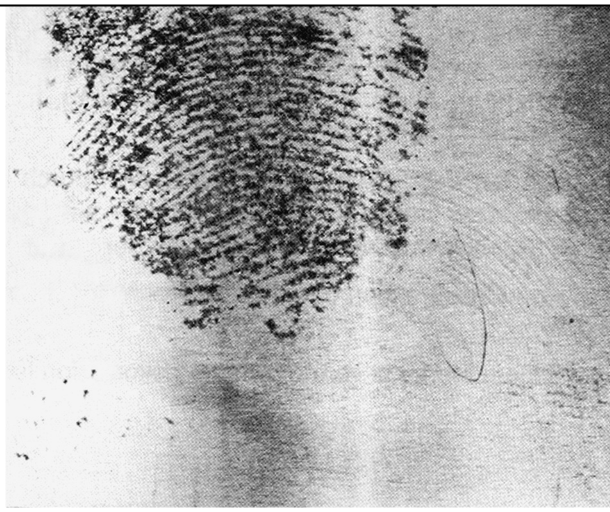
Cause of failure
Rust on new, unused bearing, caused by improper storage and handling or by insufficient preservation.

Countermeasure
Store bearings in dry places with constant temperature and low humidity. Only remove the bearing from its package just before installation.

A.2.4.3 Corrosion, hand perspiration (fingerprint)

Cause of failure
Faulty handling, bearing in the unpreserved condition was touched with perspiring hands.

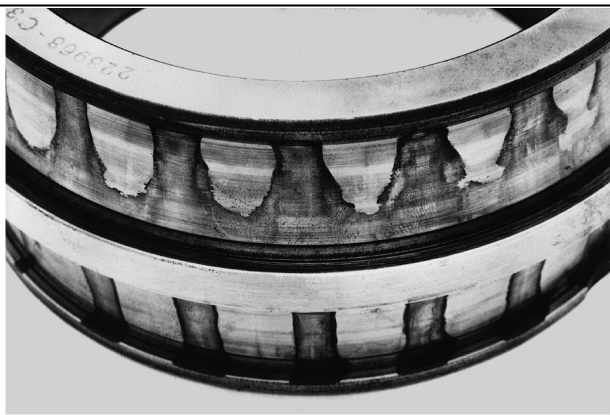
Countermeasure
Avoid touching bearings with moist/perspiring hands. Use gloves or a barrier cream.



A.2.4.4 Contact corrosion

Cause of failure
Corrosion marks on raceway at rolling element pitch due to presence of a corrosive liquid on stationary bearing during storage or service.

Countermeasure
Provide suitable preservation for storage. Check that the quality of the lubricant is adequate and the relubrication interval is correctly specified. Check seals.



A.2.4.5 Fretting corrosion on entire surface of inner ring bore

Cause of failure
Insufficient interference fit. Repeated sliding between inner ring and shaft causing fretting corrosion. In this case creeping of the inner ring has also occurred.

Countermeasure
Specify adequate fit with attention to load. Consider influence of surface roughness of shaft seating.

A.2.4.6 Circumferential crack in deep groove ball bearing outer ring with fretting corrosion on outside surface

Cause of failure
Cracks caused by fretting corrosion on outer ring outside surface. Oscillating loads and inadequate support of the outer ring contribute to this kind of failure.

Countermeasure
Provide adequate support of bearing ring. Check possible deformation of parts adjacent to the bearing.

A.2.4.7 Highly polished outside surface of outer ring over entire circumference, scratches and indications of fretting corrosion partly visible

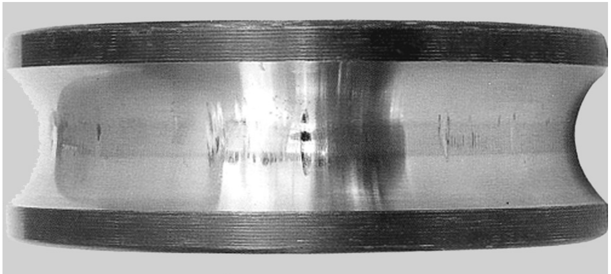
Cause of failure
Loose fit between outer ring and housing and a radial load that rotates in relation to the outer ring. Resulting creep of the outer ring in the housing had a polishing effect on the outside surface of the outer ring. Scratches and slight indication of fretting corrosion are visible.

