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.

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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.

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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	•			•	•			•	•	•					•					•		
	Excessive lubricant								•														
	Incorrect viscosity	•			•	•			•	•	•					•					•		
	Inadequate quality	•			•	•			•	•	•	•									•		
	Contamination	•	•	•						•	•	•							•				
Operating condition	Excessive speed	•			•	•			•	•	•					•		•					
	Excessive load	•			•				•	•	•				•			•	•		•		
	Frequently fluctuating loads	•		•	•	•				•	•					•							
	Vibration	•			•	•		•		•	•		•		•	•							
	Passage of electrical current						•			•	•			•									
Mounting	Faulty electrical insulation						•		•	•	•			•									
	Incorrect mounting					•				•	•				•	•	•	•	•	•			
	Incorrect heating	•																•			•		
	Misalignment	•				•				•	•							•					
	Undesirable preloading	•	•						•	•	•				•	•		•			•		
	Impact	•	•													•		•					
	Inadequate fixing	•	•		•					•	•				•		•	•			•		
	Uneven seating surface	•	•							•	•		•		•			•					
	Incorrect seating fit	•	•						•	•	•		•				•	•			•		
Design	Incorrect bearing selection				•	•			•				•		•	•	•						
	Unsuitable adjacent components				•	•			•				•		•	•	•						
Handling	Incorrect storage											•											
	Vibration during transportation					•		•					•						•	•			
Manufacture	Incorrect heat treatment	•							•	•	•											•	
	Incorrect grinding																						•
	Inadequate surface finish	•	•							•	•												
	Inaccurate application component	•	•						•	•	•				•		•						
Material	Structural defects									•	•				•								
	Combination of incompatible materials	•			•	•			•									•					

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A.1.2.2 Radial bearings

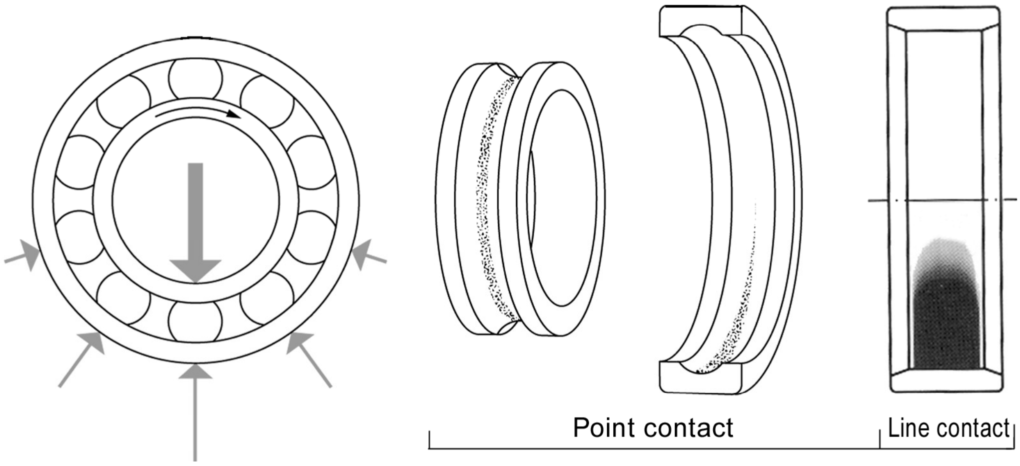

Figure A.1 — Uni-directional radial load — Rotating inner ring – Stationary outer ring

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.

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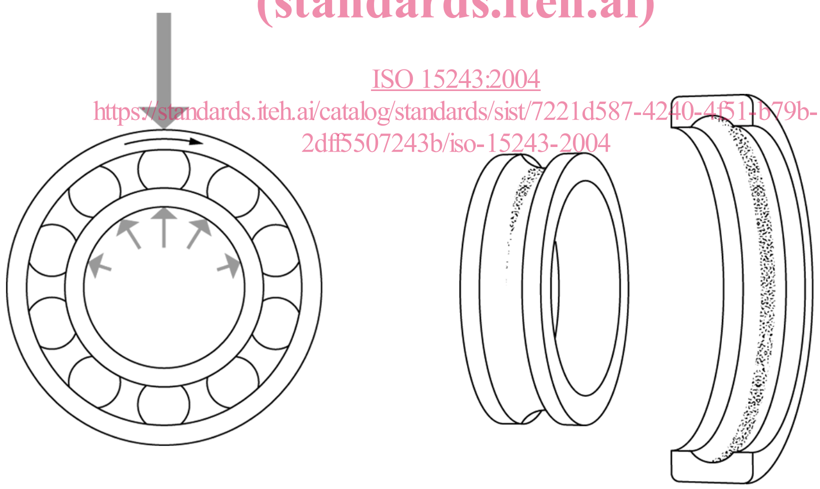

Figure A.2 — Uni-directional radial load — Stationary inner ring – Rotating outer ring

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.

