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# Workshop For STLE

Bearing Damage/Failure Analysis

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## Introduction

- Rolling bearings are most important component in Rotating Equipment
- Exacting demands made on them
- Many do not achieve theoretical life
- Premature failure results in economic loss
- Failure Analysis is key to identifying Root Cause and defining Corrective Actions



## Premature Bearing Failure - Statistics

36%

Lubrication

14%

Contamination

16%

Mounting, Handling, Storage, Other

34%

Fatigue

## Bearing Failure Analysis...

- Where, when, and why did the failure occur?
- One key piece of forensic evidence is the bearing itself
- A variety of ***causes*** lead to bearing damage and ultimately failure
- ***Causes***, such as improper installation, inadequate lubrication, contamination, and improper operation, leave distinctive marks on the bearing, be it on the raceways, cage(s), rolling elements, bore, outside diameter, or others



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## Bearing Failure Analysis – The Concept

Overview:

- Load path patterns
- Failure mode classification
- How to secure evidence



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## Load Path Patterns



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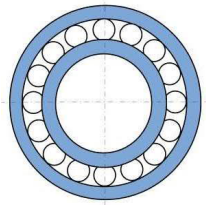
## New bearings



## Change in appearance...

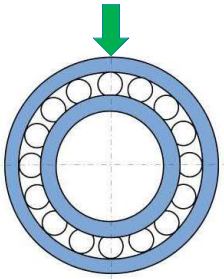
Example : electrical motor

## Change in appearance

## Most Common Arrangement

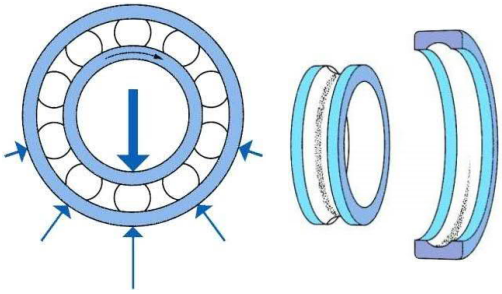
Operating conditions:

- Horizontal Shaft
- The outer ring is stationary
- The inner ring is rotating
- A constant radial load is transmitted from the shaft via the bearing into the housing
- The bearing has radial clearance



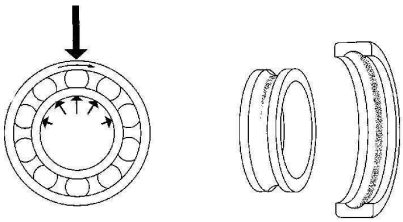


## Inner Ring Rotation – Stationary Radial Load

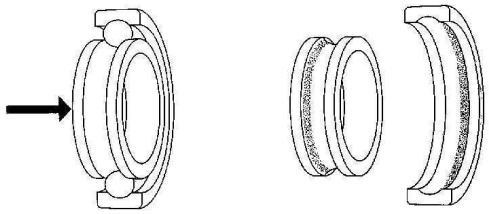




## Outer Ring Rotation – Stationary Radial Load

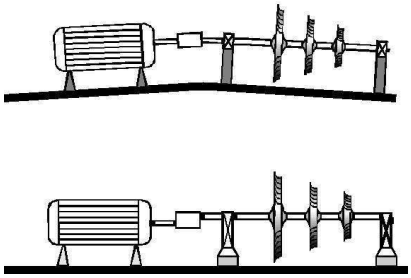


## Excessive Axial Load



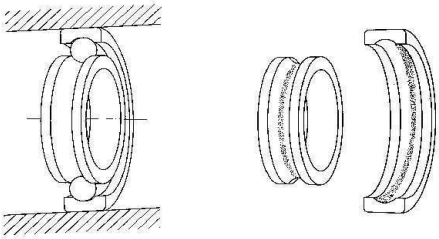


## Misalignment

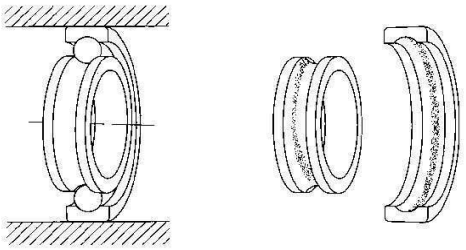




## Misaligned Outer Ring

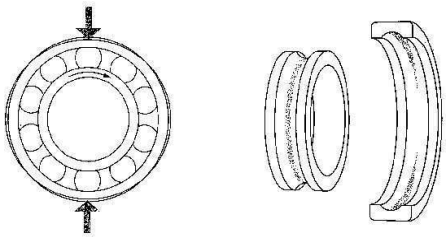


## Misaligned Inner Ring





## Oval compression – out of round/pinched housing





## Load path patterns – last word

Patterns/Marks appear in areas where load is transmitted. Some of them are straightforward; others more complex.

