Company Name
Street
City
Postcode
Country

Dear [Recipient name]

Re: JPS Reliability: **Shaft Voltage Testing Report**

I would firstly like to thank you for the courtesy and co-operation shown to JPS Reliability Limited during my recent site visit. Following the survey at your facility I have pleasure in presenting for your attention a Shaft voltage Testing report.

Please contact JPS Reliability Limited for any machinery reliability issues or required health verification, we offer full technical/diagnostic back up which includes:

- Conventional vibration analysis
- Phase analysis
- Resonance testing
- Bearing / gear analysis
- Oil analysis
- On Site dynamic fan balancing
- Laser alignment
- Thermal imaging
- Ultrasonic air leak energy saving surveys
- Shaft Voltage Bearing discharge surveys
- Motion Amplification surveys

Date of survey:

- 14/04/2021

Executive Summary:

- The Electromagnetic interference within the system increases greatly when switched from direct online to the variable speed drive
- The variable speed drive has clear indications of current discharge through the bearings with a peak to peak at over 29 Volts
- The vibration data was the first indication of lubrication deterioration due to the voltage discharge through the bearing from the drive operation
- The optimum electrical cables have not been installed and there is poor/no high frequency earthing

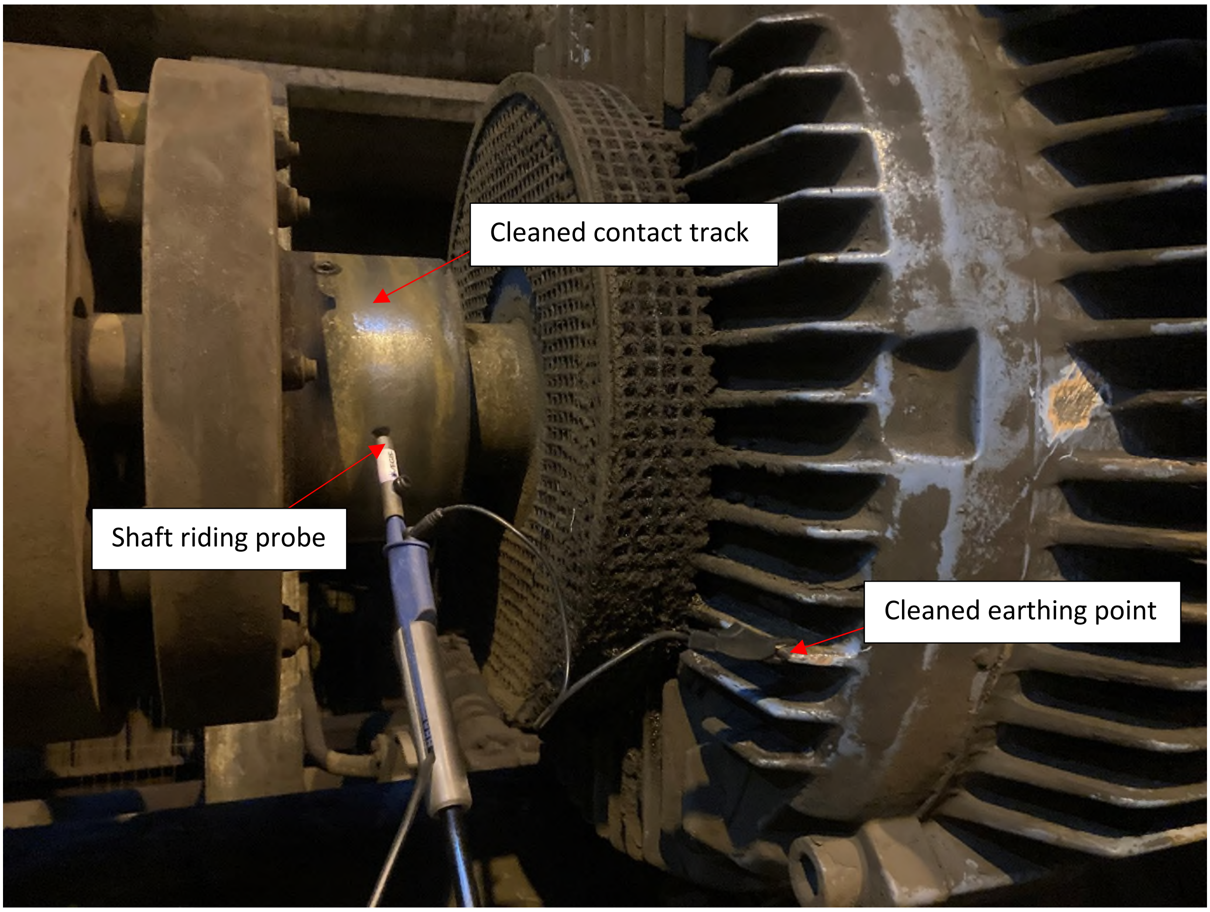
Contents

Configuration:

Instrumentation:
Fluke 190-202 Scope Meter, 200 MHz, 2.5 GS/s. Fluke 10:1 voltage probe. AEGIS® SVP - Shaft Voltage Probe Test Kit

Methodology:
To test for VFD induced shaft voltages

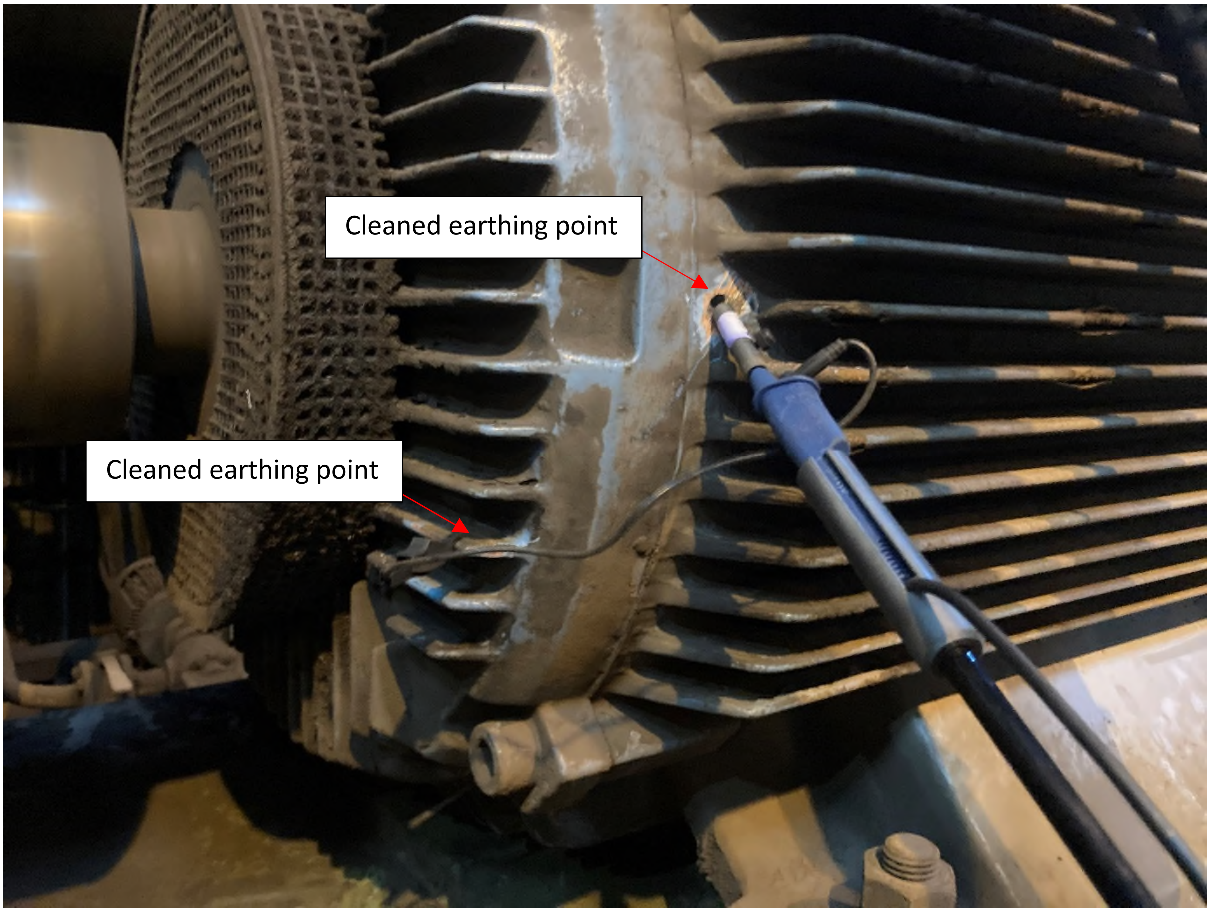
Image of setup:



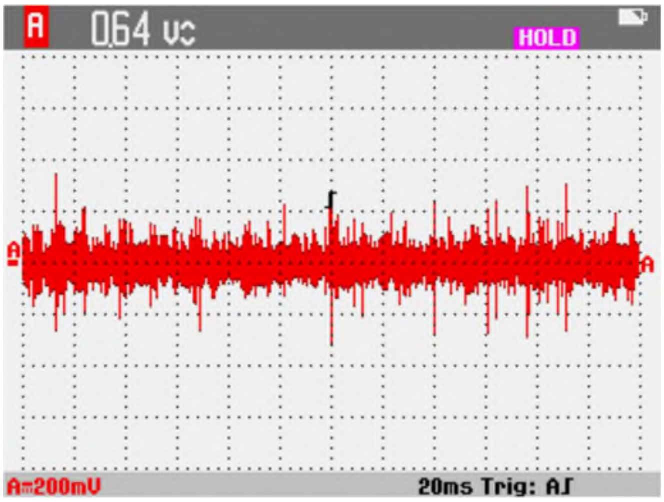
Electrical Discharge Testing Data EMI

This reading displays ground noise or EMI (Electromagnetic interference) within the system being produced by the motor/drive system; this is inherent in the system.

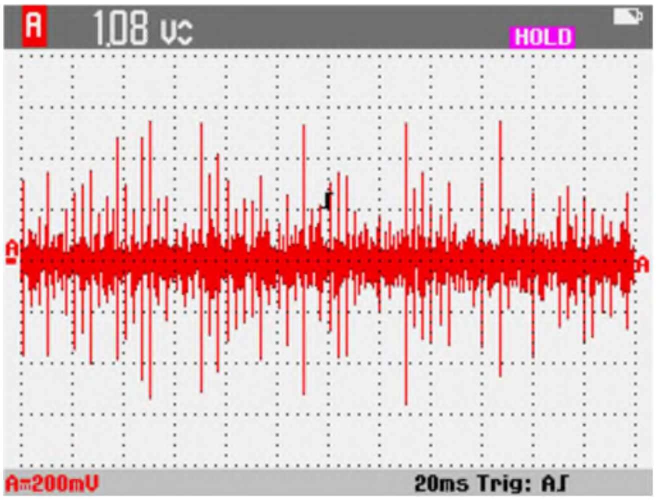
We tested the EMI when running direct online & running with the variable speed drive at 25Hz and 50Hz.



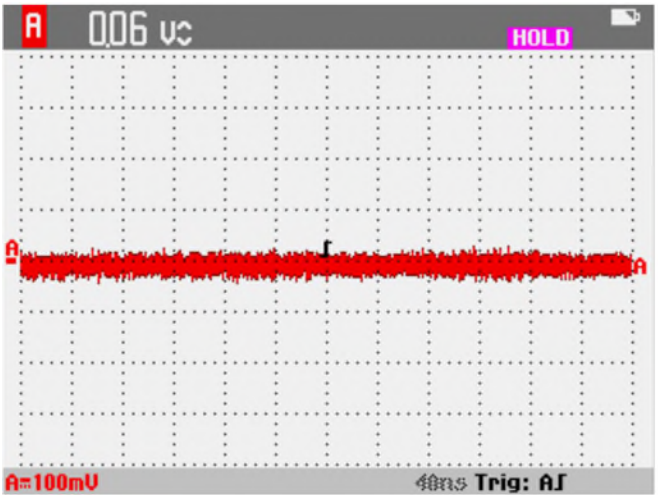
Reading 1 with the Drive at 25Hz

Reading 1 EMI Ground Reference Reading	Motor	Variable Speed Drive 25Hz
	Drive Hz	25Hz
Observation: There is induced EMI activity when at 25Hz drive speed.		

Reading 2 with the Drive at 50Hz

Reading 2 EMI Ground Reference Reading	Motor	Variable Speed Drive 50Hz
	Drive Hz	50Hz
Observation: When increased to the max drive speed the EMI activity increased with clear peaking activity, still low at 1.08V.		

Reading 3 direct online, low levels as expected with no EMI compared to the variable frequency drive.