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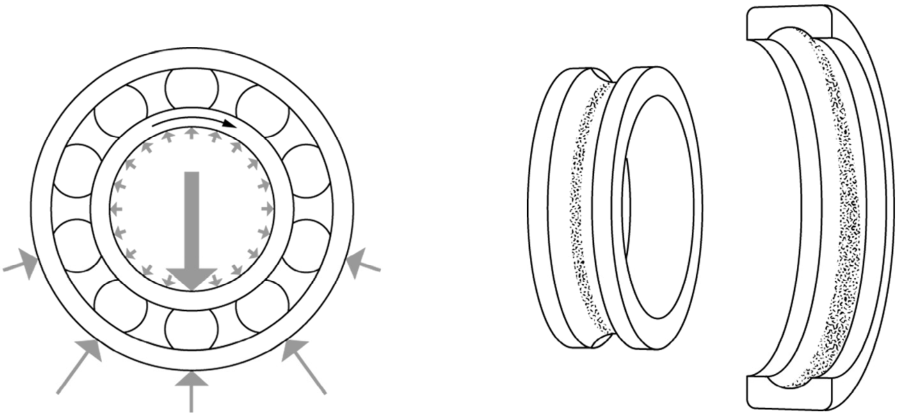

Figure A.3 — Radial preloading with uni-directional radial load — Rotating inner ring – Stationary outer ring

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.

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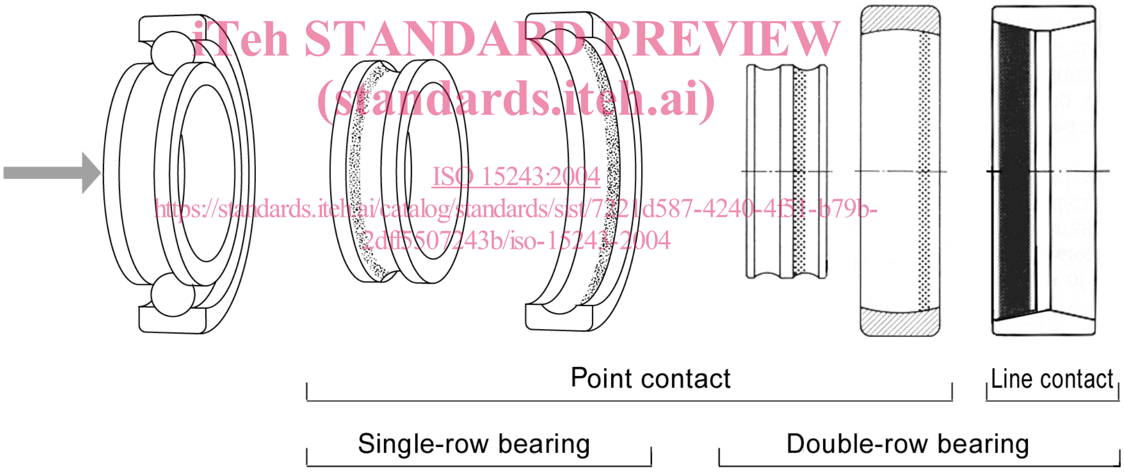

Figure A.4 — Uni-directional axial load — Rotating inner ring and/or outer ring

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

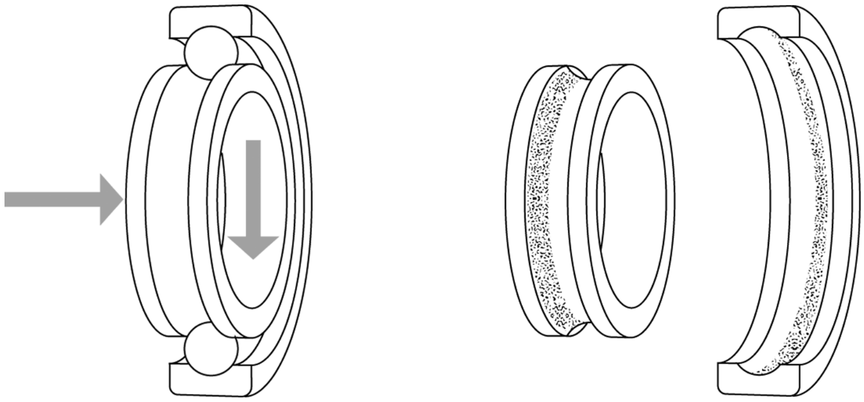

Figure A.5 — Combination of uni-directional radial and axial loads — Rotating inner ring – Stationary outer ring

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.