Countermeasure
Choose correct fit taking load and operating conditions into consideration.

A.2.4.8 False brinelling

Cause of failure
Frequent shocks or vibrations, transferred from an outside source to a stationary bearing, leading to oscillating movements between raceways and rolling elements.

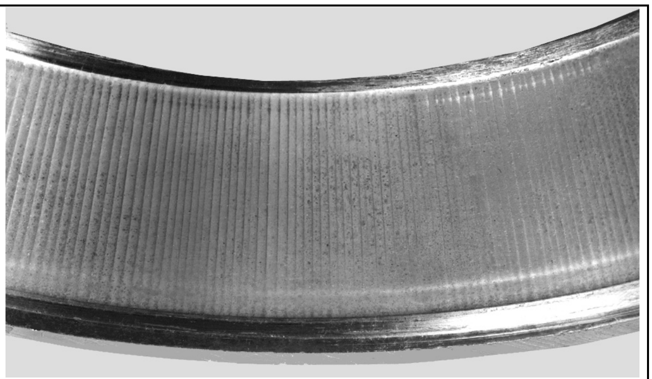
Countermeasure
Counter vibrations by taking adequate design and insulation measures. If possible, provide slow rotation of one ring relative to the other.



A.2.4.9 False brinelling (chatter marks)

Cause of failure
False brinelling caused by vibrations during rotation resulting in closely spaced flutes or chatter marks on the raceways.

Countermeasure
Counter vibrations by adequate design using dampers or, if appropriate, make the bearing less sensitive by preloading.

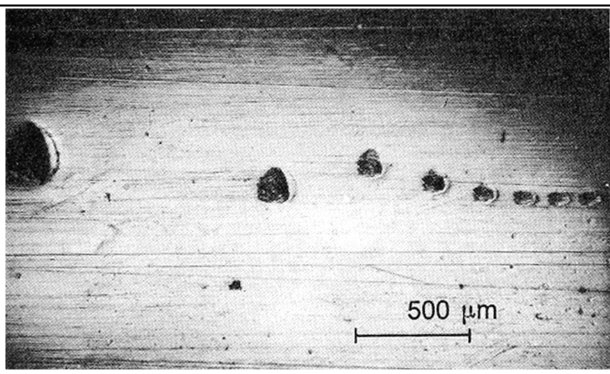


A.2.5 Electrical erosion

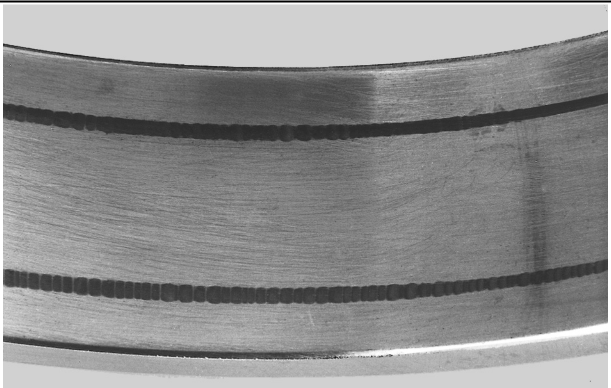
A.2.5.1 Electrical erosion, cratering

Cause of failure
Passage of an electric current causing craters on raceways and rolling elements.

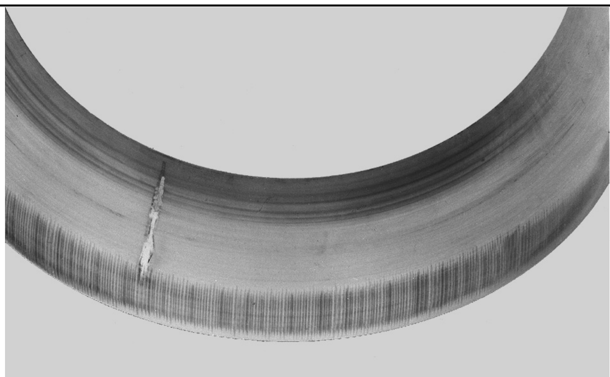
Countermeasure
Verify and apply correct electrical insulation of the machine or the bearing. Assure proper earthing of the machine during electric welding operations.