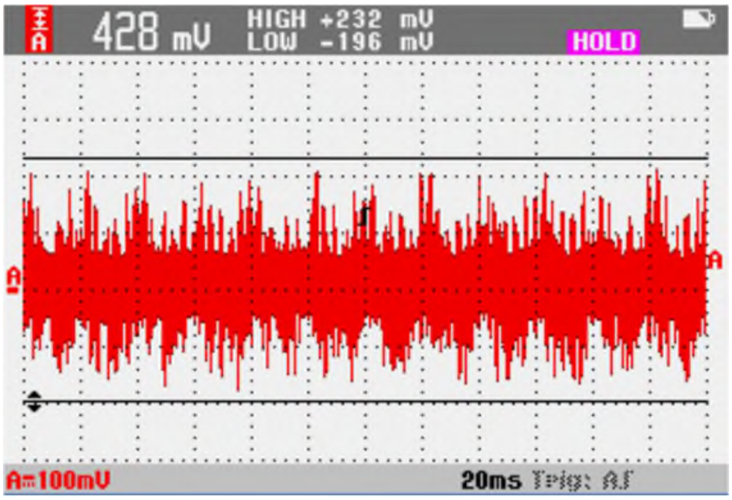
Reading 3 EMI Ground Reference Reading	Motor	Direct on Line 50Hz
	Drive Hz	50Hz
Observation: 0.06 V, no issues.		

JPS Reliability
A Reliable Plant is a Profitable Plant

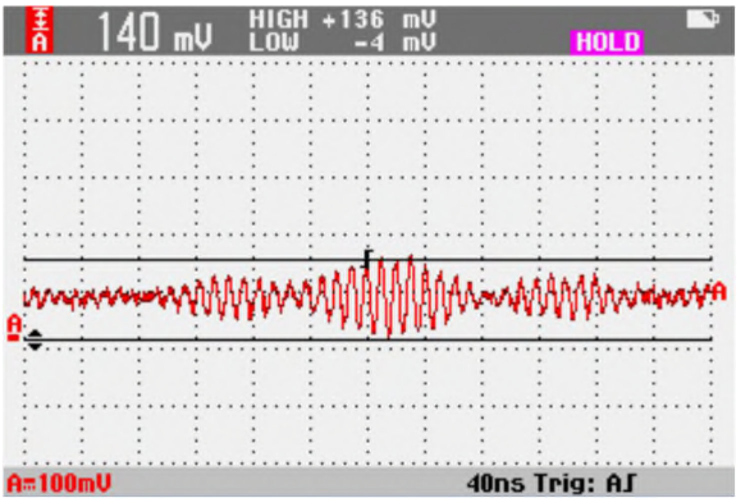
Electrical Discharge Testing Data DOL

Testing of the electrical discharge through the motor bearings when direct online

Reading 4 direct online, low levels as expected.

Reading 4	Motor	Direct on Line 50Hz
DOL	Drive Hz	50Hz
Observation: 428mV – No issues		

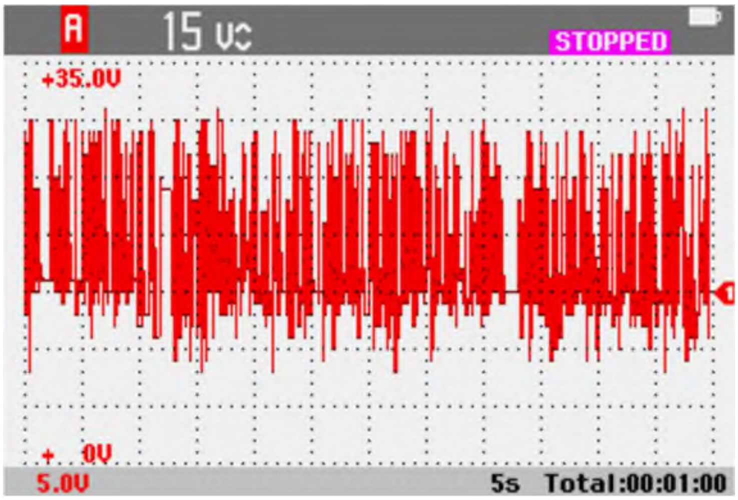
Reading 5 direct online, zoom in feature used to look for any discharges

Reading 5	Motor	Direct on Line 50Hz
DOL	Drive Hz	50Hz
Observation: On this section of the waveform no discharges and a low 140mV		