During operation, other things can result in "typical" patterns:

- Ingress of Contamination
- Incorrect Lubricant Properties
- Incorrect Mounting
- Incorrect Mating Component Fit/Form
- Temperature increase - ring growth, loss of clearance, discolouration
- All result in visible marks/patterns, eventually leading to bearing damage

There is need to understand and to classify the different types of damage:

ISO 15243 accomplishes this.

# Failure Mode Classification



## Bearing failure analysis: failure modes

- Causes of failures have identifiable characteristics
- Failure mechanisms have identifiable failure modes
- Observed damage can identify failure causes

## Failure modes: ISO 15243:2017 classification

- 5.1 Rolling Contact Fatigue
  - 5.1.2 Subsurface initiated fatigue
  - 5.1.3 Surface initiated fatigue
- 5.2 Wear
  - 5.2.2 Abrasive wear
  - 5.2.3 Adhesive wear
- 5.3 Corrosion
  - 5.3.2 Moisture corrosion
  - 5.3.3 Frictional corrosion
    - 5.3.3.2 Fretting corrosion
    - 5.3.3.3 False brinelling
- 5.4 Electrical erosion
  - 5.4.2 Excessive current erosion
  - 5.4.3 Current leakage erosion
- 5.5 Plastic deformation
  - 5.5.2 Overload deformation
  - 5.5.3 Indentations from particles
- 5.6 Cracking and fracture
  - 5.6.2 Forced fracture
  - 5.6.3 Fatigue fracture
  - 5.6.4 Thermal cracking

## The ISO classification system

- The ISO classification system is made up of 6 main modes and then further divided into sub-modes
- In total, 15 modes can be observed
- There are some other reasons for bearing damage, such as design problems, etc. These are **not** classified in the ISO standard



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## 5.1 Fatigue

### 5.1.1 - general definition

The weakening (changes in the metallurgical structure) of raceway contact and/or rolling element surfaces in a bearing, caused by accumulation of stresses or material imperfections, finally leading to spalling of the surfaces.



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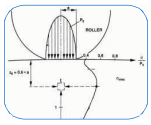
## 5.1.2 Subsurface initiated fatigue

- 5.1 Fatigue
  - 5.1.2 Subsurface fatigue
  - 5.1.3 Surface initiated fatigue
- 5.2 Wear
- 5.3 Corrosion
- 5.4 Electrical erosion
- 5.5 Plastic deformation
- 5.6 Cracking and fracture



- Repeated stress changes
- Material structural changes
- Micro-cracks under the surface
- Crack propagation
- Spalling (also known as flaking & peeling)



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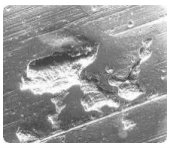
## 5.1.3 Surface initiated fatigue

- 5.1 Fatigue
  - 5.1.2 Subsurface fatigue
  - 5.1.3 Surface initiated fatigue
- 5.2 Wear
- 5.3 Corrosion
- 5.4 Electrical erosion
- 5.5 Plastic deformation
- 5.6 Cracking and fracture

- Reduced lubrication regime
- Surface distress
- Sliding motion
- Burnishing, glazing
- Asperity micro-cracks
- Asperity micro-spalls





## 5.2 Wear

### 5.2.1 general definition

Wear is the gradual removal of material from a surface



## 5.2.2 Abrasive wear

- 5.1 Fatigue
- 5.2 Wear
  - 5.2.2 Abrasive wear
  - 5.2.3 Adhesive wear
- 5.3 Corrosion
- 5.4 Electrical erosion
- 5.5 Plastic deformation
- 5.6 Fracture and cracking

- Progressive removal of material
- Inadequate lubrication
- Ingress of dirt particles
- Dull surfaces (sometimes very shiny)
- Accelerating process

## 5.2.3 Adhesive wear

- 5.1 Fatigue
- 5.2 Wear
  - 5.2.2 Abrasive wear
  - 5.2.3 Adhesive wear
- 5.3 Corrosion
- 5.4 Electrical erosion
- 5.5 Plastic deformation
- 5.6 Cracking and fracture

