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BRCE 2016
Bearing Reliability Conference & Expo

Workshop:

Bearing Root Cause Failure Analysis

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Why Failure Analysis?

Which is the very first question you must make when a bearing fails?

"How long has this bearing been working?"

Why this question?

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Why Failure Analysis?

First determine if the failure was <u>Premature</u> or <u>Natural</u>!

Natural failure is when the bearing has reached or surpassed its calculated life. If it did not, the failure was premature.

So, If it was natural,

***<u>congratulations</u>*!**

If the failure was *<u>premature</u>*, a Root Cause Failure Analysis is a must. Specially if the machine is critical for your process!**

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Why Failure Analysis?

How do you avoid bearing failures to happen again?

What is it that most affects the image of Maintenance?

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Simple (easy) Failure Analysis

It might sometimes be very easy to find the cause for bearing failures, but

Other times you have to perform as a real coroner detective to find the real cause!

Simple (easy) Failure Analysis

Sometimes just asking WHY 5 times may lead you to the failure cause, but

other times you have to perform a complete brainstorming and the corresponding investigations!

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Simple (easy) Failure Analysis

Always ask for the FAILURE MODE of the bearing!

Answers like "*Corrosion*", "*Abrasive wear*" or "*Metal-to-Metal Contact*" logically and immediately give you the failure causes!

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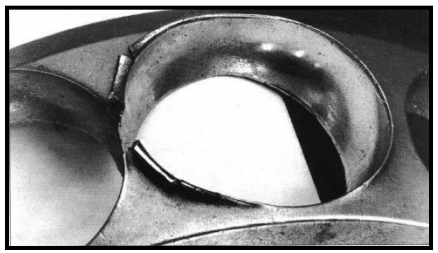
Bearing Failure Modes (General)

Machine Failure Modes

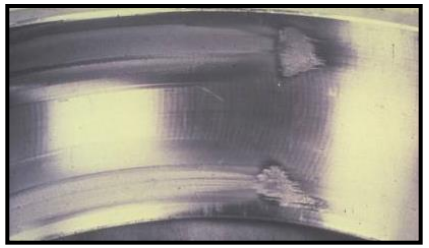
- **Obsolescence (15%)**
- **Surface degradation (70%)**
  - **Corrosion (20%)**

  - **Mechanical wear (50%)**
    - **Abrasion**



    - **Fatigue**

    - **Adhesion**



- **Accidents (15%)**

Ref. Dr. E Rabinowicz, MIT

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Simple (easy) Failure Analysis

Example:

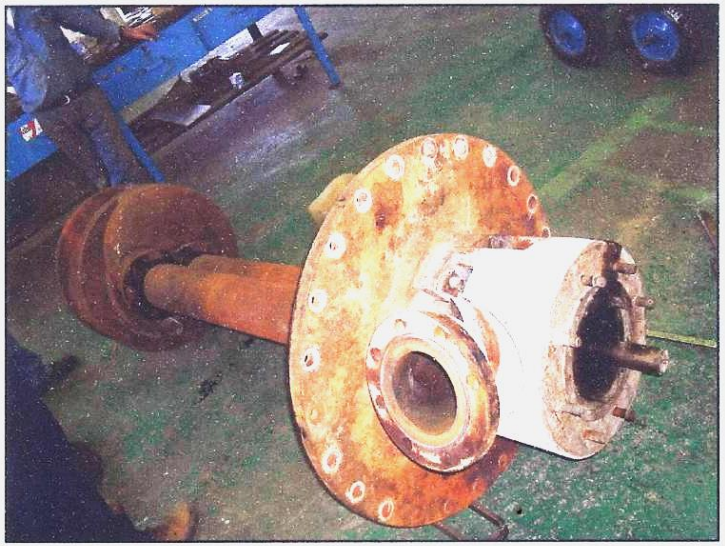
Vertical pump:

Bearings: 6215 + 51115

Lubricant: Grease ISO VG460 + "Moly".

Speed: 1500 RPM

You got 10 seconds!



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Simple (easy) Failure Analysis

Failure of a self aligning ball bearing

Look at the running path patterns in the raceway of the outer ring!

There is only one way you may get this pattern. Which???

Excessive drive up reduced the internal clearance until preload was reached!

Also look at the smearing on the outer diameter

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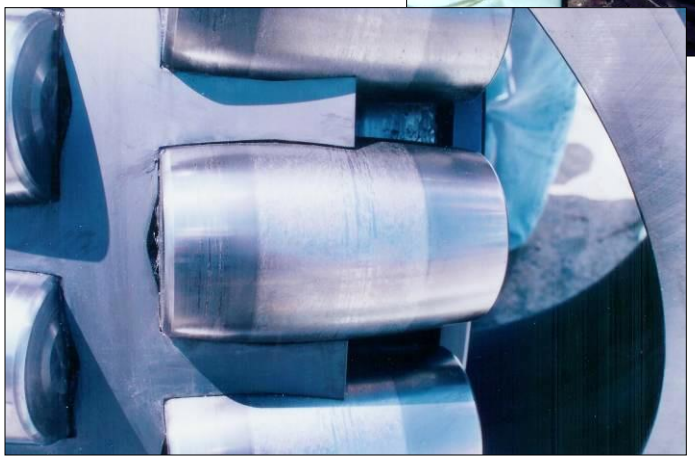
Simple (easy) Failure Analysis

Failure of a Large Spherical Roller Bearing after 4 days

Wrong grease!



Bearing cost = 32,000 USD.

Production loss = 3’200 000 USD.

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Simple (easy) Failure Analysis

Failure of Y-Units in Fin Fans

An automatic lubrication system was installed but lubricated these units as open bearings!

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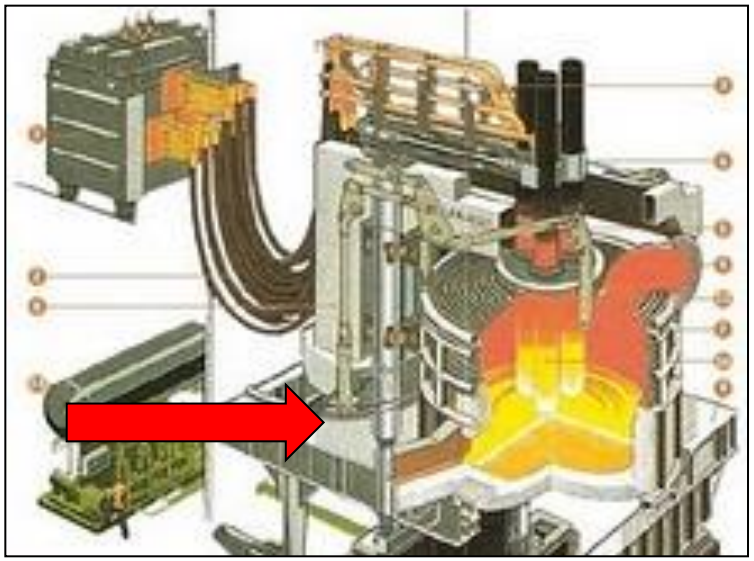
Simple (easy) Failure Analysis

Failure of a Slewing Ring Bearing after 1 year in an Electric Arc Furnace



Lubricated by an automatic system. The grease drained out is heavily degraded and after some time filled with fatigue particles, at the most one year.

The operating temperature did not surpass 45°C.

Why this failure???

Current leakage in the furnace!

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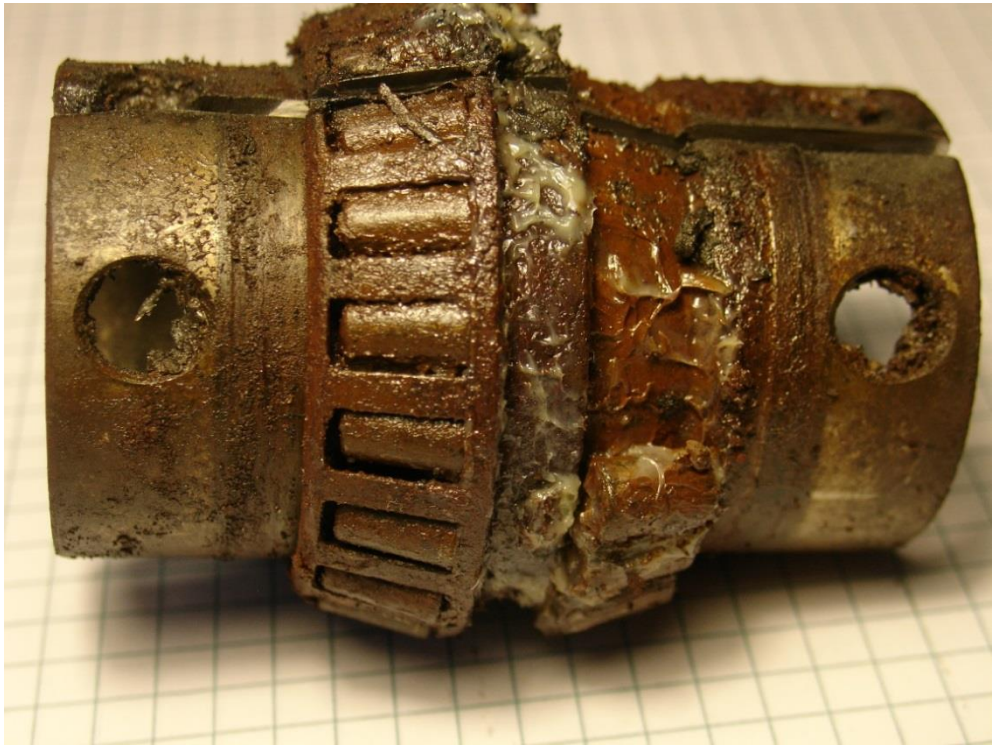
Simple (easy) Failure Analysis

Failure of a Bearing in a Potatoe Pealing Machine

Most advanced corrosion on the whole bearing.



Why this failure?

1. The anticorrosive properties of the grease were far from effective (1-1 with distilled water).

2. The bearing seals were inefficient.

ISO Standard 15243

ISO 15243 Rolling Bearings – Damages and Failures – Terms, Characteristics and Causes states:

"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".

ISO Standard 15243

The ISO 15243 also indicates:

"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 very best way to avoid the above is the Predictive Maintenance!

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Required Information for the Analysis

Bearing failure:

<u>Operation time</u>:

15 days

Why did this bearing fail???

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Required Information for the Analysis

Clues:

1. Enormous suction in front of the housing.
2. Labyrinth seals.

Conclusion:

The oil was suctioned out !

From 1 year to over 10 years!

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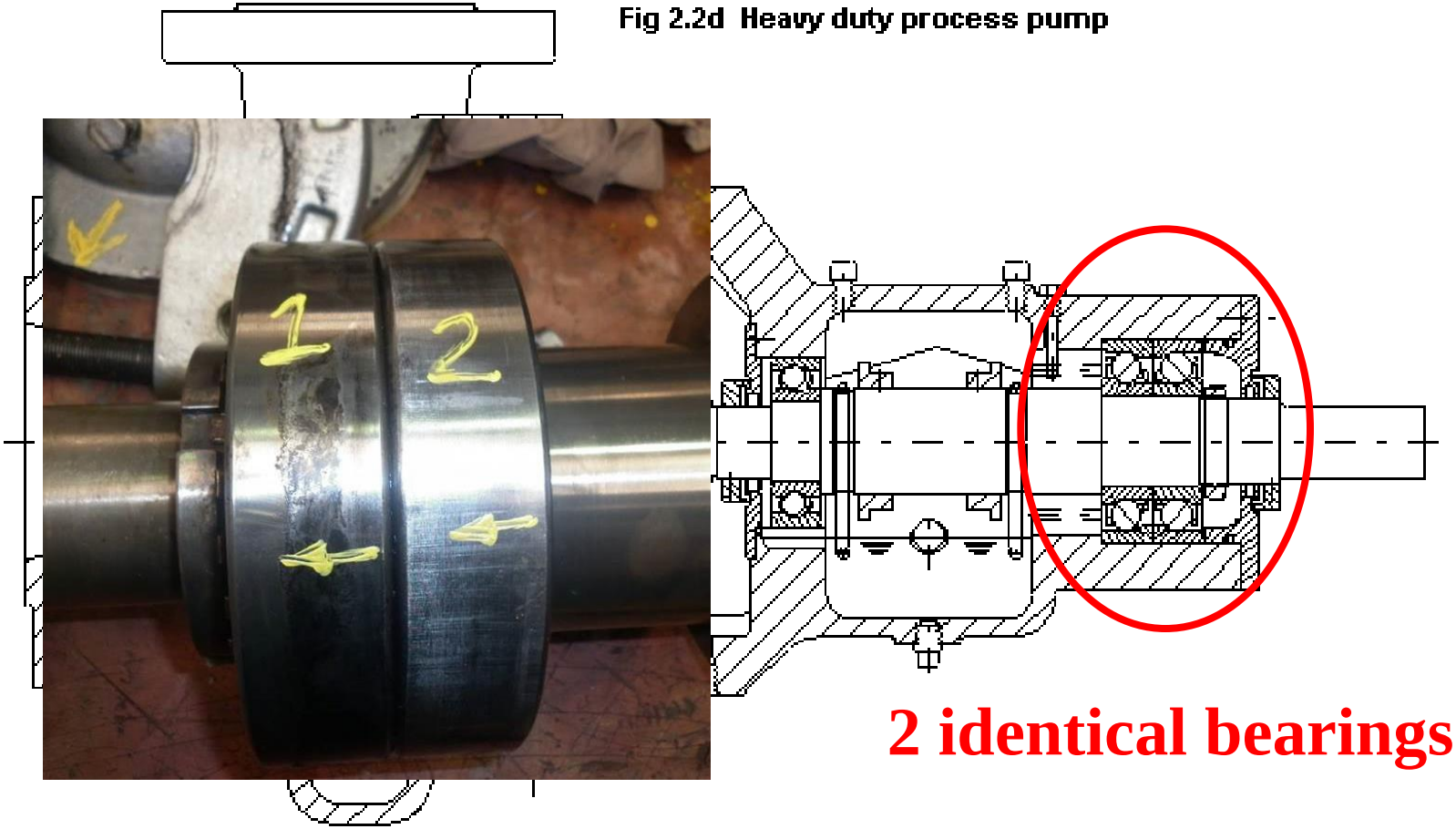
Required Information for the Analysis

Fig 2.2d Heavy duty process pump



2 identical bearings

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Required Information for the Analysis

Failure Mode + Operating conditions:

- Application.
- Bearings.
- Bearing arrangement.
- Speeds and loads.
- Environment.
- Lubrication.
- Bearing and machine history.