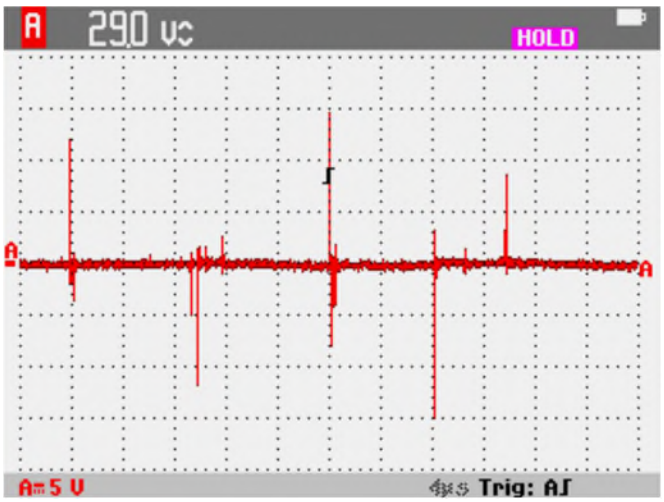
Electrical Discharge Testing Data VFD

Testing of the electrical discharge through the motor bearings when on the variable frequency drive

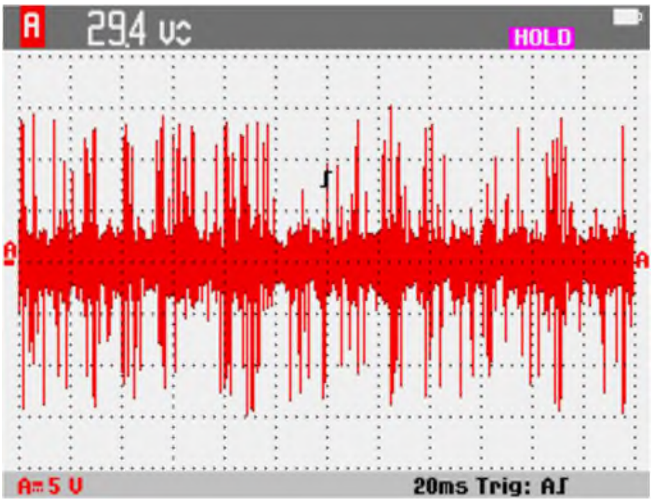
Reading 6 is a time trace peak trend for one minute with the drive at 25Hz.

Reading 6 VFD	Motor	Variable Speed Drive 25Hz
	Drive Hz	25Hz
Observation: This is a one-minute time trace and shows discharges spiking up and down to just over 30V.		

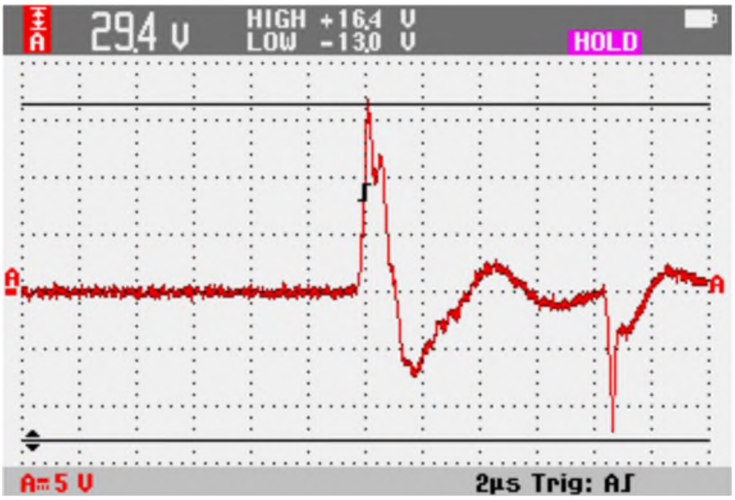
Reading 7 is a waveform showing the random discharges up to 29V peak to peak

Reading 7 VFD	Motor	Variable Speed Drive 25Hz
	Drive Hz	25Hz
Observation: Typically, EDM discharges can occur from 20 to 80 volts peak to peak, depending on the motor, the type of bearing, the age of the bearing, and other factors. This waveform image shows an increase in voltage to 29 volts peak to peak with a sharp vertical line indicating a voltage discharge.		

