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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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ISO copyright office
Ch. de Blandonnet 8 • CP 401
CH-1214 Vernier, Geneva, Switzerland
Tel. +41 22 749 01 11
Fax +41 22 749 09 47
copyright@iso.org
www.iso.org

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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).

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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.

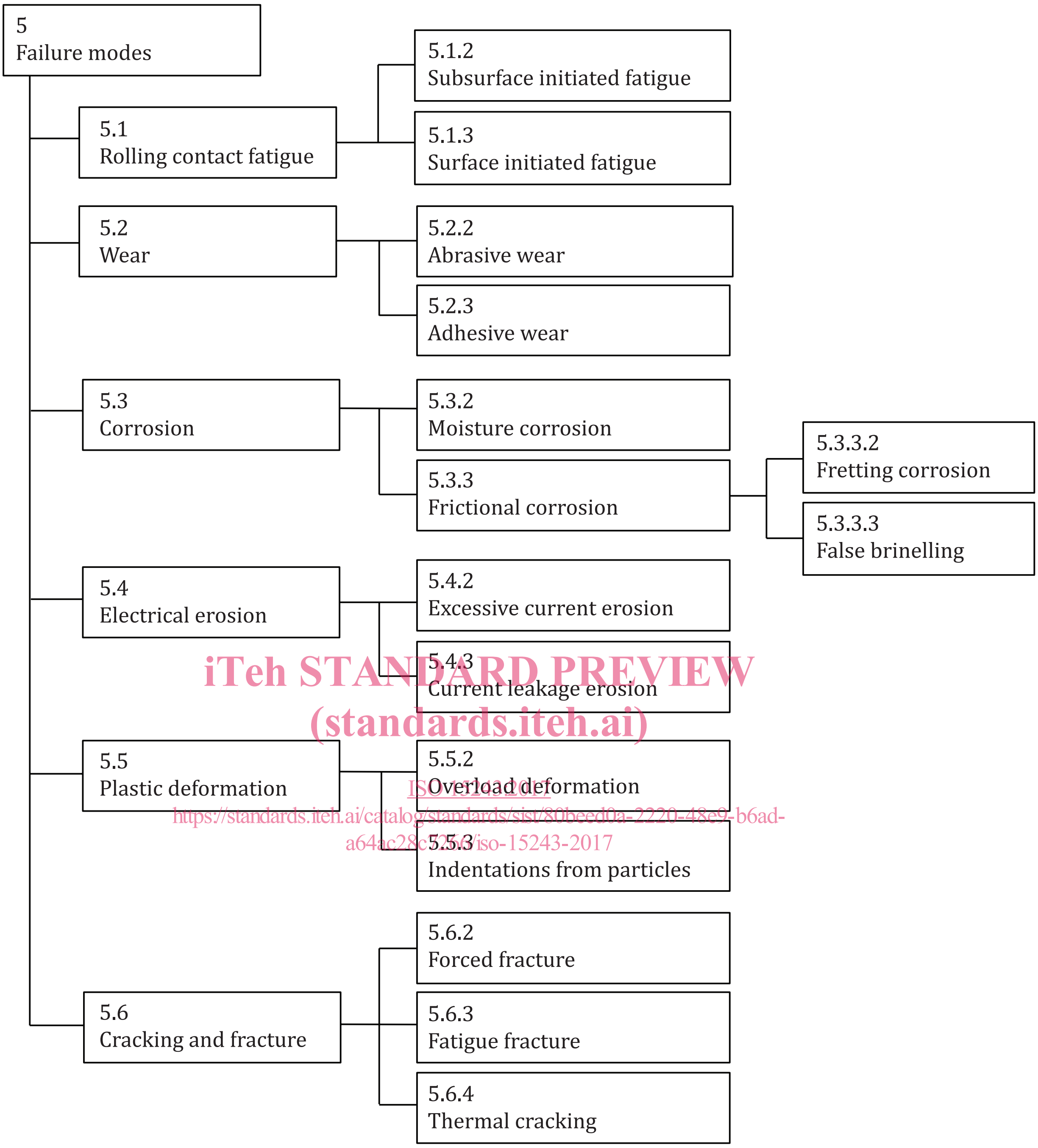

Figure 2 — Classification of failure modes

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).