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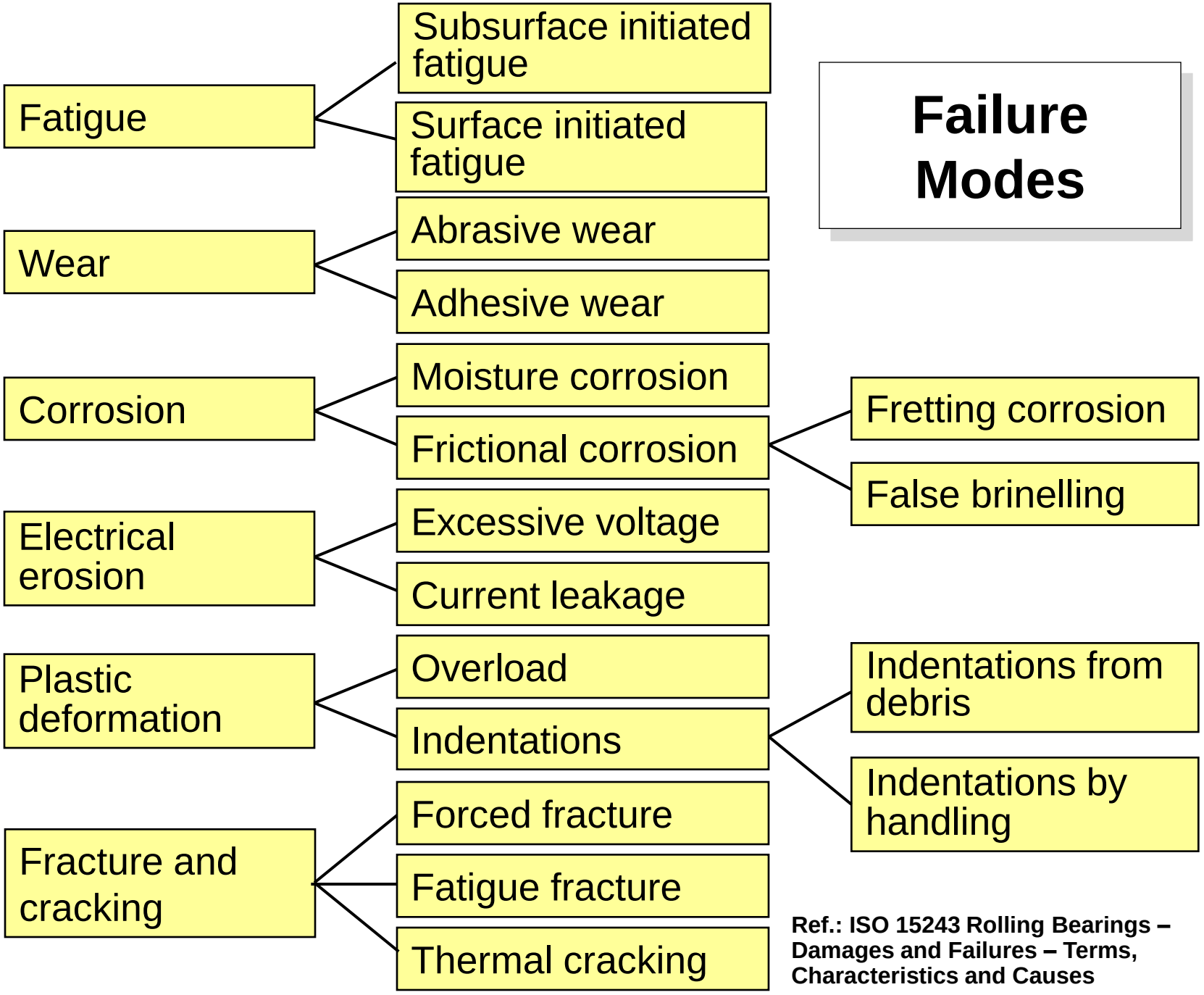
Failure Modes



Ref.: ISO 15243 Rolling Bearings – Damages and Failures – Terms, Characteristics and Causes

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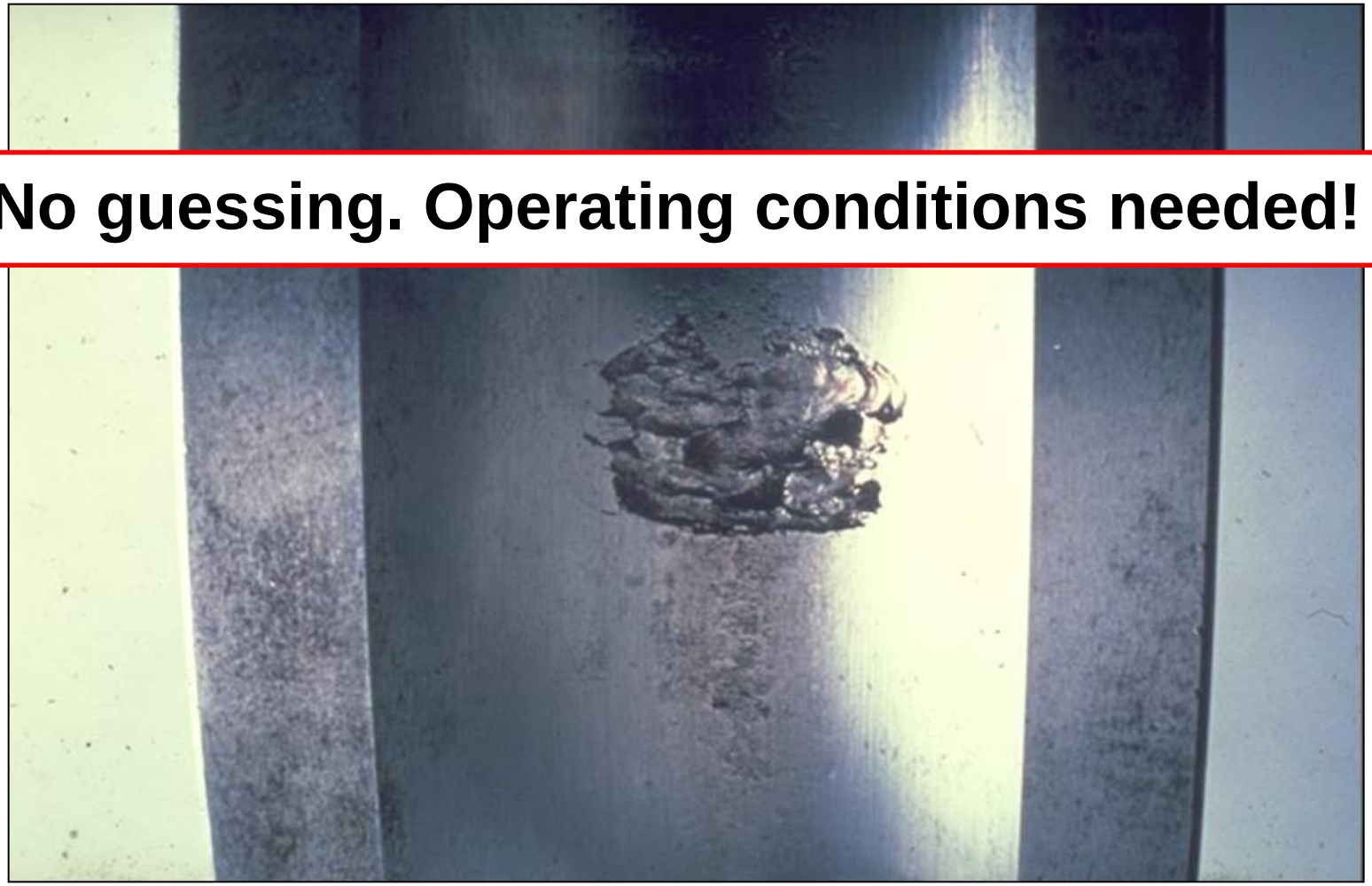
Fatigue on Inner Race



No guessing. Operating conditions needed!

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Fatigue on Inner Race

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No guessing. Operational conditions needed!

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Overloading by excessive drive up

Fatigue, obsolete Design

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Fatigue, Mounting Damage

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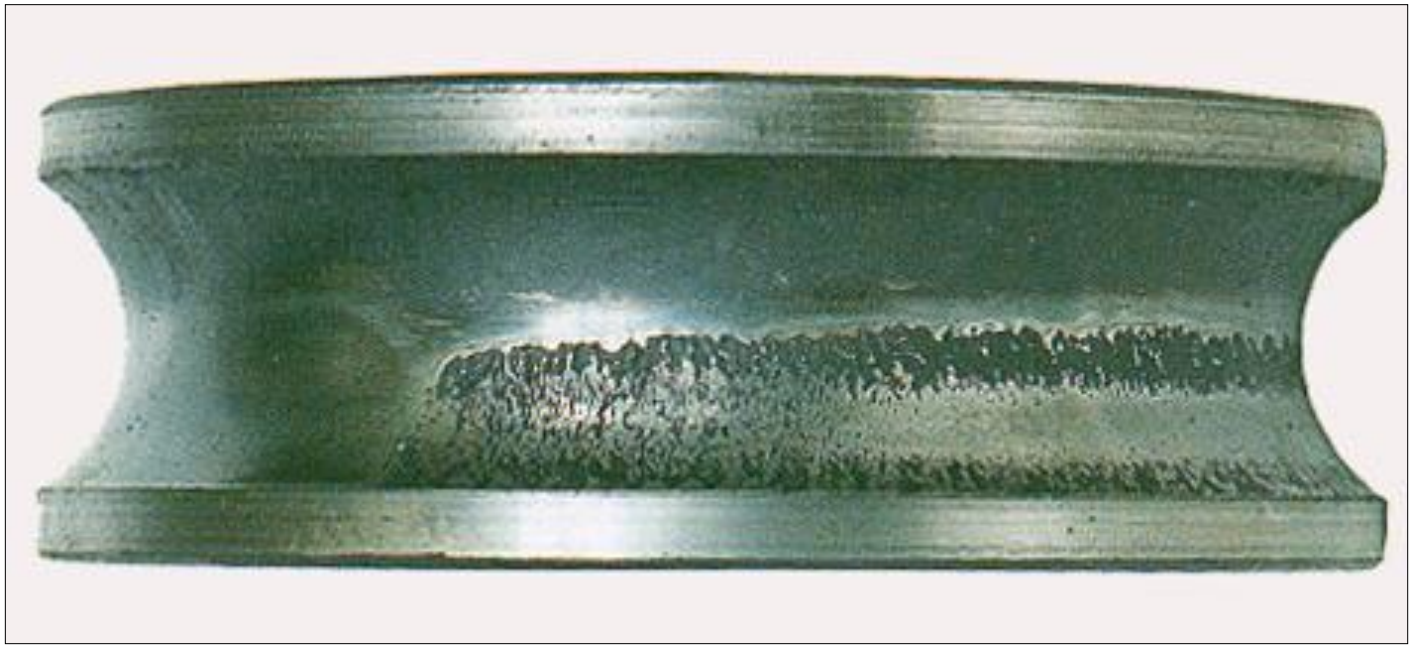
Fatigue, Misalignment



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Fatigue, Cavitation

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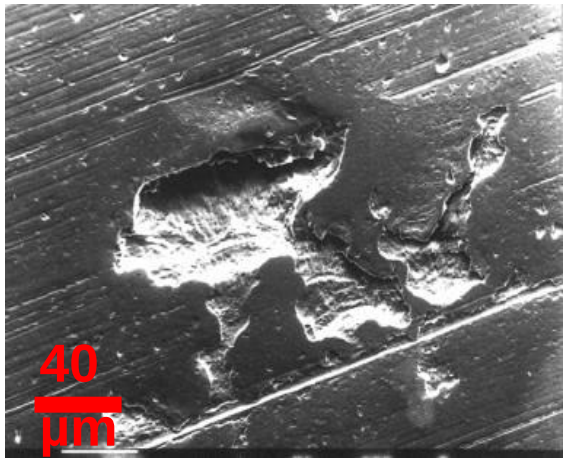
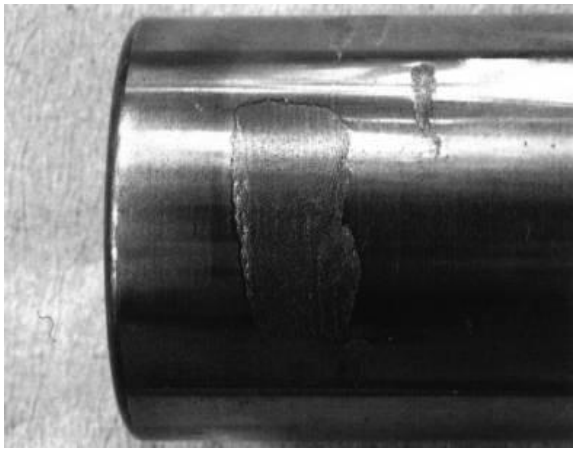
Surface initiated Fatigue

- Fatigue
  - Subsurface initiated fatigue
  - Surface initiated fatigue
- Wear
- Corrosion
- Electrical erosion
- Plastic deformation
- Fracture and cracking

– Surface distress.
– Reduced lubrication conditions.
– Sliding movements.
– Smearing.
– Micro-cracking.
– Micro-spalling.