A.2.5.2 Electrical erosion (grooving)

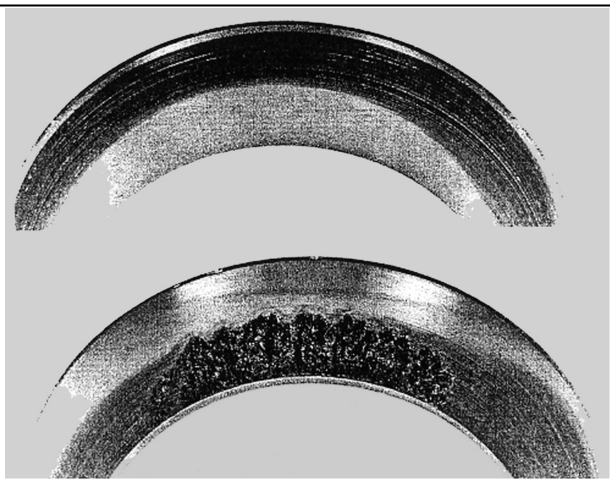
Cause of failure Grooves, formed around outer ring raceway of a rotating self-aligning ball bearing, caused by current leakage. The bottoms of the grooves have a dark appearance. The balls have a dark discolouration. **Countermeasure** Verify and apply correct electrical insulation of the bearing.	

A.2.5.3 Electrical erosion (fluting)

Cause of failure Fluting on raceway running path caused by constant passage of electric current of comparatively low intensity through rotating bearing. Dark discolouration of the bottoms of the fluting depressions. **Countermeasure** Check insulation. Provide for earthing. Use electrically insulated bearings.	

A.2.6 Plastic deformation

A.2.6.1 Overload

Cause of failure Excessive misalignment of a tapered roller bearing causing overloading and plastic deformation in part of the rolling element contact. This results in the flaking, shown as a cross contact pattern in the outer ring raceway. **Countermeasure** Check the application conditions regarding loading, alignment and shaft or housing deformation.	

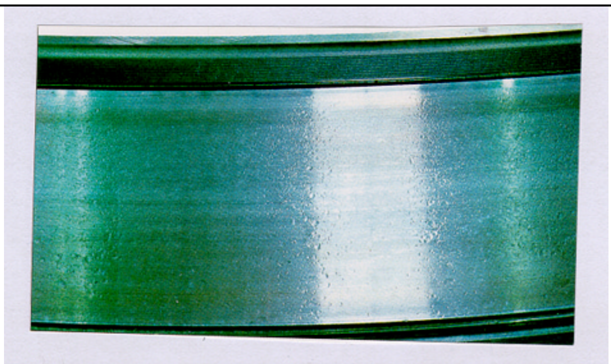
A.2.6.2 Plastic deformation, indentations on raceways spaced at rolling element pitch

Cause of failure Excessive loads during transportation, mounting or operation when the static load-carrying capacity is exceeded while the bearing is stationary, causing plastic deformation of the raceway with indentations spaced at the rolling element pitch. **Countermeasure** Use protection devices during transportation. Use suitable mounting procedures. Ensure proper handling of all machinery that incorporates rolling bearings.	

A.2.6.3 Plastic deformation, indentations corresponding to rolling element pitch

Cause of failure Shock loading while the bearing is stationary causing indentations in the raceway at rolling element pitch. Subsequent over-rolling leads to flaking at the indentations. **Countermeasure** Check loading conditions and, if needed, select a more suitable bearing.	

A.2.6.4 Indentation from debris on the raceway caused by minute particles

Cause of failure Contamination during mounting or operation; inadequate sealing. **Countermeasure** Observe utmost cleanliness during mounting and service. Clean lubricating devices, e.g. grease nipples. Improve sealing.	