- Accelerations
- Smearing/skidding/galling
- Material transfer/friction heat
- Tempering/re-hardening with stress concentrations and cracking or flaking
- Low load/high speed



## 5.3 Corrosion

### 5.3.1 general definition

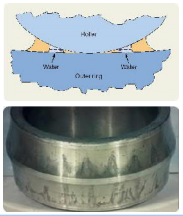
Corrosion is a chemical reaction on metal surfaces



## 5.3.2 Moisture corrosion

- 5.1 Fatigue
- 5.2 Wear
- 5.3 Corrosion
  - 5.3.2 Moisture corrosion
  - 5.3.3 Frictional corrosion
    - 5.3.3.2 Fretting corrosion
    - 5.3.3.3 False brinelling
- 5.4 Electrical erosion
- 5.5 Plastic deformation
- 5.6 Cracking and fracture

- Oxidation/rust (corrosion)
- Chemical reaction
- Corrosion pits/flaking
- Etching (water/oil mixture)



## 5.3.3 Frictional corrosion

### 5.3.3.1 general definition

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



## 5.3.3.2 Fretting corrosion

- 5.1 Fatigue
- 5.2 Wear
- 5.3 Corrosion
  - 5.3.2 Moisture corrosion
  - 5.3.3 Frictional corrosion
    - 5.3.3.2 Fretting corrosion
    - 5.3.3.3 False brinelling
- 5.4 Electrical erosion
- 5.5 Plastic deformation
- 5.6 Cracking and fracture

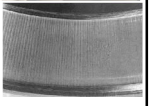
- Micro-movement between mating parts
- Oxidation of asperities
- Powdery rust/loss of material
- Occurs in interfaces transmitting loads



## 5.3.3.3 False brinelling

- 5.1 Fatigue
- 5.2 Wear
- 5.3 Corrosion
  - 5.3.2 Moisture corrosion
  - 5.3.3 Frictional corrosion
    - 5.3.3.2 Fretting corrosion
    - 5.3.3.3 False brinelling
- 5.4 Electrical erosion
- 5.5 Plastic deformation
- 5.6 Cracking and fracture

- Rolling element/raceway
- Micro movements/elastic deformations
- Vibrations
- Corrosion/wear, shiny or reddish depressions
- If stationary: at rolling element pitch
- If rotating: parallel flutes



## 5.4 Electrical erosion

### 5.4.1 general definition

Macro- or microcraters caused by local melting, when levels beyond the threshold electric current value pass through the rolling contacts of a bearing.



## 5.4.2 Excessive current erosion

- 5.1 Fatigue
- 5.2 Wear
- 5.3 Corrosion
- 5.4 Electrical erosion
  - 5.4.2 Excessive current erosion
  - 5.4.3 Current leakage erosion
- 5.5 Plastic deformation
- 5.6 Cracking and fracture

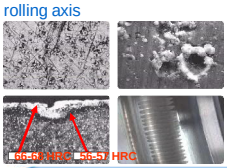
- High current: sparking
- Localized heating in very short interval: melting/welding
- Craters up to 0.100 mm



## 5.4.3 Current leakage erosion

- 5.1 Fatigue
- 5.2 Wear
- 5.3 Corrosion
- 5.4 Electrical erosion
  - 5.4.2 Excessive current erosion
  - 5.4.3 Current leakage erosion
- 5.5 Plastic deformation
- 5.6 Cracking and fracture

- Low current intensity
- Shallow craters closely positioned
- Development of flutes on raceways and rolling elements, parallel to the rolling axis
- Dark grey discoloration
- Flux asymmetries
- Unsymmetrical cabling
- High frequency currents (frequency converters)



## 5.5 Plastic deformation

### 5.5.1 general definition

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



## 5.5.2 Overload deformation

- Static or shock loads
- Plastic deformations
- Depressions at rolling element distance
- Inappropriate handling
- Nicks caused by hard/sharp objects

5.1 Fatigue
5.2 Wear
5.3 Corrosion
5.4 Electrical erosion
5.5 Plastic deformation
5.6 Cracking and fracture

5.5.2 Overload deformation
5.5.3 Indentations from particles

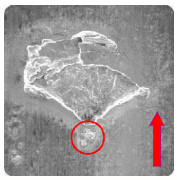


## 5.5.3 Indentations from particles

5.1 Fatigue
5.2 Wear
5.3 Corrosion
5.4 Electrical erosion
5.5 Plastic deformation
5.6 Cracking and fracture

- Localized overloading
- Over-rolling of particles: dents
- Soft/hardened steel/hard mineral