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Insufficient Lubrication - Metal to Metal Contact

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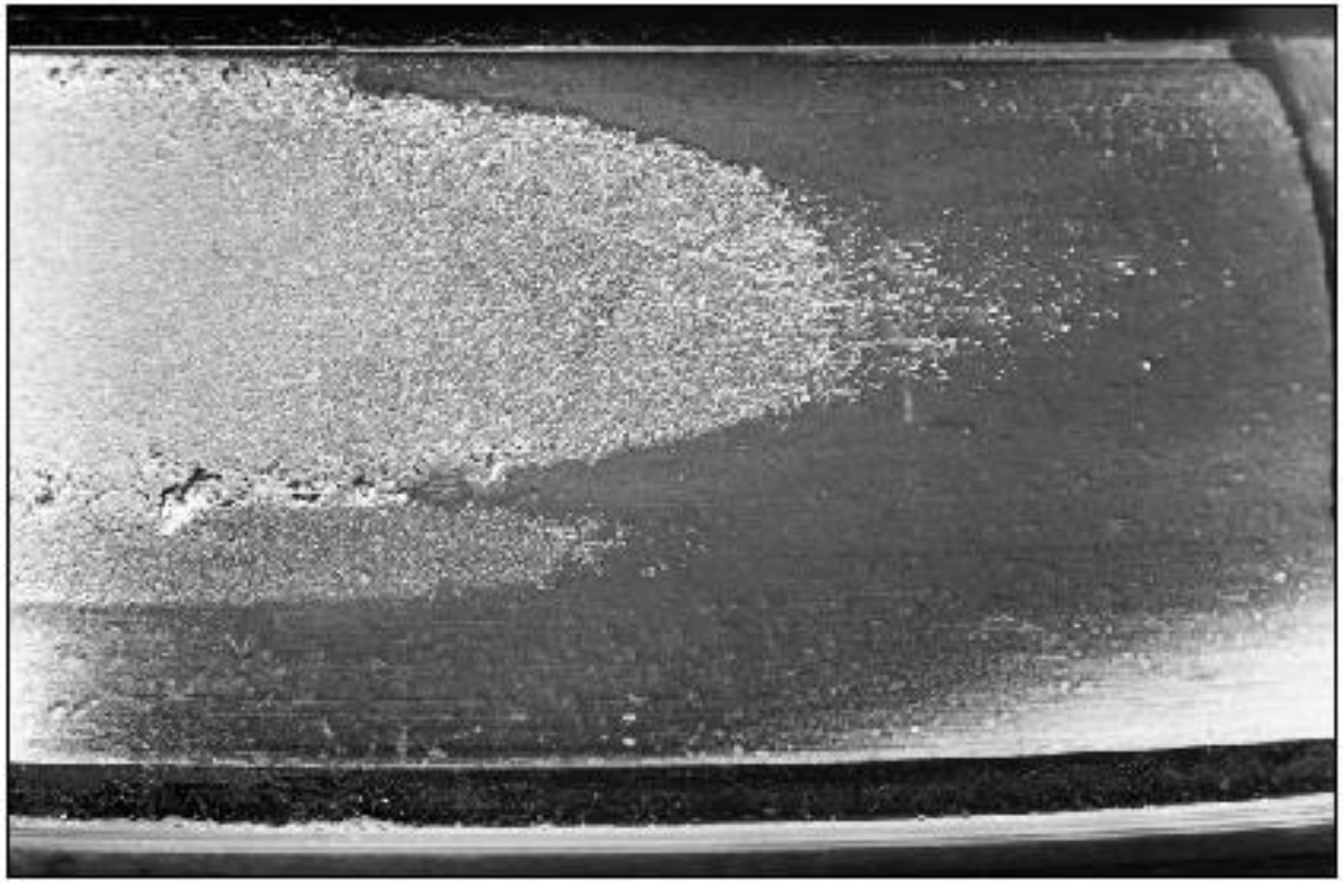
Insufficient Lubrication - Pitting



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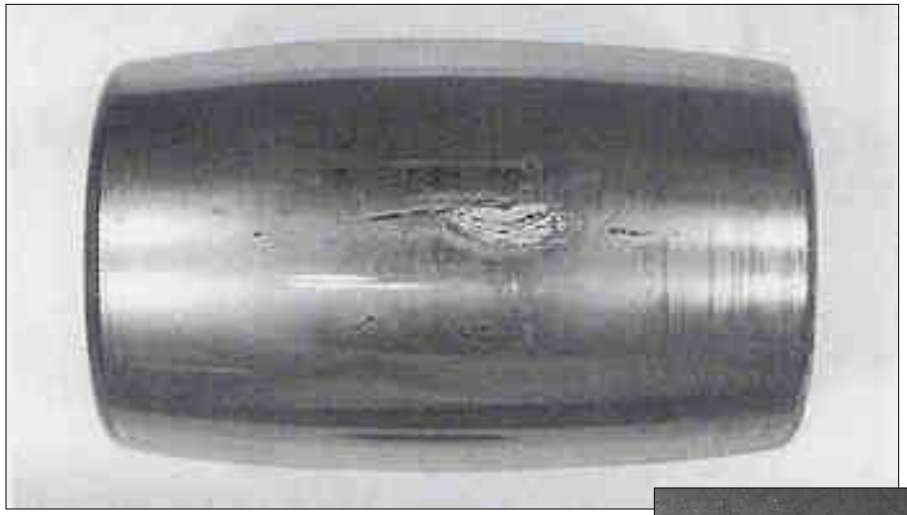
Fatigue initiated by Corrosion



Initiated by corrosion!

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Inadequate Lubrication

Both mirror type surface and pitting

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Inadequate Lubrication

Both mirror type surface and pitting

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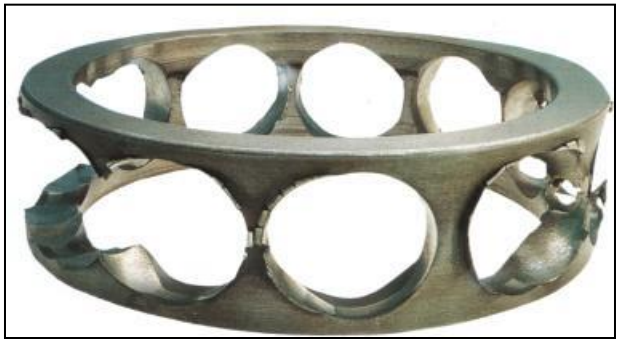
Abrasive wear

- Fatigue
- Wear
  - Abrasive wear
  - Adhesive wear
- Corrosion
- Electrical erosion
- Plastic deformation
- Fracture and cracking



- Entry of hard solid particles
- Progressive elimination of the material.
- Accelerated process.
- Incorrect lubrication.

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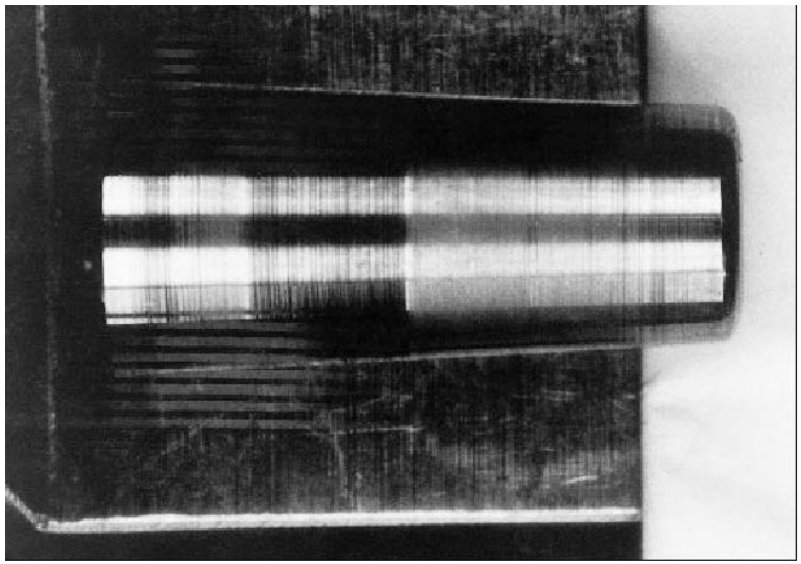
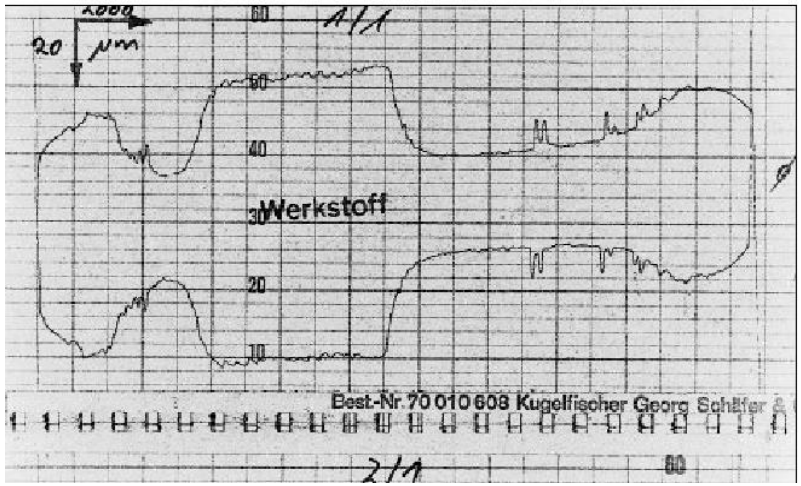
Abrasive wear





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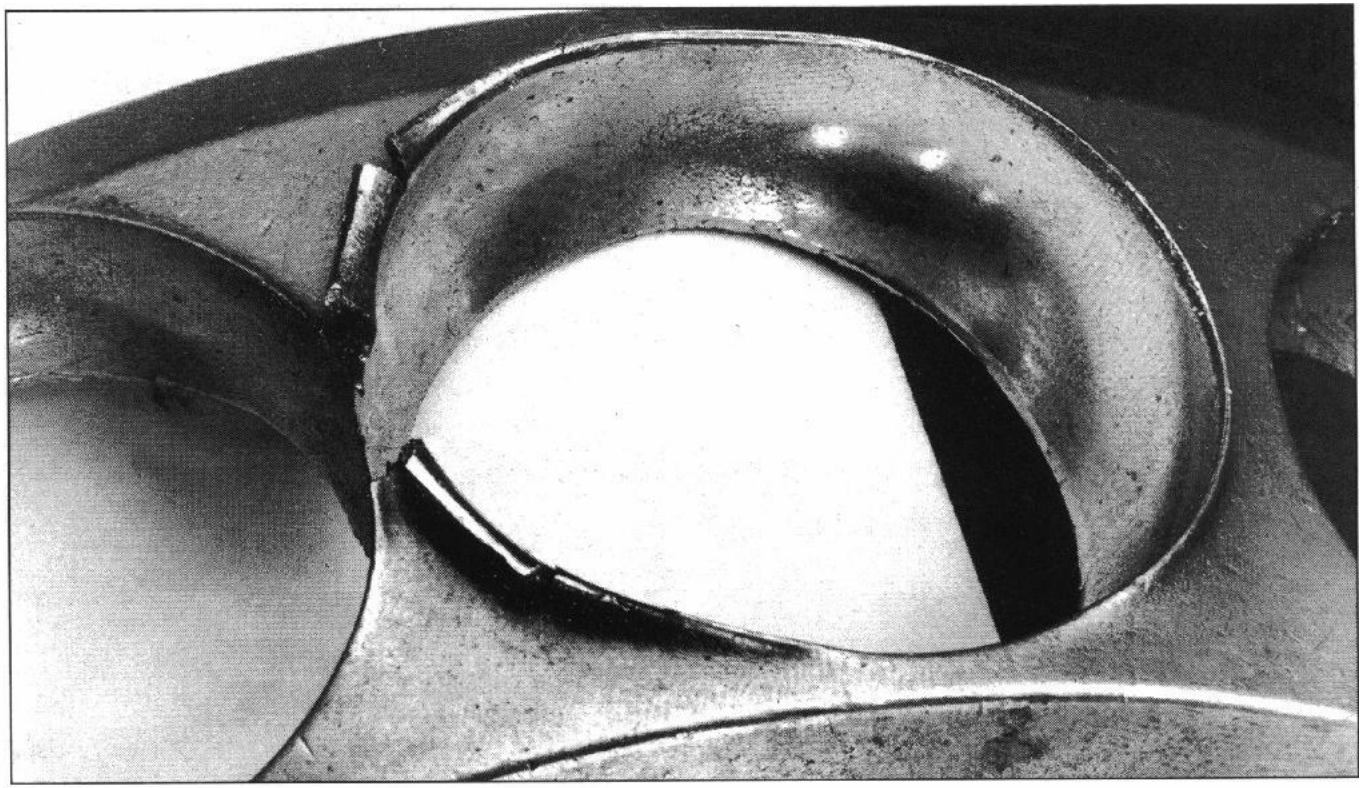
Abrasive wear