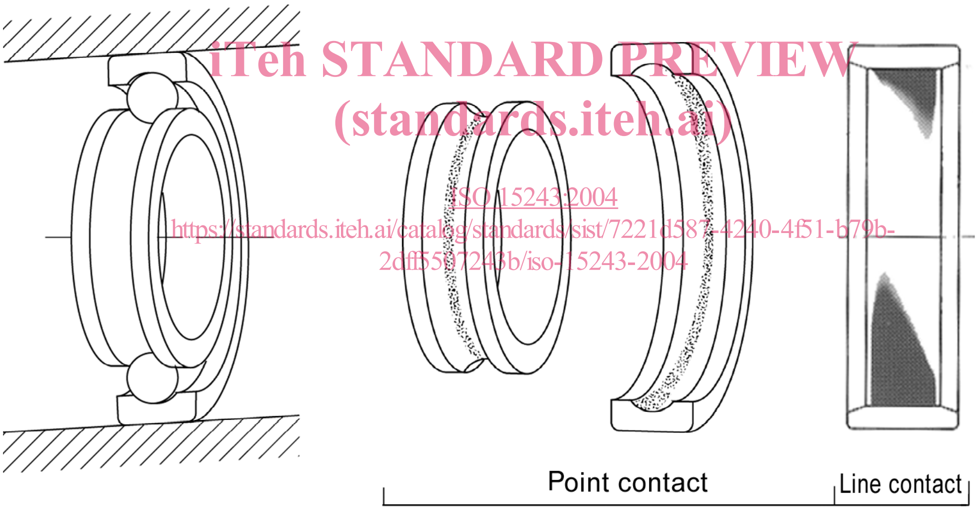

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Figure A.6 — Outer ring misaligned in housing — Rotating inner ring – Stationary outer ring

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.

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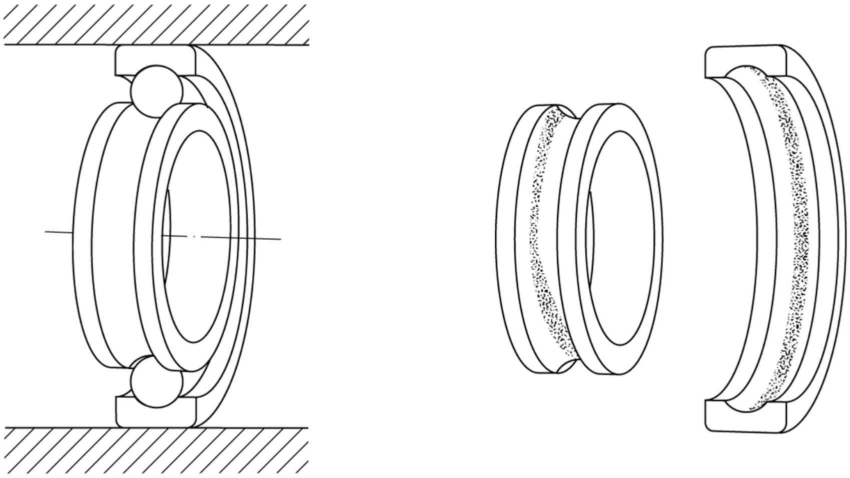

Figure A.7 — Inner ring misaligned on shaft — Rotating inner ring – Stationary outer ring

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.

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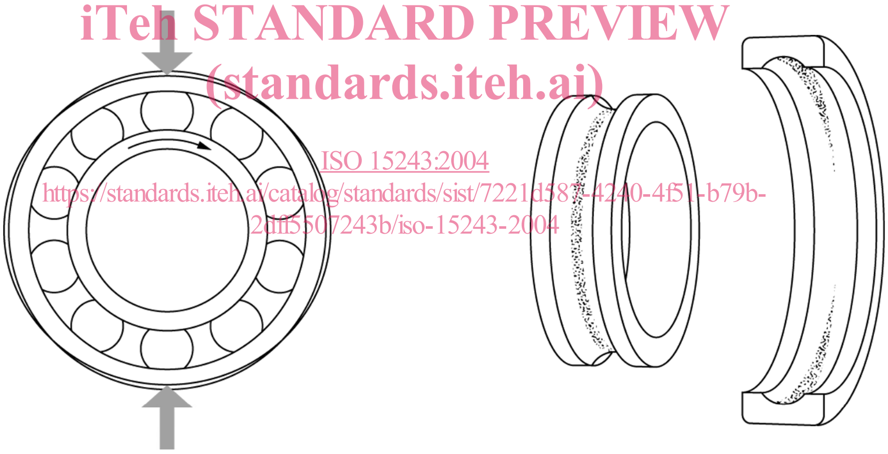

Figure A.8 — Oval compression of outer ring — Rotating inner ring – Stationary outer ring

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.