A.2.7 Fracture

A.2.7.1 Localized forced fracture

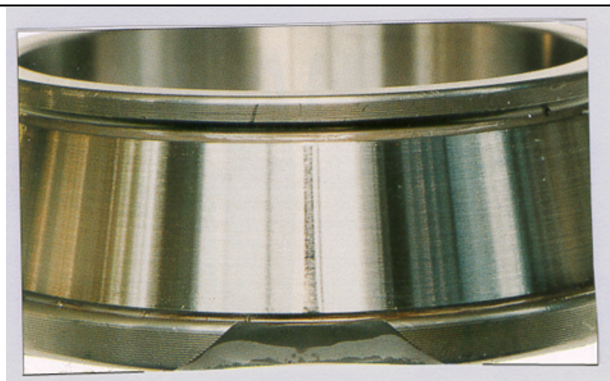
Cause of failure
Faulty mounting. Tool blows applied against hardened rolling bearing part causing metal removal.

Countermeasure
Apply suitable mounting tools and procedures.

A.2.7.2 Fractured ribs

Cause of failure
Faulty mounting. Tool blows applied against hardened rolling bearing part.

Countermeasure
Apply suitable mounting tools and procedures.

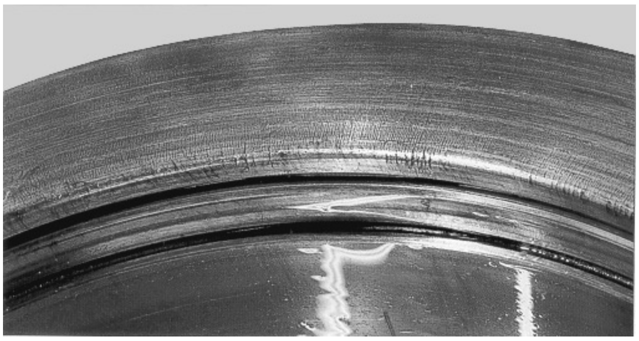


A.2.7.3 Fatigue fracture of inner ring

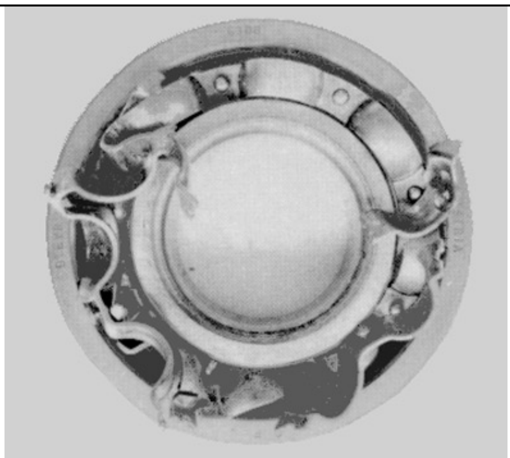
Cause of failure
Shaft fit too tight, and tensile stress from the tight fit contributing to the fatigue crack; adjacent parts not made to specified dimensions. The crack started from fatigue crack below the raceway surface.

Countermeasure
Check dimensions of adjacent parts. Review mounting procedure. Select looser fit, if permissible. If tight fit is required, review suitability of ring material and select a more suitable material if necessary.

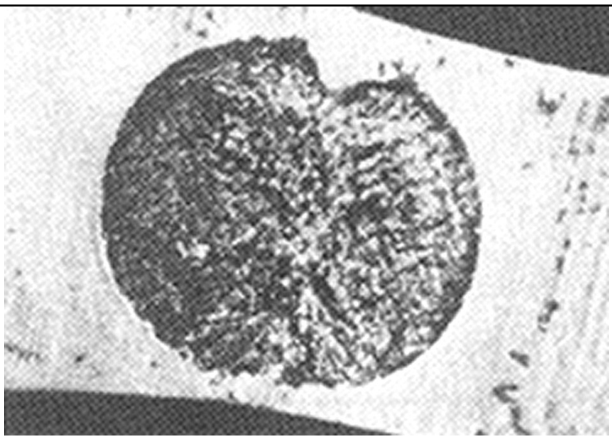
A.2.7.4 Thermal cracking

Cause of failure Sliding between end face of ring and adjacent part resulting in high frictional heating and heating cracks. **Countermeasure** Select a bearing execution that is adapted to the application conditions. Review means of locating bearing, e.g. by suitable fit or axial clamping.	