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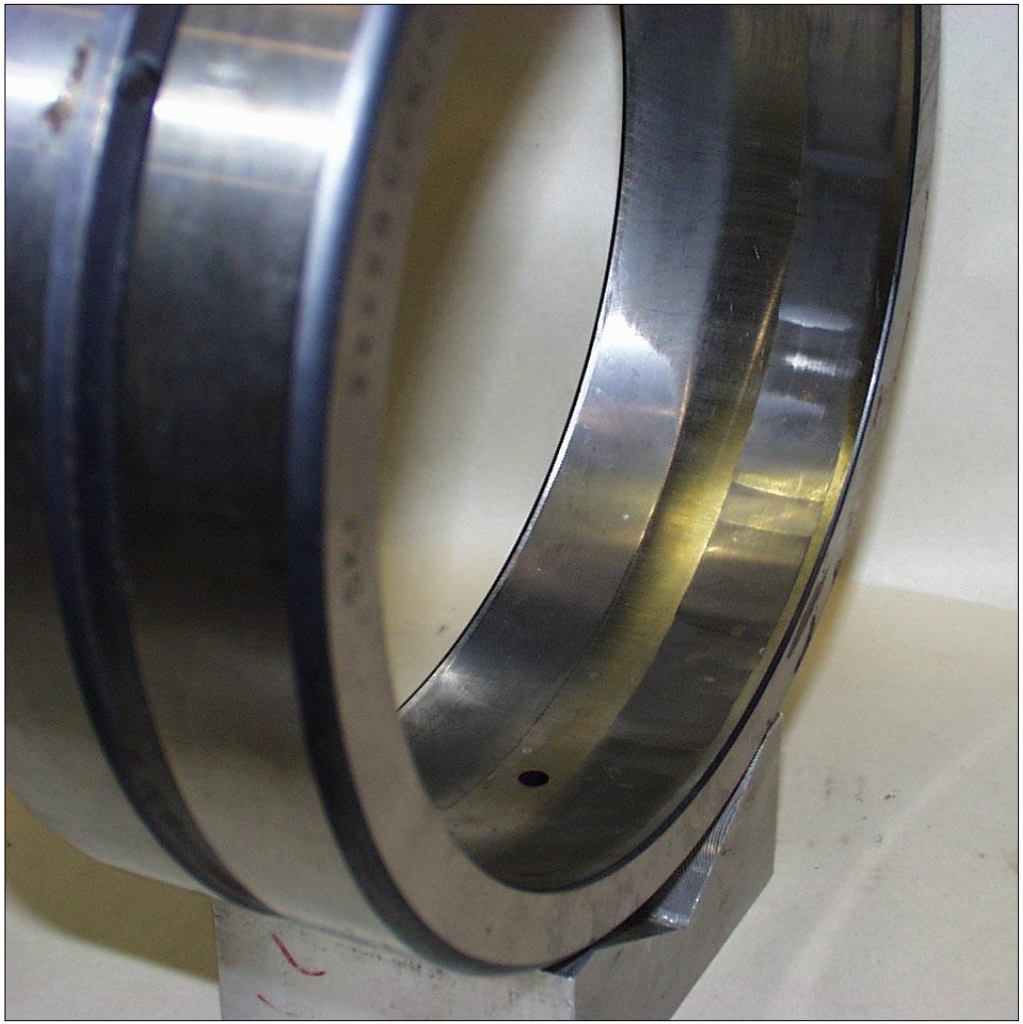
Abrasive wear

Advanced abrasive wear led to heavy vibrations increasing the damage



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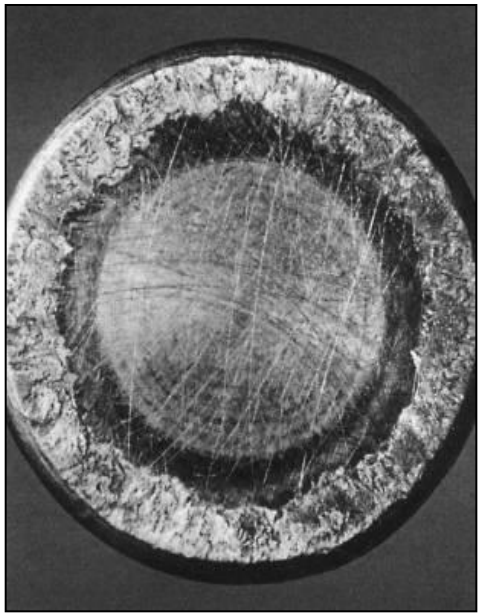
Adhesive Wear

- Fatigue
- Wear
  - Abrasive wear
  - Adhesive wear
- Corrosion
- Electrical erosion
- Plastic deformation
- Fracture and cracking

– Smearing.
– Transfer of material / hear due to friction
– Tempering / annealing creating tensions causing cracks and fatigue.



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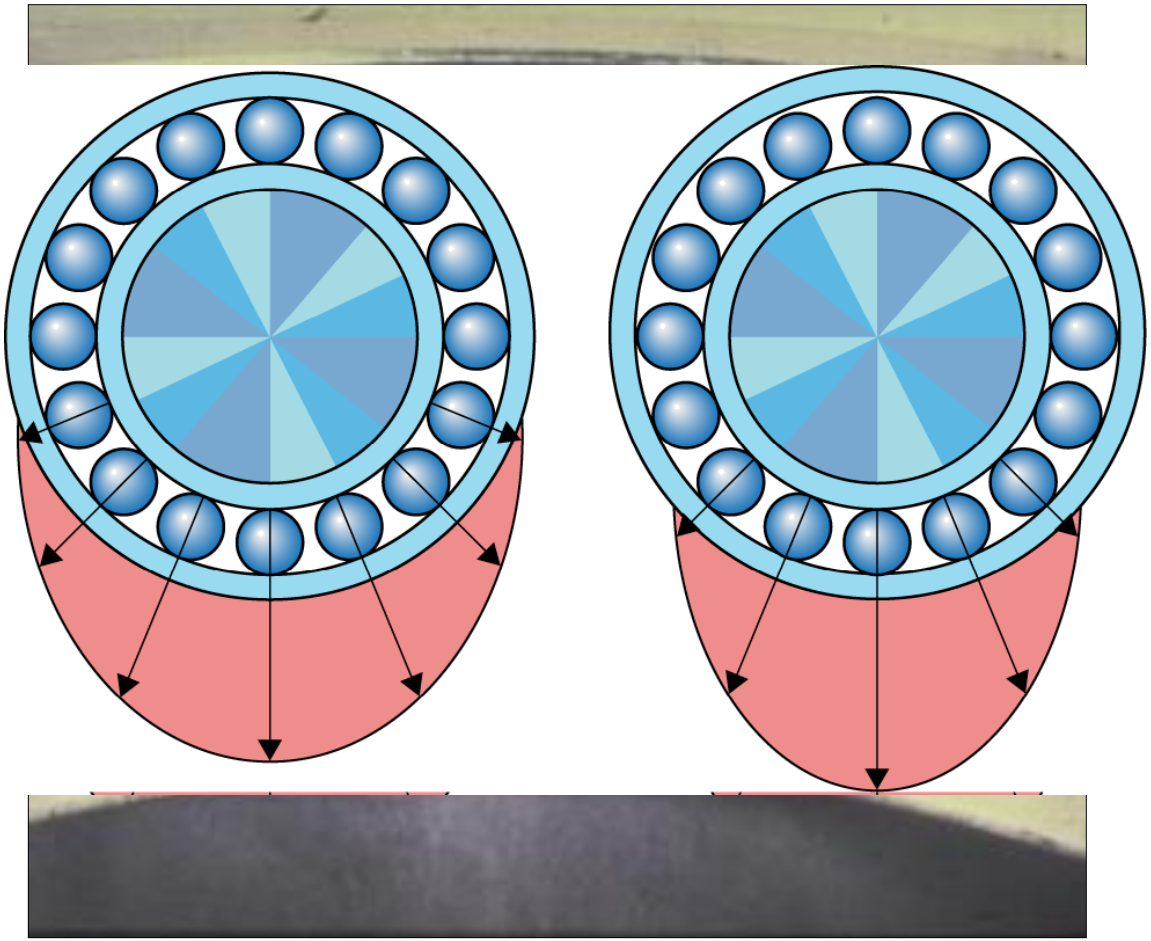
Smearing due to Sliding

Raceway of an outer rind of a self aligning ball bearing.

Possible causes?



<u>Causes</u>:

- **Excessive internal clearance.**
- **Poor lubrication.**

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Sliding in Bearing Seatings

Heavy sliding both on inner and outer diameter

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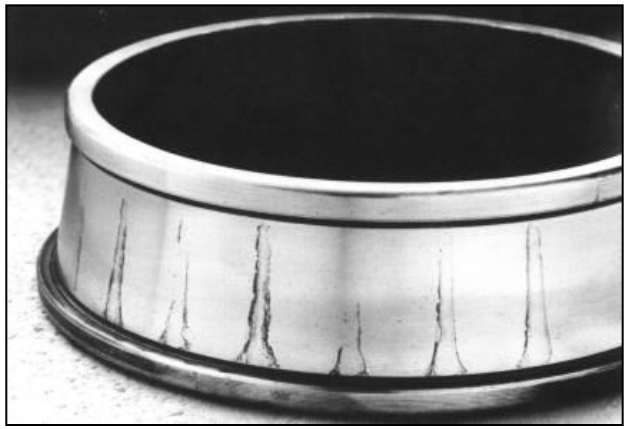
Corrosion

- Fatigue
- Wear
- Corrosion
  - Moisture corrosion
  - Frictional corrosion
    - Fretting corrosion
    - False brinelling
- Electrical erosion
- Plastic deformation
- Fracture and cracking

– Corrosion / rust
– Chemical reaction.
– Fatigue.



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Corrosion - Water in the Oil

When is water in the oil most dangerous: During operation or stand still?

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Corrosion

Corrosion at stand still

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Fretting Corrosion

- Fatigue
- Wear
- Corrosion
  - Moisture corrosion
  - Frictional corrosion
    - Fretting corrosion
    - False brinelling
- Electrical erosion
- Plastic deformation
- Fracture and cracking

– Small relative movements in between the mating surfaces

– Oxidation of the wear particles.

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Fretting Corrosion

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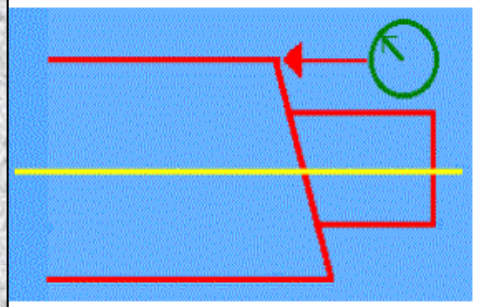
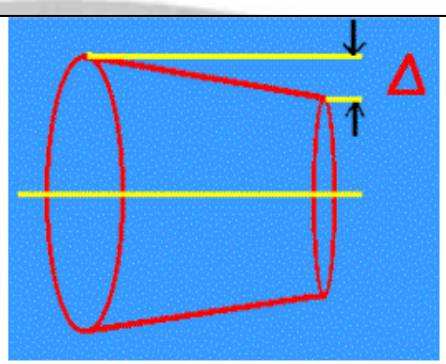
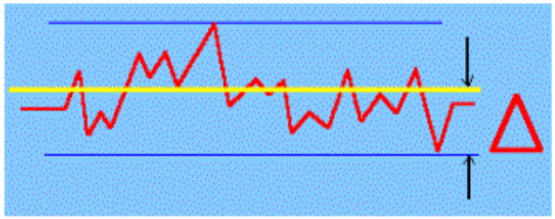
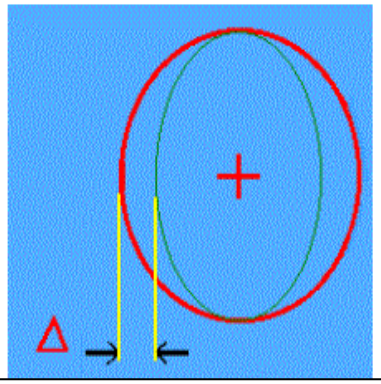
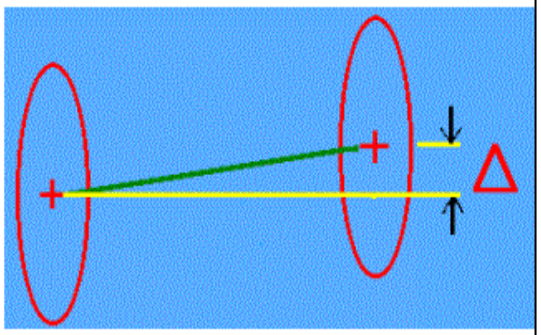
Fretting Corrosion