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A.1.2.3 Thrust bearings

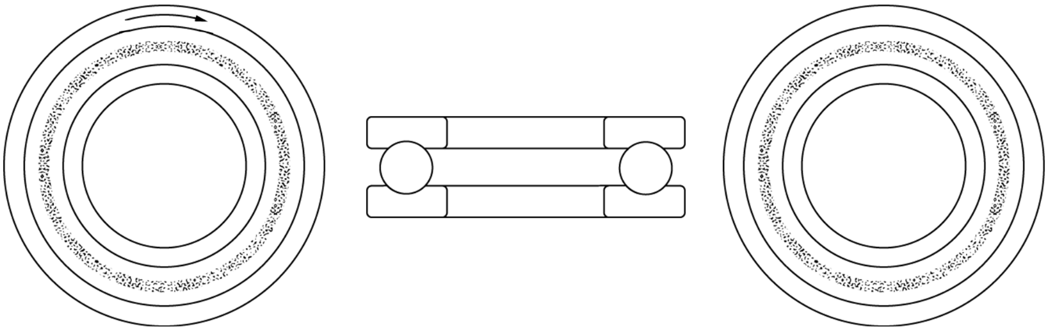

Figure A.9 — Uni-directional axial load — Rotating shaft washer – Stationary housing washer

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.

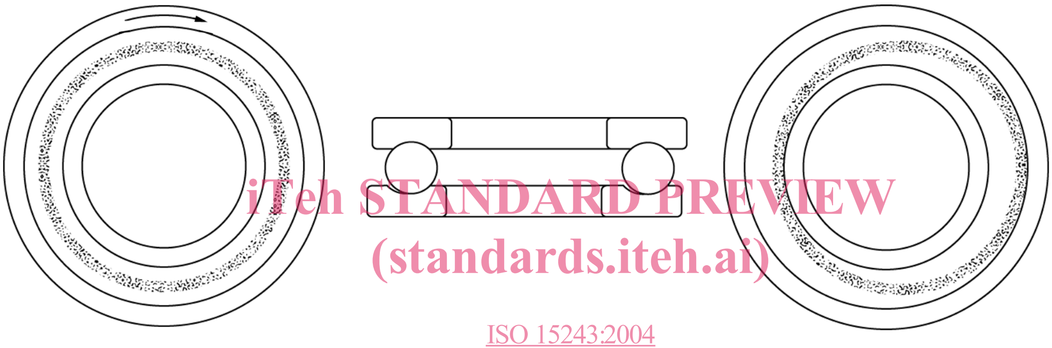

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Figure A.10 — Uni-directional axial load on eccentrically positioned housing washer relative to shaft washer — Rotating shaft washer – Stationary housing washer

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.

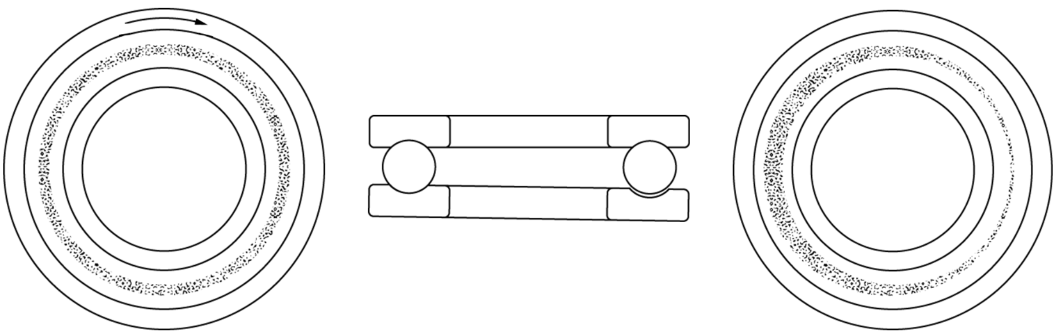

Figure A.11 — Misaligned housing washer — Rotating shaft washer – Stationary housing washer

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.

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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.

