Motor Bearing Damage and Variable Frequency Drives:
- Diagnosing the Causes,
- Implementing a Cure, and
- Avoiding the Pitfalls

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Anatomy of an AC induction motor

AC current in the stator windings produces a rotating magnetic field.

This generates a current in the rotor bars, which makes its own magnetic field.

The interaction of the two magnetic fields produces the motor’s torque.
The frequency of the AC in the stator controls the speed of the motor.
How does a variable frequency drive (VFD) work?
How does a variable frequency drive (VFD) work?
How is a VFD different from the AC power line?

**Fast-rising pulses**

AC Line-to-Ground Voltage

The voltage of the AC power line changes gradually from minimum to maximum in about 8 ms.

PWM Voltage Pulses

The voltage from the PWM VFD can change from minimum to maximum in less than 1 µs (0.001 ms).
Fast-rising pulses

- Fast-rising voltage pulses can readily induce voltage across the air gap between the motor’s stator and its rotor
- This can drive stray currents in the motor

How is a VFD different from the AC power line?
Circulating currents

- Asymmetries in the motor can result in a circulating current between the motor's frame and the motor's shaft
- This seldom happens in motors < 50 HP; more common in 480 V and higher voltage AC motors
What causes bearing currents in smaller motors?

**Common mode voltage**

AC Line-to-Ground Voltage

- When powered from a balanced center-grounded wye transformer, the net voltage with respect to ground is always 0 V (*no common mode voltage*)
- Common mode voltage can induce voltage on the motor’s shaft
What causes bearing currents in smaller motors?

Common mode voltage

- When powered from a VFD, only two voltages (+ & -) make the three-phase voltage to the motor.
- The 3-phase voltage applied to the motor isn't balanced with respect to ground.
What causes bearing currents in smaller motors?

Common mode voltage

- If the stator has a net positive voltage, it will induce a positive voltage onto the shaft.
- If the voltage on the shaft is high enough, current will arc through the grease in the bearings.
How can you detect the onset of bearing damage?

- Noise from the bearings
  *That's a bit late*
- Motor vibration
  *That's a bit late and difficult*
- Measure the current
  *That's hard to do*
- Measure the shaft voltage
  *There's an idea*
How can you detect the onset of bearing damage?

Measuring shaft voltage

- Use a brush to contact the motor’s shaft
  - Home-made: fine steel wool brush
  - Commercial: carbon fiber brush
How can you detect the onset of bearing damage?

Measuring shaft voltage

• Use a magnetic stand to hold the brush in place
How can you detect the onset of bearing damage?

Measuring shaft voltage

• Use a digital storage oscilloscope to capture the motor shaft voltage
  • Use the trigger function to capture the highest shaft voltages
  • Save the waveforms in computer files
How can you detect the onset of bearing damage?

Interpreting the voltage waveforms

- The shaft voltage smoothly increases and then quickly drops due to a discharge

28.8 V peak

1 µs/div
Interpreting the voltage waveforms

How can you detect the onset of bearing damage?

- The shaft voltage oscillates, but no sharp drop is detected
- No shaft current was present
How can you detect the onset of bearing damage?

Remotely detecting bearing discharges

- When a discharge occurs, it generates a pulse of electromagnetic noise, like radio static
- A hand-held radio frequency detector can detect the “static” and count the discharges
How can you detect the onset of bearing damage?

Non-contact detection of bearing discharges

• Advantages
  • Little set-up is required
  • Counts the discharges over time
• Concerns
  • Proper positioning of the meter is required for accurate readings
  • Practice and experience are required
Identifying the cause of bearing damage

Not all bearing damage is caused by bearing current

• There are also mechanical causes for bearing damage
• Before implementing a solution, it is important to understand the cause of the problem
  • Study the damage to the bearings
  • Ideally, the grease in the bearing should not be cleaned away before the bearing is submitted for evaluation
Identifying the cause of bearing damage

Images of damaged bearings

- Classic bearing fluting, likely caused by shaft voltage discharges
Identifying the cause of bearing damage

Bearing electrical arc damage process

• Damage occurs when current passes through bearing
• Oil film between balls and raceways acts as an insulator
• Film is only microns thick at most
• Shaft voltage can exceed ‘dielectric strength’ (when insulating property fails) of film
• Arcing occurs – melting a minute area of surfaces
• Melted metal enters grease or is rolled over onto raceways
• Initially forms a dull grey ‘frosted’ or matte appearance
• Fluting can develop with continued arcing
Identifying the cause of bearing damage