5.5.2 Overload deformation
5.5.3 Indentations from particles



## 5.6 Cracking and fracture

### 5.6.1 general definition

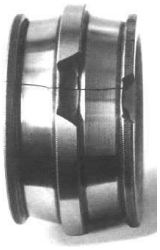
- Cracking is the incomplete separation of material under stress conditions
- Cracks are initiated and propagate when the ultimate tensile strength of the material is exceeded
- Fracture is the result of a crack propagating to the point of complete separation of a part of the component



## 5.6.2 Forced fracture

5.1 Fatigue
5.2 Wear
5.3 Corrosion
5.4 Electrical erosion
5.5 Plastic deformation
5.6 Cracking and fracture
- 5.6.2 Forced fracture
- 5.6.3 Fatigue fracture
- 5.6.4 Thermal cracking

- Stress concentration in excess of the material's tensile strength
- Impact/overstressing

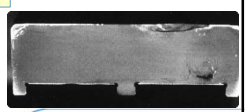




## 5.6.3 Fatigue fracture

5.1 Fatigue
5.2 Wear
5.3 Corrosion
5.4 Electrical erosion
5.5 Plastic deformation
5.6 Cracking and fracture
- 5.6.2 Forced fracture
- 5.6.3 Fatigue fracture
- 5.6.4 Thermal cracking

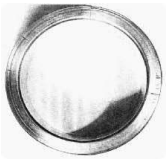
- Exceeding fatigue strength under bending
- A crack is initiated and propagated
- Causing forced fracture of rings and cages



## 5.6.4 Thermal cracking

- 5.1 Fatigue
- 5.2 Wear
- 5.3 Corrosion
- 5.4 Electrical erosion
- 5.5 Plastic deformation
- 5.6 Cracking and fracture
  - 5.6.2 Forced fracture
  - 5.6.3 Fatigue fracture
  - 5.6.4 Thermal cracking

- Heavy sliding and/or insufficient lubrication
- High frictional heat
- Cracks at right angle to sliding direction





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## How to Secure Evidence



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## Classifications: securing evidence

- Collect operating data, monitoring data
- Collect lubricant samples
- Check bearing environment(s)
- Assess bearing(s) in mounted condition
- Mark mounting position(s)
- Remove, mark and bag bearing(s) and parts
- Check bearing seats



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## Classifications: conducting the analysis

- Examine bearing(s) and parts
- Record visual observations
- Use the failure modes to eliminate improbable possible causes and determine the original cause of the failure.
- Contact external resources for assistance, if needed
- Initiate corrective action, if desired.



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# RCFA:
# A Brief Overview



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## Definition

- Root Cause Failure Analysis is a method to determine the primary cause of a failure or a problem, and to eliminate it
- It is finding the **true cause** of the problem instead of focusing on the **apparent cause**




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## An example

- Problem:
  - Your car's engine overheats and shuts down
  - What caused the engine to overheat?
- Observation:
  - The water pump belts were loose
- Solution
  - Tighten the belts

End of analysis

WRONG!



## Why was it wrong ?

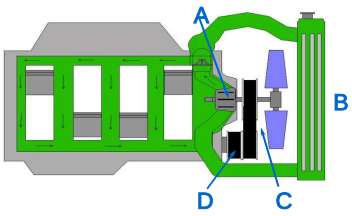
- Only a partial analysis was carried out
- Why were the belts loose?
- Leaves a returning problem...



## Using RCFA – observations

- Engine overheated and shut down
- Water pump belts loose
- Belts in good physical condition...

## Using RCFA – decomposition




A: Water Pump
B: Radiator
C: Belts
D: Engine crankshaft



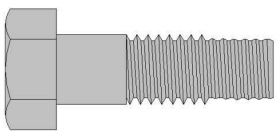
## Using RCFA – cause of overheating

- The belts are not tight enough
- Why?



## Using RCFA – the true cause of problems

- Worn bolt thread
- Replace the tensioning bolt, AND
- Verify all procedures and operating conditions



## Why, why, why, why, why?

| | |
|---|---|
| Why was the bolt stripped? | Over-tightened |
| Why was it over-tightened? | Mechanic did not use torque wrench |
| Why no torque wrench? | Not trained properly |
| Why not trained? | Time and money |



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## Questions?



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