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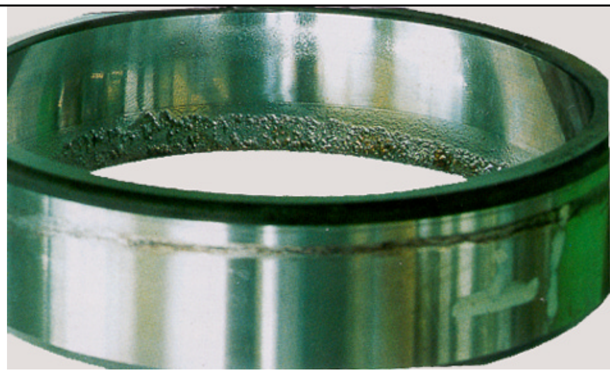
A.2.2.2 Flaking of only one raceway of spherical roller bearing

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.



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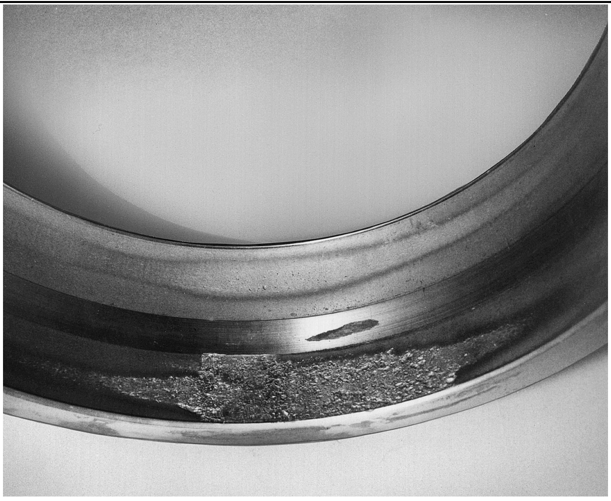
A.2.2.3 Raceway fatigue at two diametrically opposite locations

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.

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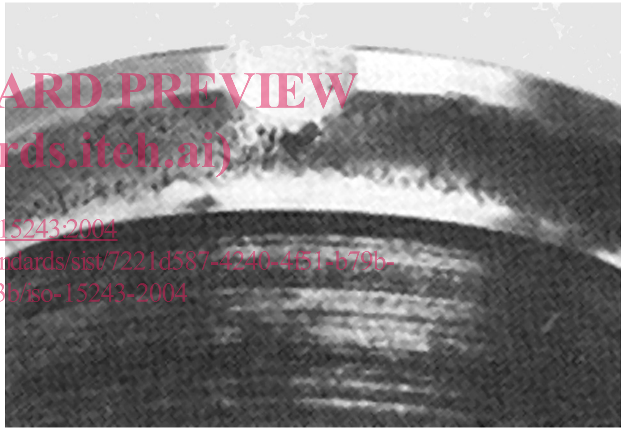
Countermeasure
In the case of double-row bearings with filling slots only on one row, consider the direction of the axial load during operation when mounting the bearing. In the case of alternating axial loads use a bearing without the filling slot or, at least, apply only light axial loads in the direction 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.

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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).

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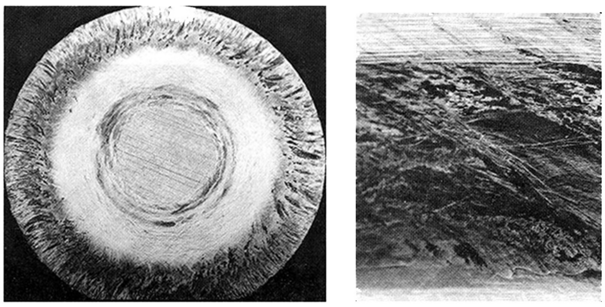
A.2.3 Wear

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.



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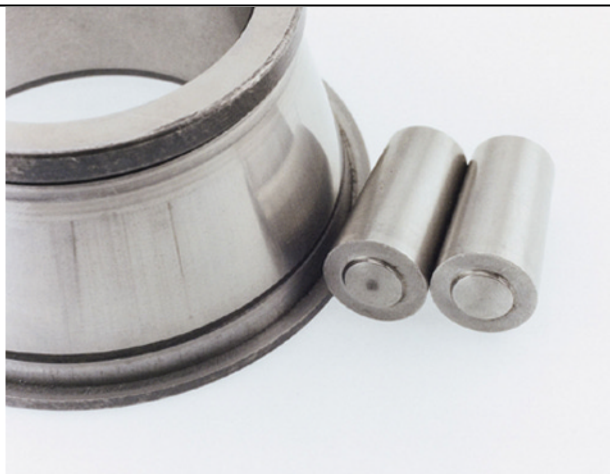
A.2.3.2 (Abrasive) Wear on tapered roller bearing

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.

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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.

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