Initial electrical arc damage

- A frosted ball path appears
  - Potentially electrical arc damage
  - Potentially lubrication contamination
- Extreme magnification required to verify
  - Scanning electron microscope
  - Confocal microscope
Identifying the cause of bearing damage

Advanced electrical arc damage – Fluting

• Overlapping arcs
• Fluting’s repetitive appearance related to dynamic system of arcing and rolling motion
Identifying the cause of bearing damage

Images of damaged bearings

- Electrical arc damage similar to electric discharge machining (EDM) process
- Bearing surface material removed
Images of damaged bearings

- Likely caused by shaft voltage discharges, made worse by a large radial load.

- With light radial loading, the insulating grease layer is uniform and thick.

- A large radial load reduces the thickness of lubricant in the load zone.
Identifying the cause of bearing damage

Possible solutions for this problem

• Belt drive application:
  • Reduce the belt tension
  • Use larger diameter sheaves on the motor and the load

• When the load is shaft-mounted:
  • Mount the load as close to the motor as possible
  • Reduce the weight of the load
  • Use external bearing(s) to support the load
  • Increase the minimum speed
Identifying the cause of bearing damage

Why increase the minimum speed?

- Test on three motors with radial loads
Identifying the cause of bearing damage

Not all bearing damage is caused by bearing current

- The motor made a “clicking” noise when it was rotated slowly
- A fluting pattern is too dense to make such a sound
- The shaft voltage and hand-held detector showed no discharges

![Graph showing 2.84 V and 5 µs/div](image)
Identifying the cause of bearing damage

Study of the bearings

- The races of the bearing showed regularly spaced marks
- The spacing of the marks was the same as the spacing of the balls in the cage of the bearing
Identifying the cause of bearing damage

Diagnosis: False Brinelling

- The motor was driving a shaft-mounted fan wheel
- It appears that the problem was caused by vibration during shipping
Identifying the cause of bearing damage

Other mechanical damage: Brinelling

• Brinelling is generally caused by a sharp impact on the bearing
• This causes an indent in the bearing’s race
• It often indicates damage during the assembly of the equipment
Identifying the cause of bearing damage

Summary

- Not all bearing damage is the result of electrical discharges through the bearings
  - Mechanical damage
  - Lubrication problems
    - Too little
    - Too much
    - Contamination
  - Overloading
- It is important to know the problem before developing a solution
Avoiding bearing discharge currents

A variety of solutions are available

1. Proper wiring
2. VFD adjustments
3. System maintenance
4. High frequency toroids
5. Blocking the discharge
6. Re-routing the discharge
Avoiding bearing discharge currents

1. Proper wiring

- The VFD sends pulses with high frequency content to the motor
- It is important to provide a low impedance return path for the high frequencies to protect the...
  - ... motor bearings
  - ... the building from radio frequency noise
1. **Wiring: only a safety ground**

- The VFD sends pulses with high frequency content to the motor.
- It is important to provide a low impedance return path for the high frequencies to protect the...
  - ... motor bearings
  - ... the building from radio frequency noise

**Radio frequency noise in the facility**
Avoiding bearing discharge currents

1. **Wiring**: only a safety ground

   ![Wiring Diagram]

   - **Lab test**
   - **60 ft cable**

   ![Graph with 24 V and Discharge label]
Avoiding bearing discharge currents

1. **Wiring: traditional ground, motor to VFD**

  - Normally sized ground wire
  - No conductive conduit
Avoiding bearing discharge currents

1. **Wiring**: large ground and conductive sheath

   - 1-3 large ground wires with large strand count
   - Ground wires are close to the motor wires; this reduces magnetic fields to minimize impedance
   - Grounded, conductive shield around all of the wires

* With VFD’s RFI/EMC filter engaged
Avoiding bearing discharge currents

1. **Wiring:** large ground and conductive sheath

![Diagram showing electrical connections and voltage readings]

**Lab test**
- 60 ft cable

![Graph showing voltage readings with no discharge]

0.92 V
No discharge
Avoiding bearing discharge currents

1. **Proper wiring**

- **Advantages**
  - No maintenance required
  - Can have a major impact

- **Concerns**
  - Requires attention to details
  - VFD cable can be expensive, but it is not absolutely necessary; carefully installed conduit can be used
Reducing bearing discharge currents