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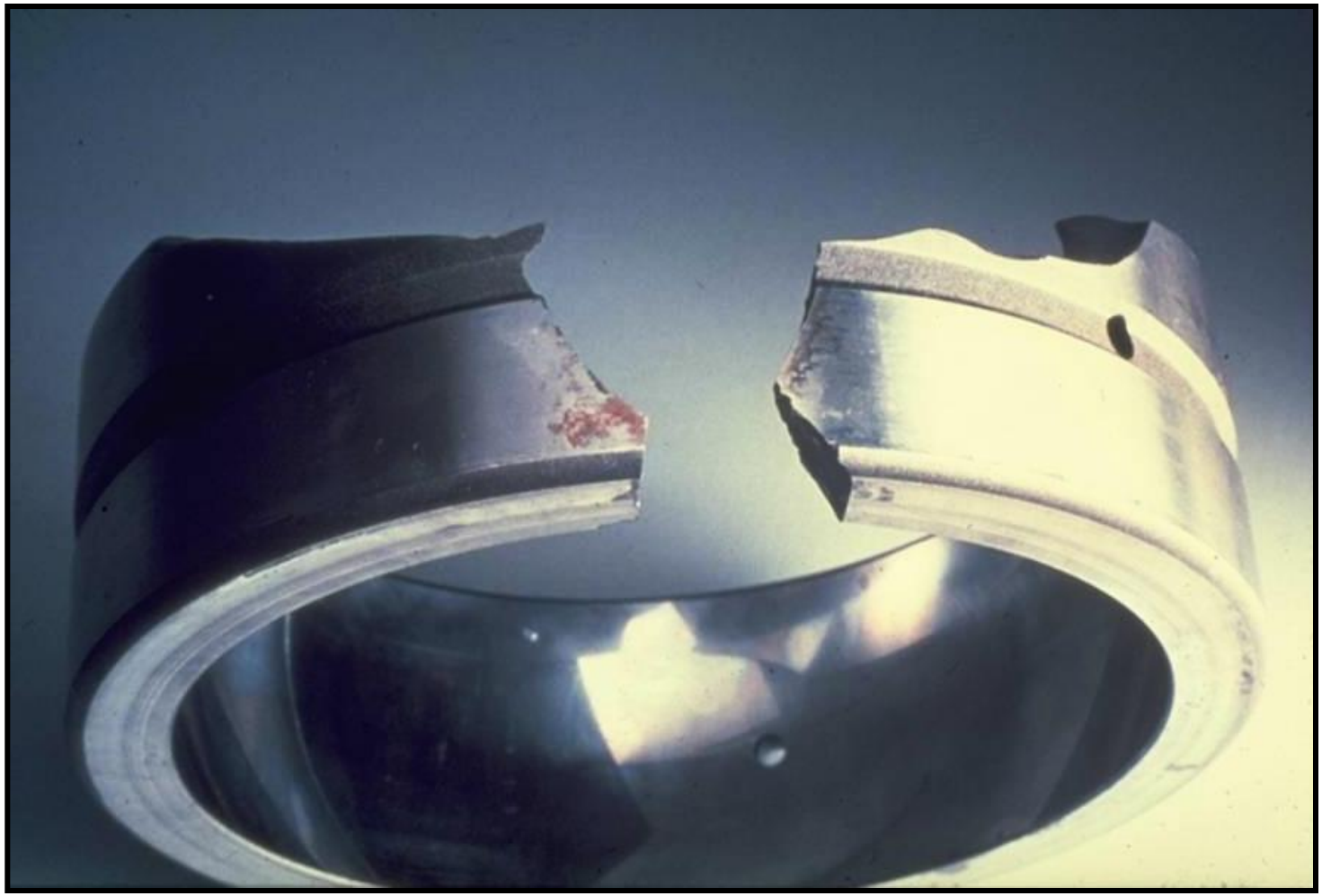
Fractures caused by heavy Fretting corrosion



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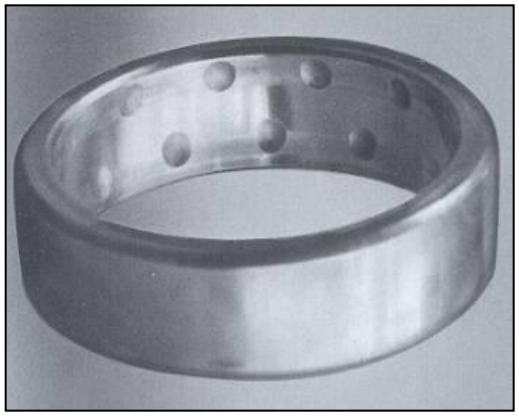
False Brinelling, Marks made by Vibrations

- Fatigue
- Wear
- Corrosion
  - Moisture Corrosion
  - Frictional Corrosion
    - Fretting Corrosion
    - False brinelling
- Electrical erosion
- Plastic deformation
- Fracture and cracking



- Rolling elements vs. raceways.
- Micro-movements / deformations.
- Vibrations under static conditions.
- Corrosion / wear: deep brilliant or red colored marks with the form of the rolling elements.
- Stationary: Mark typically spaced equally as the rolling elements.

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Vibration

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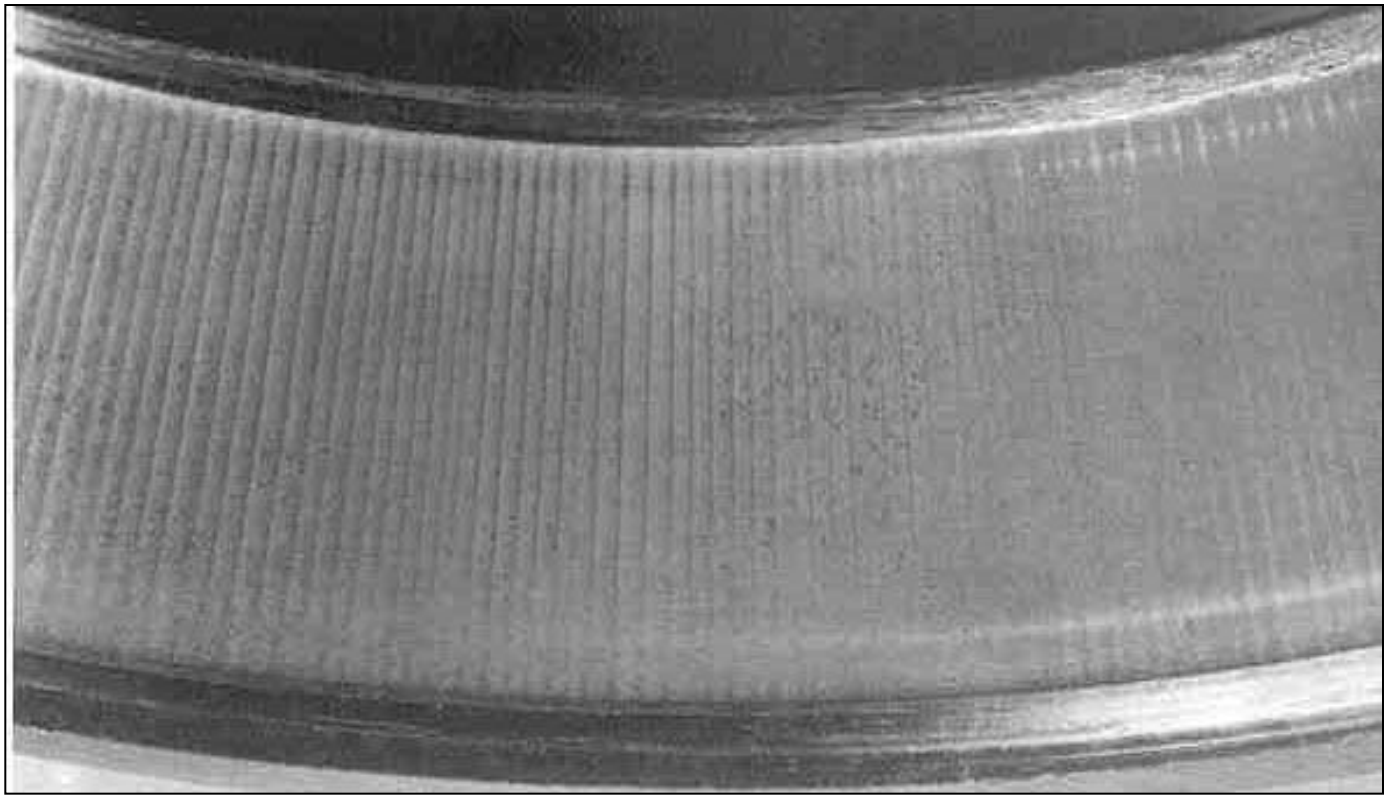
Vibration



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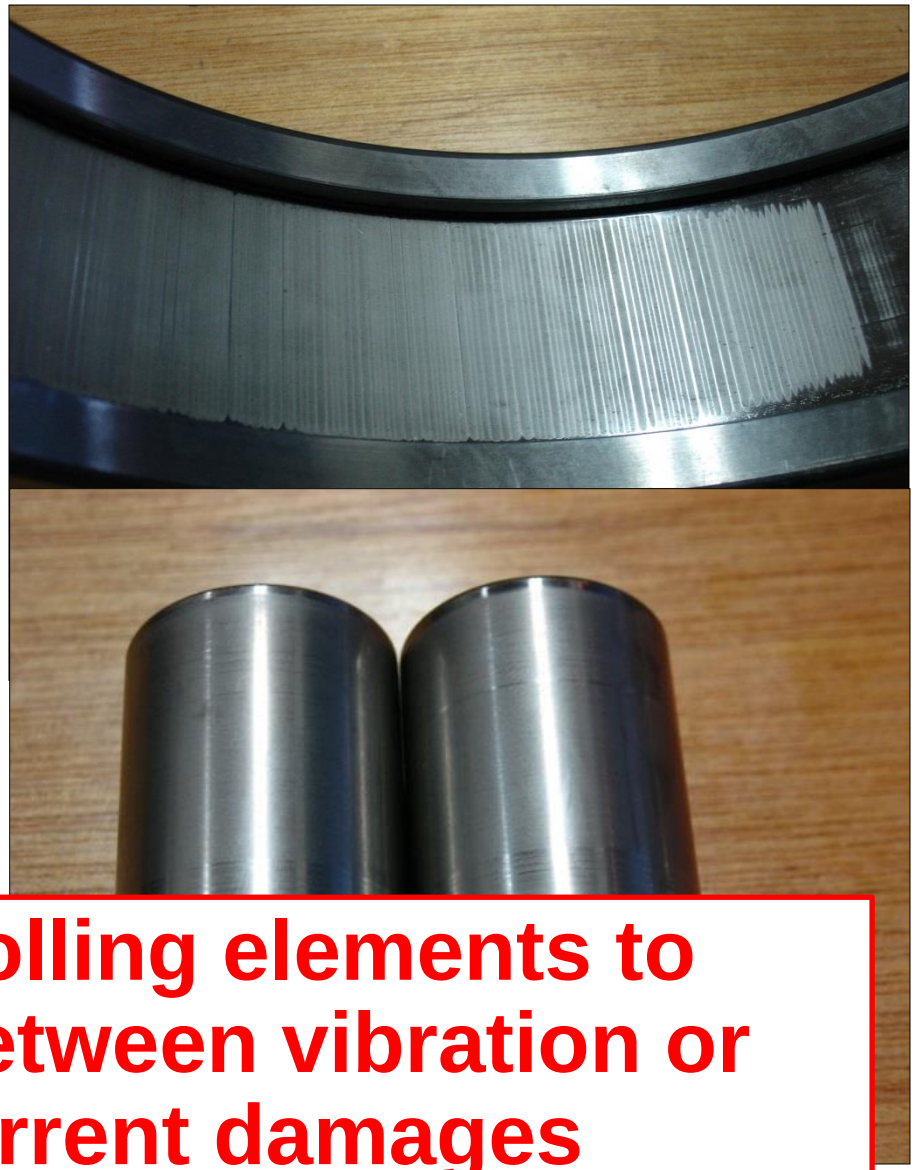
Vibration

Typical damage pattern in the outer race.

The corresponding rollers only show dull surface.



Look at the rolling elements to differentiate between vibration or electric current damages

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False Brinelling (Gearbox)

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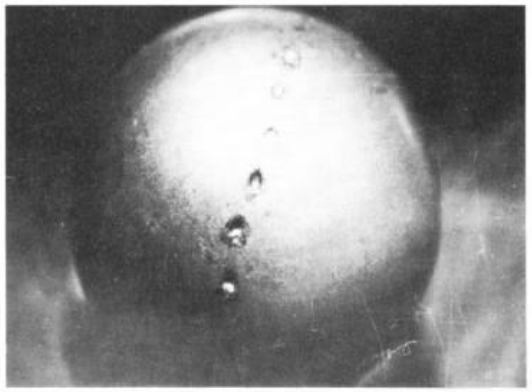
Electrical Erosion

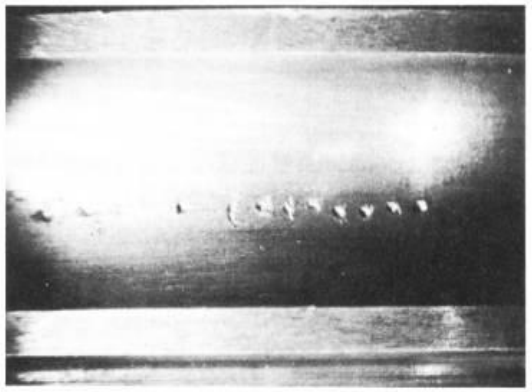
- Fatigue
- Wear
- Corrosion
- Electrical erosion
  - Excessive voltage
  - Current leakage
- Plastic deformation
- Fracture and cracking

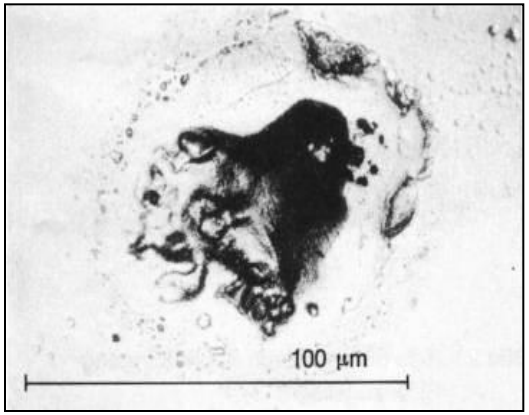
– High voltage = electric arks.

– Instantaneous overheating at the contacts leading to fusions and weldings.

– Craters up to100 µm in diameter.