A.2.7.5 Cage fracture, rivets and bars cracked, broken and deformed

Cause of failure Excessive forces acting on the cage due to insufficient lubrication and jamming balls or high rotational acceleration or misaligned bearing. **Countermeasure** Provide suitable lubrication. Avoid excessive forces acting on cage. Select more suitable type of cage and/or bearing.	

A.2.7.6 Fracture of machined brass cage rivet

Cause of failure Fatigue fracture caused by vibration. **Countermeasure** Reduce vibration or select a more suitable cage design and/or material, e.g. one-piece cage.	

A.3 Terms and definitions

In order to provide a better understanding of the terms used in this document, the following definitions apply.

A.3.1
burnishing
smoothing action, which alters the original manufactured surface of a rolling bearing component to a more polished appearance

A.3.2
chattering
severe high frequency circumferential waviness on raceways

A.3.3
cleavage flaking
see **frosting**

A.3.4
corrosion
chemical reaction on metal surfaces

See 5.3.1.

A.3.5
crack
break within the bulk of the material without complete separation

A.3.6
cratering
formation of craters due to an electric current passing between the contacting surfaces

See 5.4.

A.3.7
creep
rolling motion of a bearing ring against its seating, which occurs when the bearing ring is mounted with a loose fit and the load rotates relative to the bearing ring

NOTE The over-rolling during creep leads to a minute 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.3.8
damage
any change to a component, subsequent to its manufacture or assembly by the manufacturer, which causes an impairment of its functioning

A.3.9
defect
material or product fault introduced by either manufacture or assembly of the bearing component parts by the manufacturer

A.3.10
discolouration
change of appearance caused either by heat or by a chemical reaction

A.3.11
electrical erosion
removal of material caused by the passage of an electric current

See 5.4.

A.3.12
eroding
removal of material by electrical erosion

See **electrical erosion**.

A.3.13
failure
defect or damage that prevents the bearing meeting the intended design performance

NOTE Changes in appearance of the surfaces of the bearing occurring during service do not necessarily imply failure of the bearing.

A.3.14
fatigue
change in the structure caused by the repeated stresses developed in the contacts between the rolling elements and the raceways

See 5.1.1.

A.3.15
flaking
loss of surface material due to subsurface initiated fatigue

See 5.1.2.

A.3.16
fluting
formation of close equally spaced grooves

See 5.3.3.3 and 5.4.3.

A.3.17
fracture
propagation of a crack to complete separation

See 5.6.1.

A.3.18
fretting
fretting corrosion
oxidation and discolouration due to micromovements between components

See 5.3.3.2.

A.3.19
frosting
specific form of adhesive wear, fine slivers of metal being 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.3.20
galling
type of adhesive wear

See 5.2.3.

A.3.21
glazing

See **burnishing**.

A.3.22
grey staining

See **microspalling**.

A.3.23
jamming
obstruction between bearing components which inhibits normal motion

A.3.24
microspalling
shallow spalling of asperity contacts

A.3.25
peeling
severe stage of flaking/spalling

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

A.3.26
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.3.27
plastic deformation
permanent deformation occurring whenever the yield strength of the material is exceeded

See 5.5.1.

A.3.28
pressure polishing
natural microwear which improves the appearance of the surface (running-in)

A.3.29
scoring
severe scratching

See **scratching**.

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

A.3.30
scratching
formation of fine grooves, caused by sharp edges or asperities or hard particles embedded in one or distributed between two surfaces

A.3.31
scuffing
type of adhesive wear

See 5.2.3.

A.3.32
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

A.3.33
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

A.3.34
smearing
type of adhesive wear

See 5.2.3.

A.3.35
spalling
advanced stage of flaking

A.3.36
surface distress
surface initiated fatigue

See 5.1.3.

A.3.37
washboarding

See **fluting**.

A.3.38
wear
progressive removal of material resulting from the interaction of the asperities of two sliding or rolling/sliding contacting surfaces during service

See 5.2.1.

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