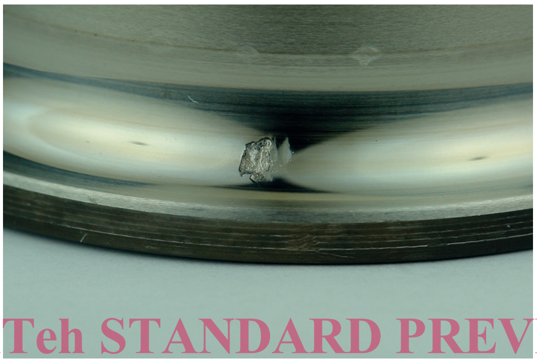

Figure 3 — Initial subsurface spalling in a deep groove ball bearing — Rotating inner ring

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.

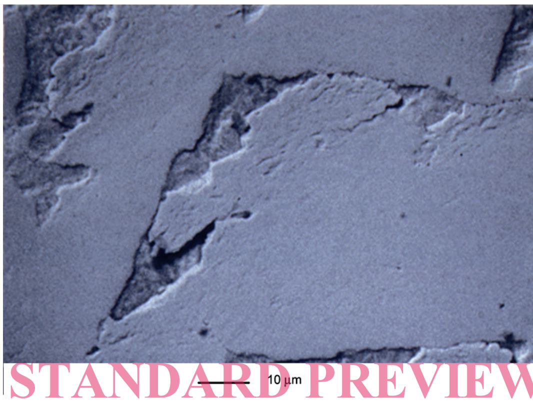

Figure 5 — Asperity microcracks and microspalls on a raceway

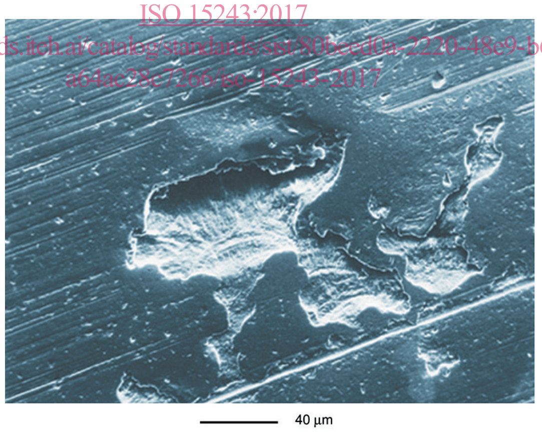

Figure 6 — Surface initiated microspalls on a raceway

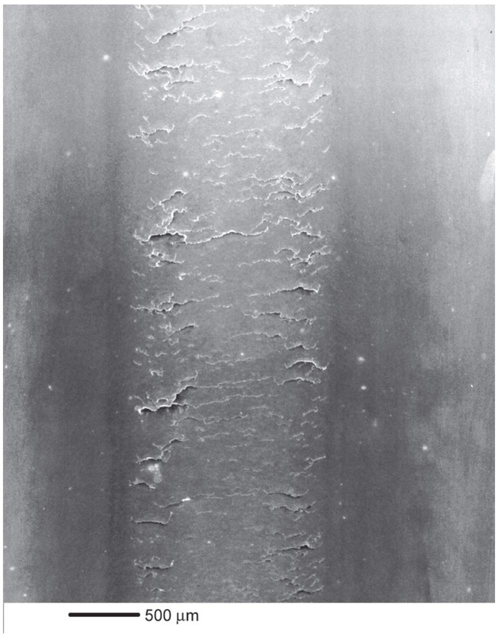

Figure 7 — Microspalled areas on a raceway

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

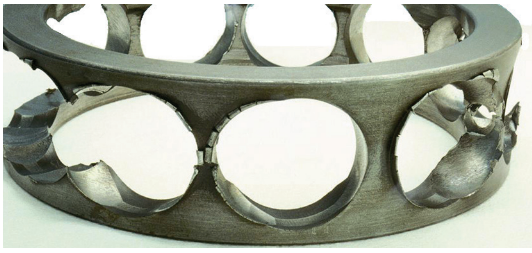

Figure 9 — Advanced abrasive wear on the cage pockets of a solid metal cage

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

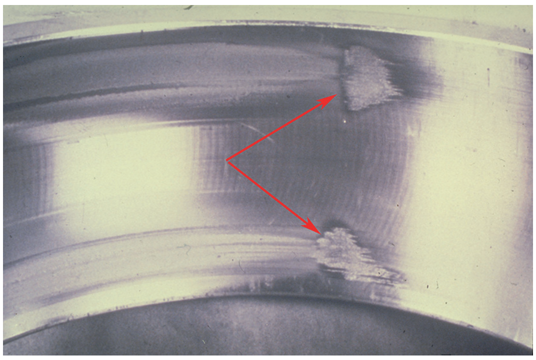

Figure 12 — Smearing on the outer ring raceways of a spherical roller bearing

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