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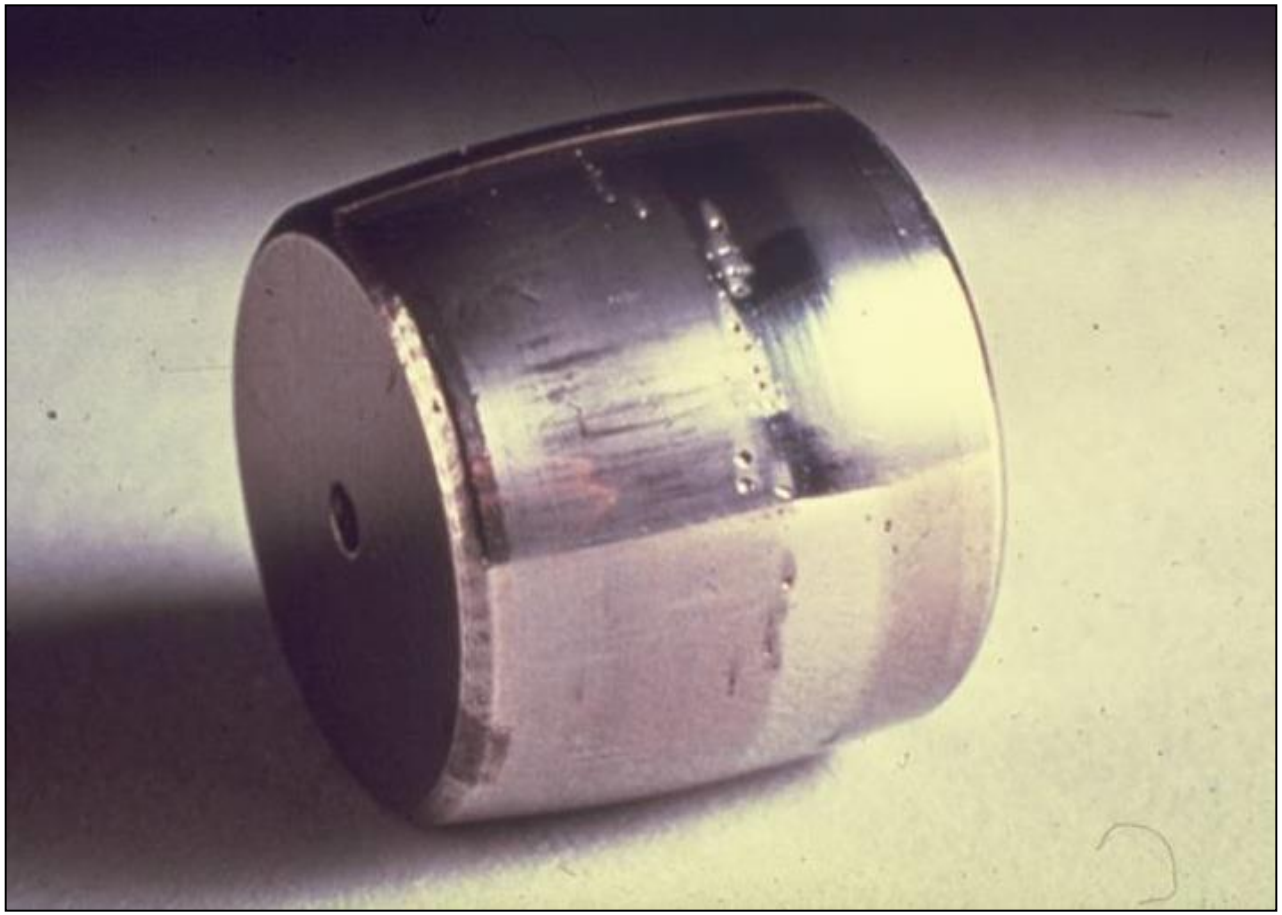
Electrical Erosion – Excessive Voltage



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Electrical Erosion – Current Leakage

- Fatigue
- Wear
- Corrosion
- Electrical erosion
  - Excessive
  - Current leakage
- Plastic deformation
- Fracture and cracking

- Low intensity current.
- Shape of shallow craters, which are closely positioned to one another and small in size
- Equally spaced flutes will develop from the craters on raceways and rollers.
- Balls will have dark coloration or the surface all covered with miniature craters.

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Electrical Erosion – Current Leakage

Look at the rolling elements to differentiate between vibration or electric current damages

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Electrical Erosion – Current Leakage

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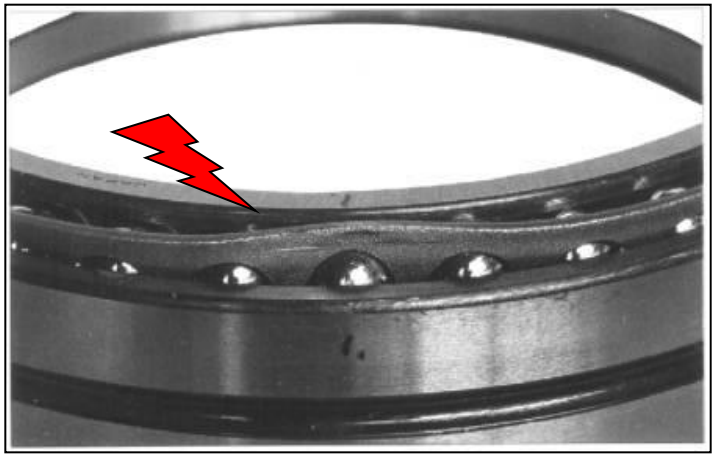
Electrical Erosion – Current Leakage

Plastic Deformation - Overloading

- Fatigue
- Wear
- Corrosion
- Electrical erosion
- **Plastic deformation**
  - Overload
  - Indentaciones
    - Indentation from debris
    - Indentation by handling
- Fracture and cracking

– Permanent deformation occurring whenever the yield strength of the material is exceeded.

– Microscale or a microscale.



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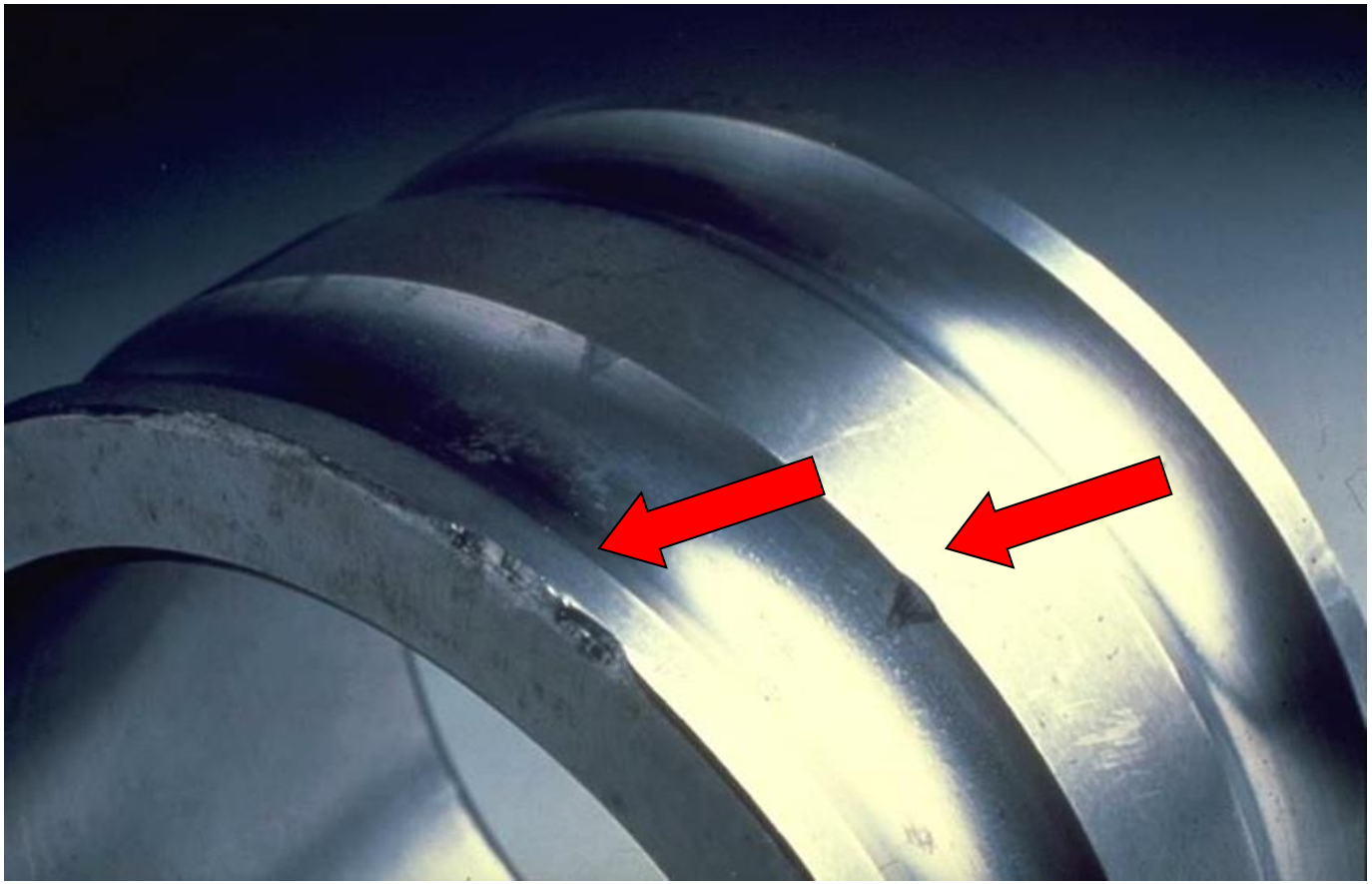
Mounting Damages



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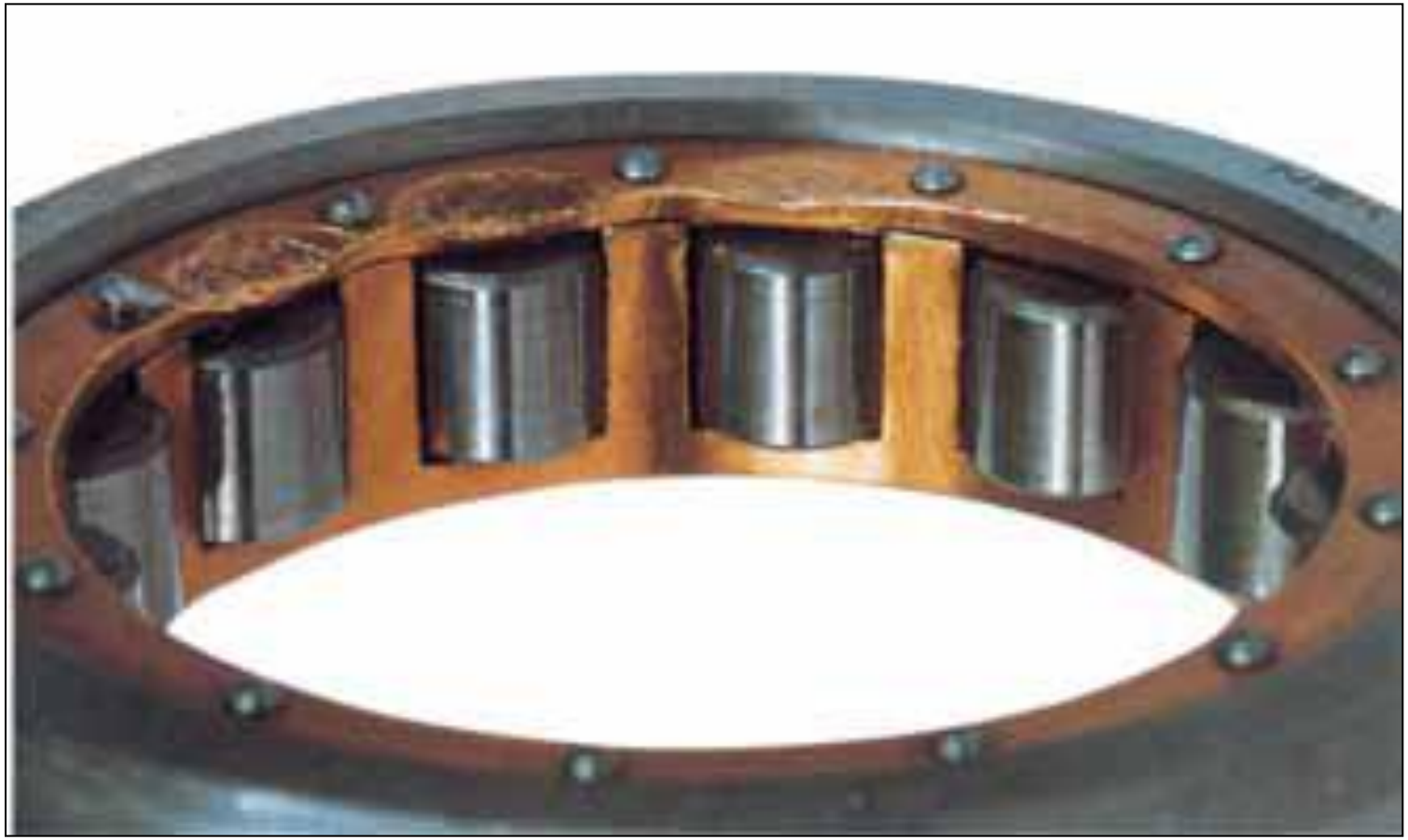
Inappropriate Handling

Cage damaged by direct impacts during mounting



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Inappropriate Handling

Customer: "*We do not accept plastic cages*"

Me: "*Why not?*"

Customer: "*Because plastic cages do not resist strokes or impacts*".