2. **VFD adjustments**

- Enter the motor nameplate data
- Activate energy optimization in the VFD
  - Both minimize the motor current
- Reduce the switching frequency
  - Cutting the pulse rate reduces the number of possible discharges
- Increase the minimum frequency
  - Helps center a radially-loaded shaft
  - A “sleep” function could stop the motor automatically
Avoiding bearing discharge currents

2. **VFD adjustments**

- **Advantages**
  - Easy to implement

- **Concerns**
  - Mostly only extends the life of the bearings; doesn’t eliminate the problem
Avoiding bearing discharge currents

3. **System maintenance**

- Check belt tension
- Check shaft alignment
- Check balancing of the load
- Check bearing lubrication
- Check environmental concerns
Avoiding bearing discharge currents

3. **System maintenance**

- **Advantages**
  - Should be done anyway

- **Concerns**
  - May not be the problem
Avoiding bearing discharge currents

4. **High frequency toroids**

- A high frequency toroidal core concentrates the magnetic field of high frequency currents passing through it, impeding their flow.
- It can be used in two ways:
  - To combat common mode voltage and current.
  - To combat the high frequency components of pulses to the motor.
Avoiding bearing discharge currents

4. **High frequency toroids**

- Common mode filter
- Built into the VFD

There are other designs of common mode filters
Avoiding bearing discharge currents

4. High frequency toroids

- Common mode filter
  - Added between the VFD and the motor

The ground wire does not pass through the toroid
Avoiding bearing discharge currents

4. **High frequency toroids**

- High frequency filters, for circulating currents
- Added between the VFD and the motor

The ground wire does not have a toroid around it
Avoiding bearing discharge currents

4. **High frequency toroids**

   - **Advantages**
     - No maintenance required
     - Can be retrofit in most situations
   
   - **Concerns**
     - Requires proper wiring between the VFD and the motor
5. Blocking the discharge: insulating sleeve

- Doesn’t need to block a particularly high voltage
- There are a number of ways to block the flow of current through a motor’s bearings
  - Add an insulating sleeve between the bearing and the motor
Avoiding bearing discharge currents

5. **Blocking the discharge: insulating sleeve**

- **Advantages**
  - Blocks current flow through the bearing

- **Concerns**
  - For retrofits, requires disassembling and machining of the motor
  - Conductive dirt across the sleeve
  - For common mode shaft voltage, both bearings must be insulated
  - May transfer bearing damage to the connected load unless an insulated coupling is used
Avoiding bearing discharge currents

5. **Blocking the discharge: insulated bearings**

- Insulated bearings are of two general types:
  - With rolling elements made of a non-conductive material, such as a ceramic
  - Using an inner and/or outer ring with an electrically insulated mounting surface
- In most case, this does not impact the mounting dimensions of the bearing
Avoiding bearing discharge currents

5. **Blocking the discharge: insulated bearings**

- **Advantages**
  - Blocks current flow through the bearing
  - Can be a drop-in replacement

- **Concerns**
  - For common mode shaft voltage, both bearings must be insulated
  - May transfer bearing damage to the connected load unless an insulated coupling is used
  - When the rolling element is non-metallic, the ratings of the bearing may be impacted
Avoiding bearing discharge currents

6. Re-routing the discharge

- By electrically “grounding” the motor’s shaft to the motor’s frame, shaft voltage can be dissipated around the bearing as long as the low impedance conductive path is maintained
- A number of methods are available
Avoiding bearing discharge currents

6. Re-routing the discharge
   - Rotary contact
   - Spring-loaded carbon brush
   - Conductive fiber brush
Avoiding bearing discharge currents

6. **Re-routing the discharge**

- **Advantages**
  - Can generally be retrofitted in the field
  - For common mode voltage, only one may be needed

- **Concerns**
  - For circulating current, using only one only makes the problem worse
  - Often, insulating the other bearing is recommended
Avoiding bearing discharge currents

6. Re-routing the discharge

- Concerns, *continued*
  - For large motors, multiple devices may be needed
  - Proper mounting and shaft preparation are essential
  - Environmental conditions may impact its operation
  - May require periodic inspection and/or maintenance

This band formed under the brushes.
VFDs and Motor Bearing Damage

Review

• Background on motors, VFDs and bearing currents
• How to detect bearing current
• How to diagnose causes of bearing damage
• How to avoid damage due to bearing current

Questions?