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?
Why Failure Analysis?

First determine if the failure was **Premature** or **Natural**!

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, **congratulations**!

If the failure was **premature**, a Root Cause Failure Analysis is a must. Specially if the machine is critical for your process!
Why Failure Analysis?

How do you avoid bearing failures to happen again?

What is it that most affects the image of Maintenance?
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!
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!
Bearing Failure Modes (General)

Machine Failure Modes

- Obsolescence (15%)
- Surface degradation (70%)
- Accidents (15%)

Corrosion (20%)

Mechanical wear (50%)

Abrasion

Fatigue

Adhesion

Ref. Dr. E Rabinowicz, MIT
Simple (easy) Failure Analysis

**Example:**
Vertical pump:
Bearings: 6215 + 51115
Lubricant: Grease ISO VG460 + “Moly”.
Speed: 1500 RPM

You got 10 seconds!
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
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.
Simple (easy) Failure Analysis

Failure of Y-Units in Fin Fans

An automatic lubrication system was installed but lubricated these units as open bearings!
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!
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
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!
Required Information for the Analysis

Bearing failure:

Operation time:
15 days

Why did this bearing fail???
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!
Required Information for the Analysis

Fig 2.2d Heavy duty process pump

2 identical bearings
Required Information for the Analysis

Failure Mode + Operating conditions:

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

- Fatigue
  - Subsurface initiated fatigue
  - Surface initiated fatigue
- Wear
  - Abrasive wear
  - Adhesive wear
- Corrosion
  - Moisture corrosion
  - Frictional corrosion
  - Excessive voltage
  - Current leakage
- Electrical erosion
  - Overload
  - Indentations
  - Forced fracture
  - Fatigue fracture
  - Thermal cracking
- Plastic deformation
- Fracture and cracking

Ref.: ISO 15243 Rolling Bearings – Damages and Failures – Terms, Characteristics and Causes
Fatigue on Inner Race

No guessing. Operating conditions needed!

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Fatigue on Inner Race

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Fatigue on Inner Race

No guessing. Operational conditions needed!

Ref.: ISO 15243 Rolling Bearings – Damages and Failures – Terms, Characteristics and Causes
Overloading by excessive drive up
Fatigue, obsolete Design

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

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

Ref.: ISO 15243 Rolling Bearings – Damages and Failures – Terms, Characteristics and Causes
Fatigue, Cavitation
Surface initiated Fatigue

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

Ref.: ISO 15243 Rolling Bearings – Damages and Failures – Terms, Characteristics and Causes
Insufficient Lubrication - Metal to Metal Contact

Mirror like appearance

Ref.: ISO 15243 Rolling Bearings – Damages and Failures – Terms, Characteristics and Causes
Insufficient Lubrication - Pitting

Ref.: ISO 15243 Rolling Bearings – Damages and Failures – Terms, Characteristics and Causes
Fatigue initiated by Corrosion

Initiated by corrosion!

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

Both mirror type surface and pitting

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

Both mirror type surface and pitting

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

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

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

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

Advanced abrasive wear led to heavy vibrations increasing the damage

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

- Fatigue
- Wear
- Corrosion
- Electrical erosion
- Plastic deformation
- Fracture and cracking

Abnormal Wear

- Abrasive wear
- Adhesive wear

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

Ref.: ISO 15243 Rolling Bearings – Damages and Failures – Terms, Characteristics and Causes
Smearing due to Sliding

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

Possible causes?

Causes:
- Excessive internal clearance.
- Poor lubrication.

Ref.: ISO 15243 Rolling Bearings – Damages and Failures – Terms, Characteristics and Causes
Heavy sliding both on inner and outer diameter

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

- Fatigue
- Wear
- Corrosion
- Electrical erosion
- Plastic deformation
- Fracture and cracking

Moisture corrosion
Frictional corrosion
Fretting corrosion
False brinelling

- Corrosion / rust
- Chemical reaction.
- Fatigue.

Ref.: ISO 15243 Rolling Bearings – Damages and Failures – Terms, Characteristics and Causes
When is water in the oil most dangerous: During operation or stand still?

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

Corrosion at stand still

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

- Small relative movements in between the mating surfaces
- Oxidation of the wear particles.

Fatigue
Wear
Corrosion
Electrical erosion
Plastic deformation
Fracture and cracking

Moisture corrosion
Frictional corrosion
Fretting corrosion
False brinelling

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

Ref.: ISO 15243 Rolling Bearings – Damages and Failures – Terms, Characteristics and Causes
Fretting Corrosion
Fractures caused by heavy Fretting corrosion

Ref.: ISO 15243 Rolling Bearings – Damages and Failures – Terms, Characteristics and Causes
False Brinelling, Marks made by Vibrations

- 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.

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

Ref.: ISO 15243 Rolling Bearings – Damages and Failures – Terms, Characteristics and Causes
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
False Brinelling (Gearbox)

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

- High voltage = electric arks.
- Instantaneous overheating at the contacts leading to fusions and weldings.
- Craters up to 100 µm in diameter.

Ref.: ISO 15243 Rolling Bearings – Damages and Failures – Terms, Characteristics and Causes
Electrical Erosion – Excessive Voltage

Ref.: ISO 15243 Rolling Bearings – Damages and Failures – Terms, Characteristics and Causes
Electrical Erosion – Current Leakage

- 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.

Ref.: ISO 15243 Rolling Bearings – Damages and Failures – Terms, Characteristics and Causes
Electrical Erosion – Current Leakage

Look at the rolling elements to differentiate between vibration or electric current damages.
Electrical Erosion – Current Leakage

Ref.: ISO 15243 Rolling Bearings – Damages and Failures – Terms, Characteristics and Causes
Electrical Erosion – Current Leakage
Permanent deformation occurring whenever the yield strength of the material is exceeded.

Microscale or a microscale.

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

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

Cage damaged by direct impacts during mounting

Ref.: ISO 15243 Rolling Bearings – Damages and Failures – Terms, Characteristics and Causes
Customer: “We do not accept plastic cages”

Me: “Why not?”

Customer: “Because plastic cages do not resist strokes or impacts.”
Inappropriate Handling

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

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

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

Determine the origin of the debris!

Ref.: ISO 15243 Rolling Bearings – Damages and Failures – Terms, Characteristics and Causes
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
- Fracture and cracking
- Overload
- Indentaciones
- Indentations from debris
- Indentations by handling

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

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Indentations by Handling

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

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

Wear

Corrosion

Electrical erosion

Plastic deformation

Fracture and cracking

Subsurface initiated fatigue

Surface initiated fatigue

Abrasive wear

Adhesive wear

Moisture corrosion

Frictional corrosion

Excessive voltage

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Forced fracture

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False brinelling

Indentations from debris

Indentations by handling

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

**Failure causes:** 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???
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 the machine.
The seal is a radial contact seal mounted in the wall.
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!**