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Inappropriate Handling

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Mounting Damages

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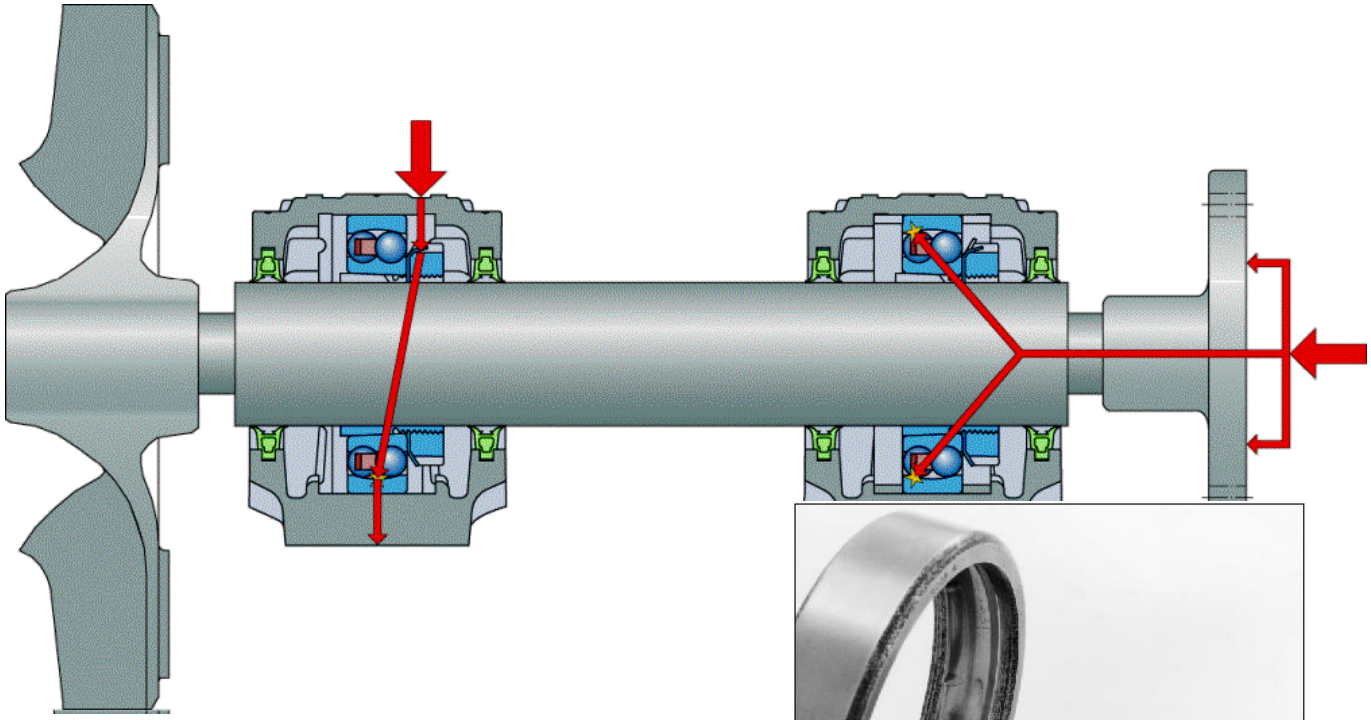
Installation Damages

Impacts at the installation of the equipment



Bearings were OK as the equipment left the workshop but damaged at the installation in the field

Indentations 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 from soft particles, hardened steel particles or worse, from hard mineral particles

- Fatigue
- Wear
- Corrosion
- Electrical erosion
- Plastic deformation
  - Overload
  - Indentations
    - Indentations from debris
    - Indentations by handling
- Fracture and cracking

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Indentations from Debris

Determine the origin of the debris!

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Indentations by Handling

Raceways and rolling elements can incur indentations and nicks caused by hard, possibly sharp objects.

- Fatigue
- Wear
- Corrosion
- Electrical erosion
- **Plastic deformation**
  - Overload
  - **Indentaciones**
    - Indentations from debris
    - **Indentations by handling**
- Fracture and cracking

Ref.: ISO 15243 Rolling Bearings – Damages and Failures – Terms, Characteristics and Causes

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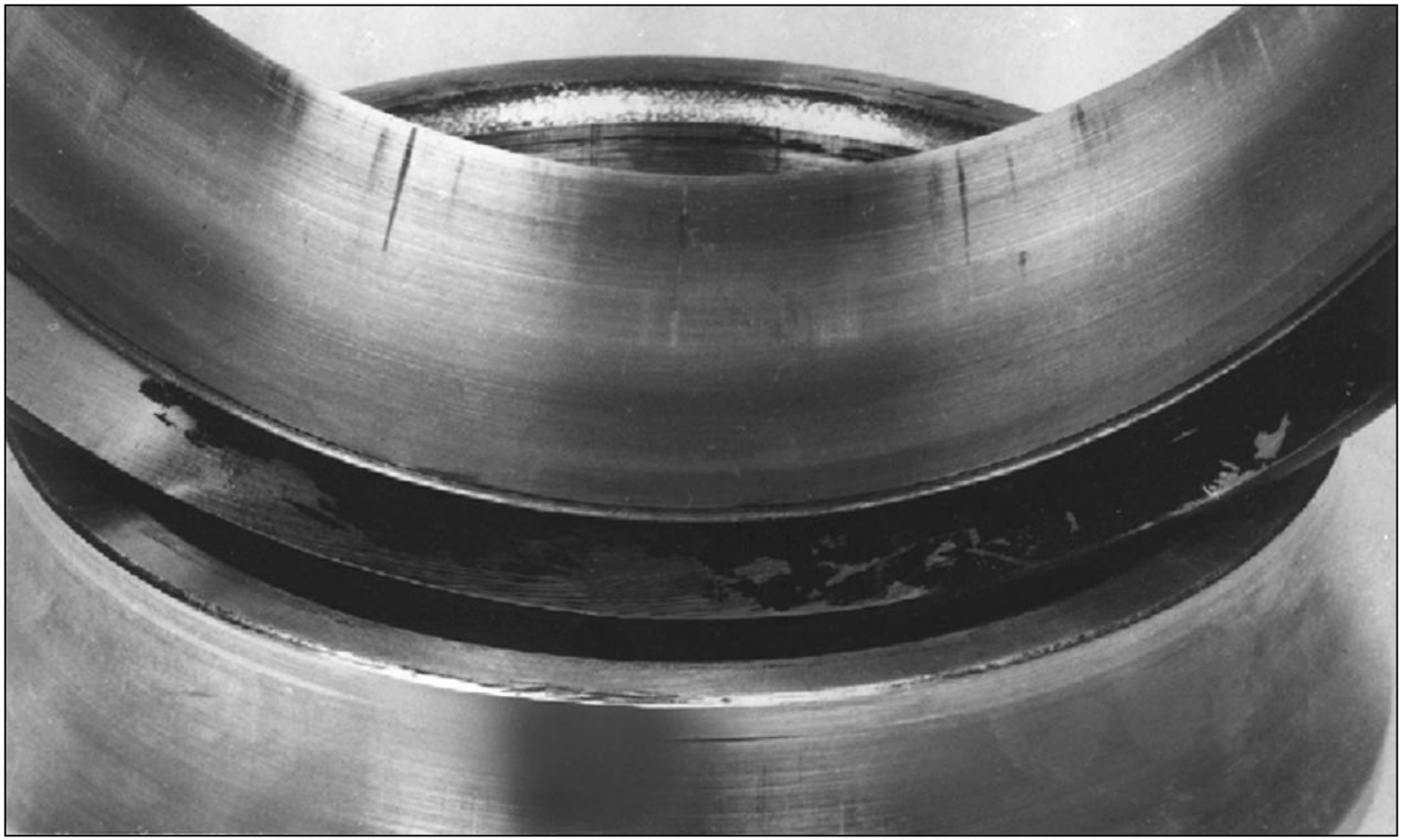
Indentations by Handling



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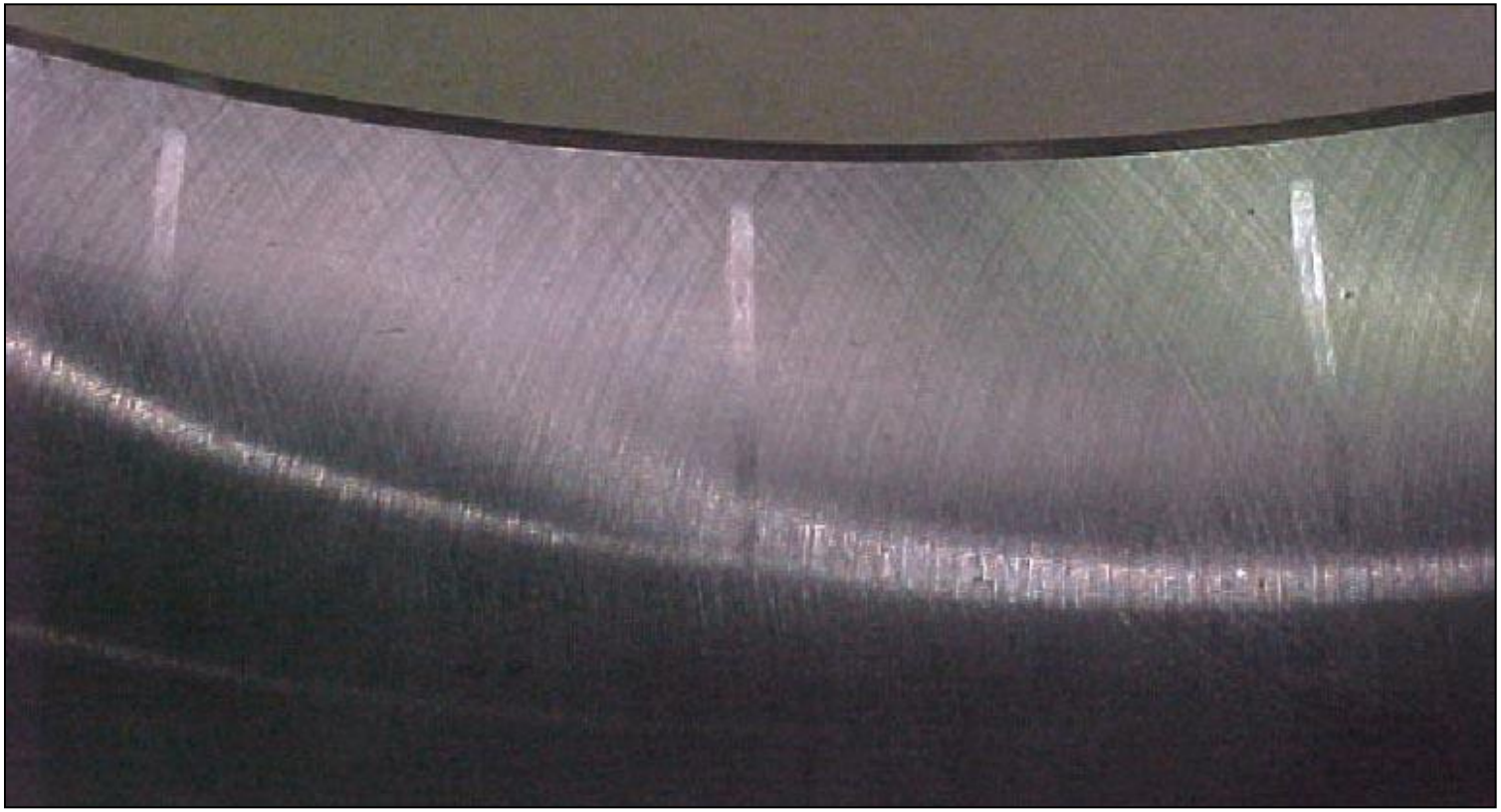
Indentations by Handling



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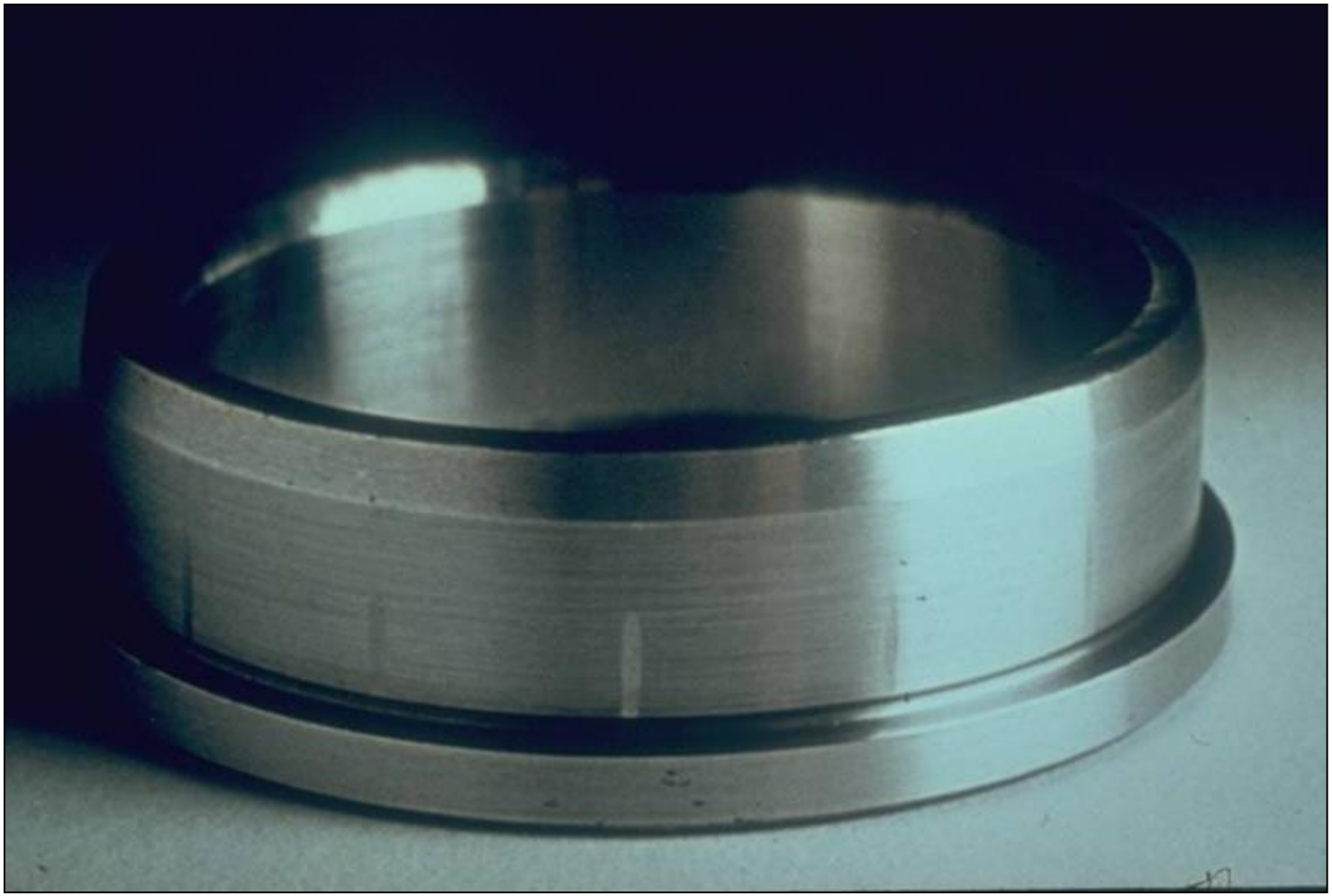
Indentations by Handling



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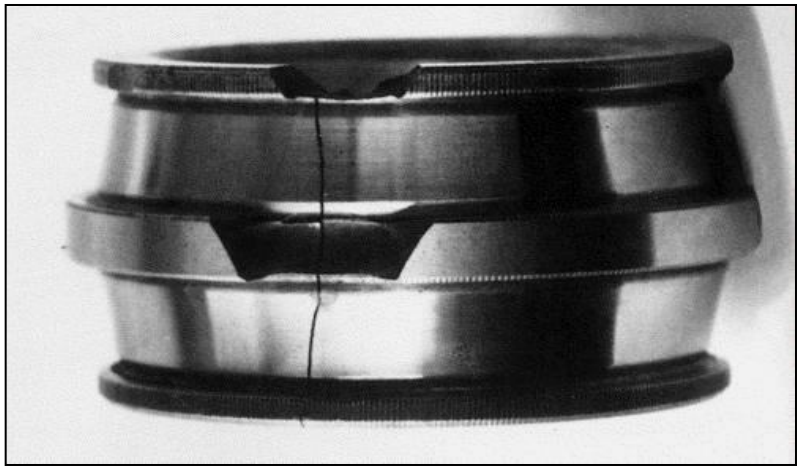
Forced Fracture

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 or by over-stressing due to an excessive interference

- Fatigue
- Wear
- Corrosion
- Electrical erosion
- Plastic deformation
- Fracture and cracking
  - Forced fracture
  - Fatigue fracture
  - Thermal fracture



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Fatigue Fracture

- Fatigue
- Wear
- Corrosion
- Electrical erosion
- Plastic deformation
- Fracture and cracking
  - Forced fracture
  - **Fatigue fracture**
  - Thermal 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

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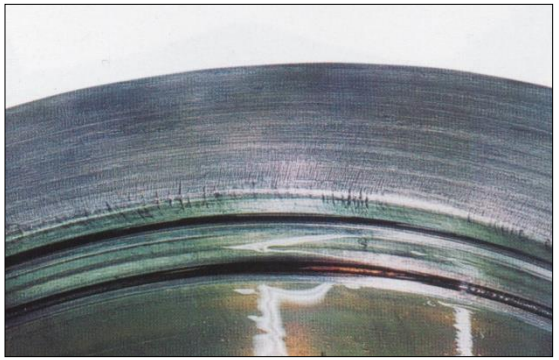
Thermal Fracture

- Fatigue
- Wear
- Corrosion
- Electrical erosion
- Plastic deformation
- Fracture and cracking
  - Forced fracture
  - Fatigue fracture
  - Thermal fracture

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



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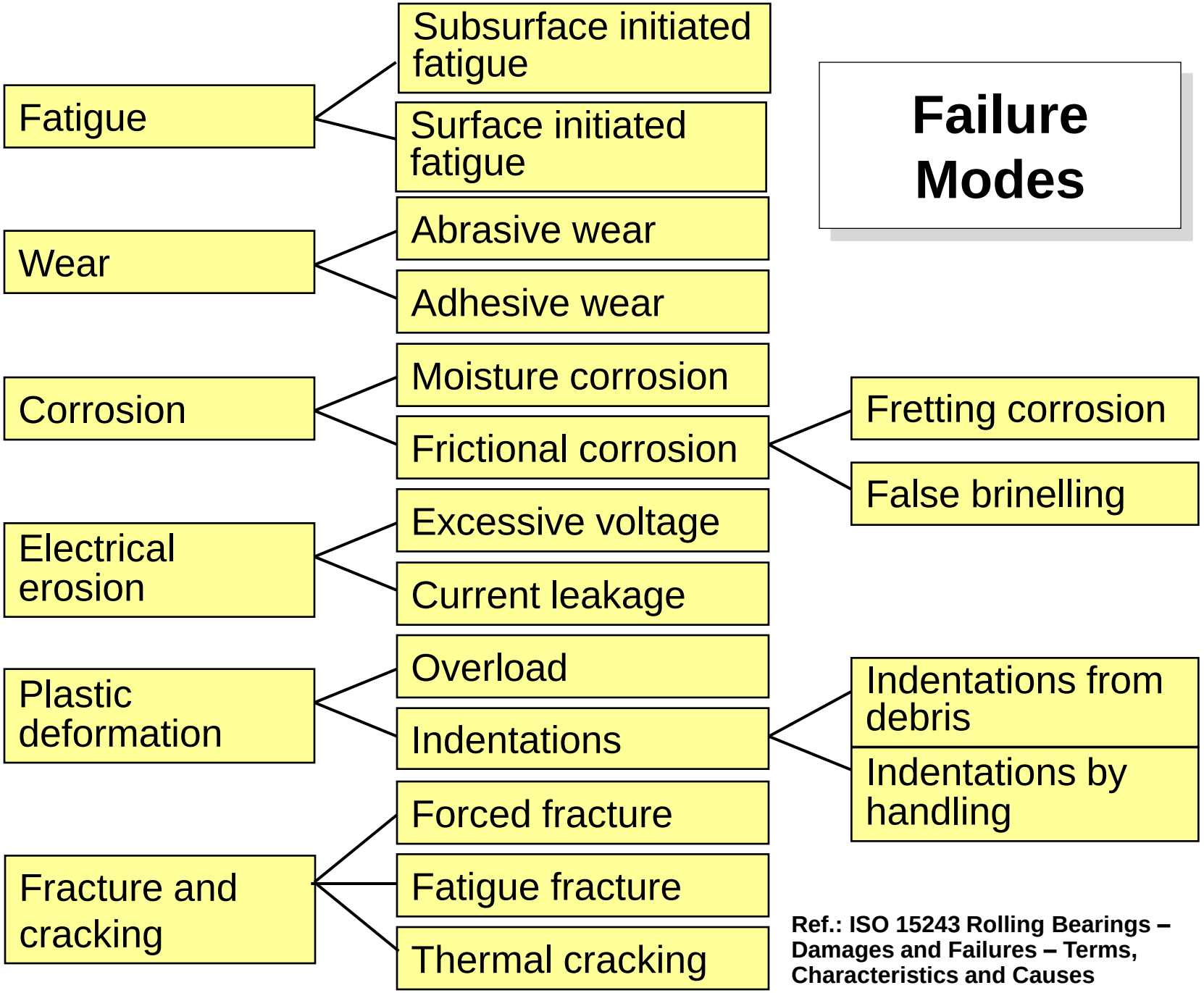
Failure Modes



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Conclusion – The Process

A complete Failure Analysis Process should include:

1. Determination of the most complete information on the operating conditions.
2. Relevant photos during the process.
3. Samples of the lubricant from the application and sample of unused lubricant for comparison.
4. Marking of the bearings and their position in the equipment.
5. Careful dismounting of the bearing avoiding unnecessary additional damages.
6. Inspection of the other machine components to determine collateral damages.

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Conclusion – The Process

7. Verify bearing seating on shafts and in housings.
8. Verify the condition and distribution of the lubricant inside the bearings. If possible take additional samples.
9. Clean the bearings and the components and take note if possible of the markings, brand and complete designations.
10. Realize the analysis of the bearing and corresponding components. Take additional photos.
11. Determine the causes of the failure comparing the failure patterns with available standard photos from ISO 15243 and/or bearing manufacturers.
12. Determine the necessary corrective actions required in order to avoid the recurrence of the same failure.
13. Protect and keep the failed bearing for future use as comparison.

Examples

Spherical roller bearing in a drying cylinder in a brewery.

Fatigue pattern in the raceway corresponding the contacts of the rollers.

<u>Failure causes</u>: Impacts during the mounting of the bearing and/or the transmission gear and/or corrosion due to water entering the bearing.

Examples

Totally wrong grease:

Hot application (120°C), extremely slow speed (7 RPM) in food industry (washed daily.

Conclusion:

The used grease did not have the anticorrosive protection nor the sufficient water resistance and the adequate basic oil viscosity.

Examples

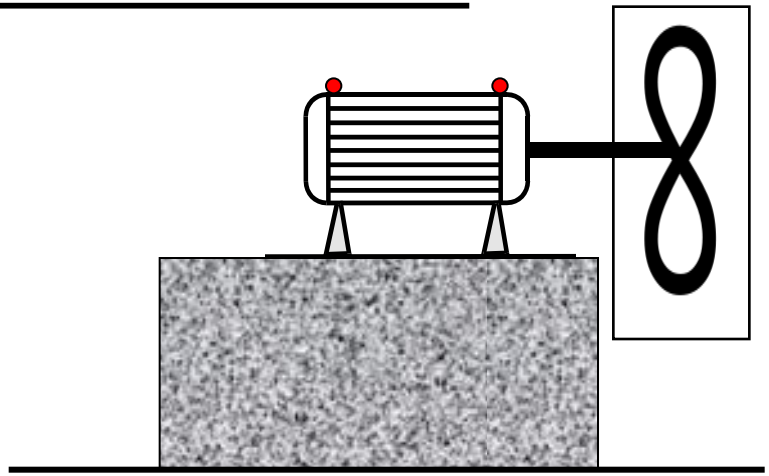
Bearing failure in blowers:

Actual application:

Blower mounted directly on an electrical motor mounted on a pedestal.

Deep groove ball bearings 6208/C3 relubricated manually weekly through the grease nipples on the motor.

Service life: 6 months

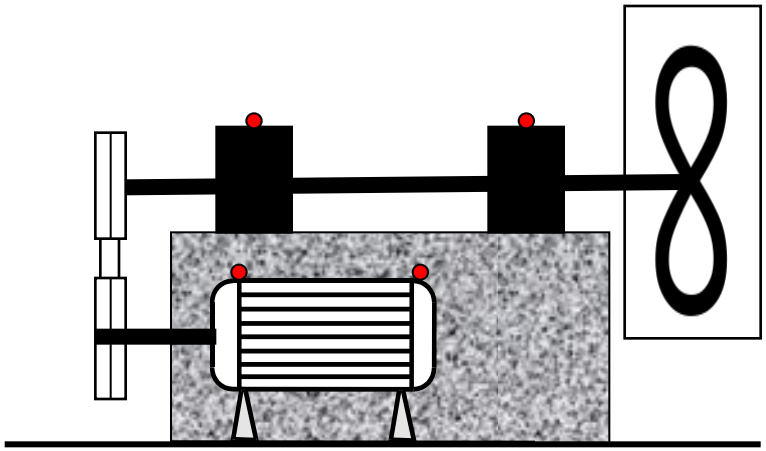


Customer Proposal:

Blower to be mounted on a shaft supported by larger bearings in pillow blocks on the pedestal.

The electrical motor mounted on the floor with belt transmission.

Comments???



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Exercise

Bearing failure in a washing machine:

Bearing life: 60 to 90 days.

Bearings: 22218 EK/C3

Speed: 30 RPM.

Application:

Washing machine for glass bottles for soft drinks that uses hot water (90°C) and caustic soda. The shafts that transport the bottles inside the machine are 3 meter long and are supported by bearings in special flange housings on the outside of he machine.

The seal is a radial contact seal mounted in the wall.

Exercise

I got the following relevant comments from the maintenance personal:

"We do not use the grease nipples. Instead during the weekend we take away the bearing cover and lubricate by hand."

"The bearing fit in the housings is so hard so we have to mount them in an hydraulic press".

"We tighten the mounting nuts as tight as possible using a chisel and hammer".

As we dismounted a bearing cover we found the bearing filled with washing liquid and very advanced corrosion on the bearing.

Please let me have at least 5 causes for this failure, specially the trigger for the failure.

Conclusion

Go for all the possible **ROOT CAUSES!**

Determine all the **CORRECTIVE ACTIONS!**

Verify the **RESULTS!**

Good Luck!