Reading 8 is a waveform showing the random discharges + 29V with the drive at 50Hz

Reading 8	Motor	Direct on Line 50Hz
VFD	Drive Hz	50Hz
Observation: When at full drive frequency the discharges were clearer. This shows the multiple fast discharges up to 29.4 volts peak to peak.		

Reading 9 is a zoom into one of the high frequency discharges

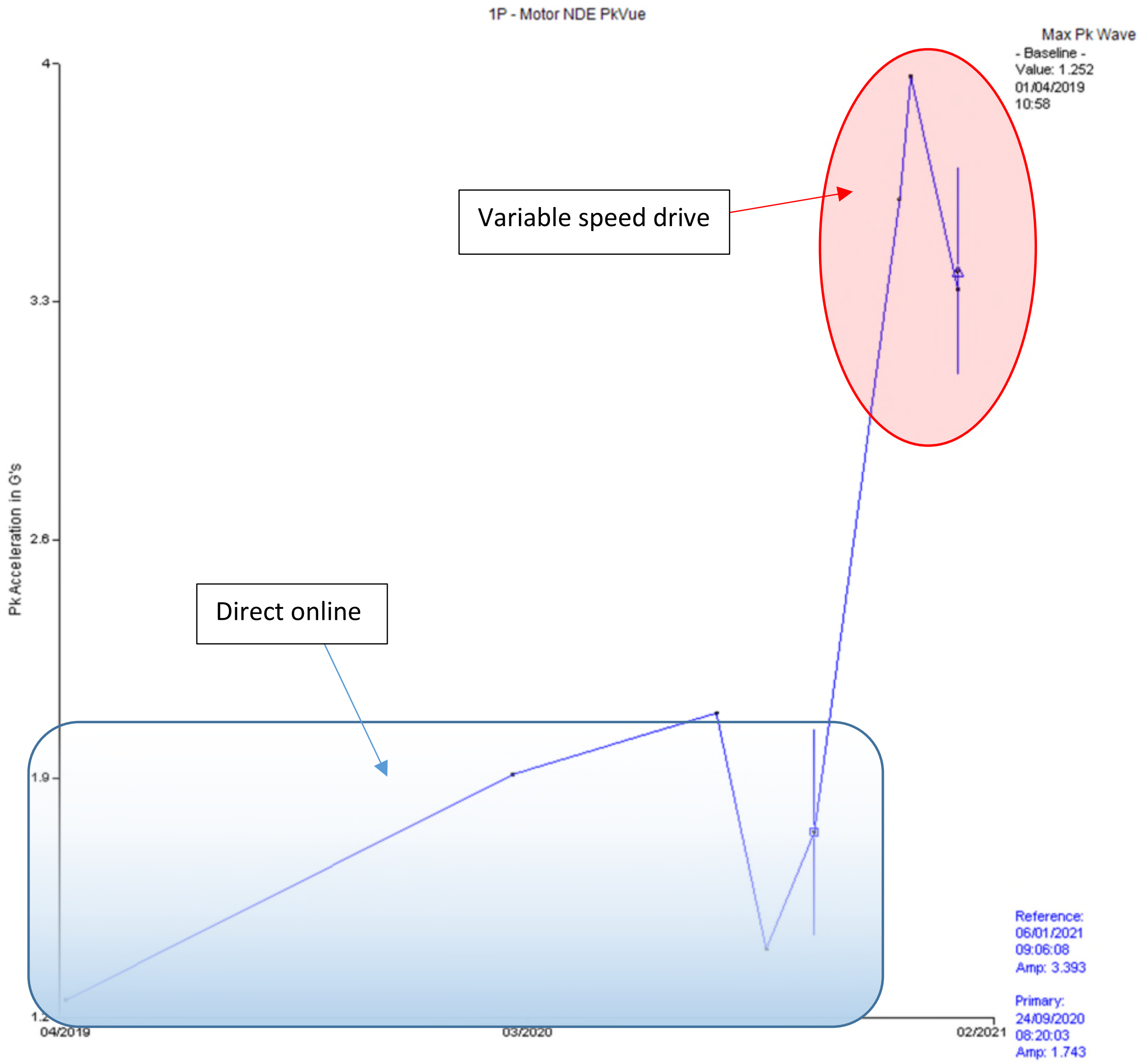
Reading 9	Motor	Direct on Line 50Hz
VFD	Drive Hz	50Hz
Observation: High frequency discharges at EDM level of 29.4 volts peak to peak		

Vibration Data

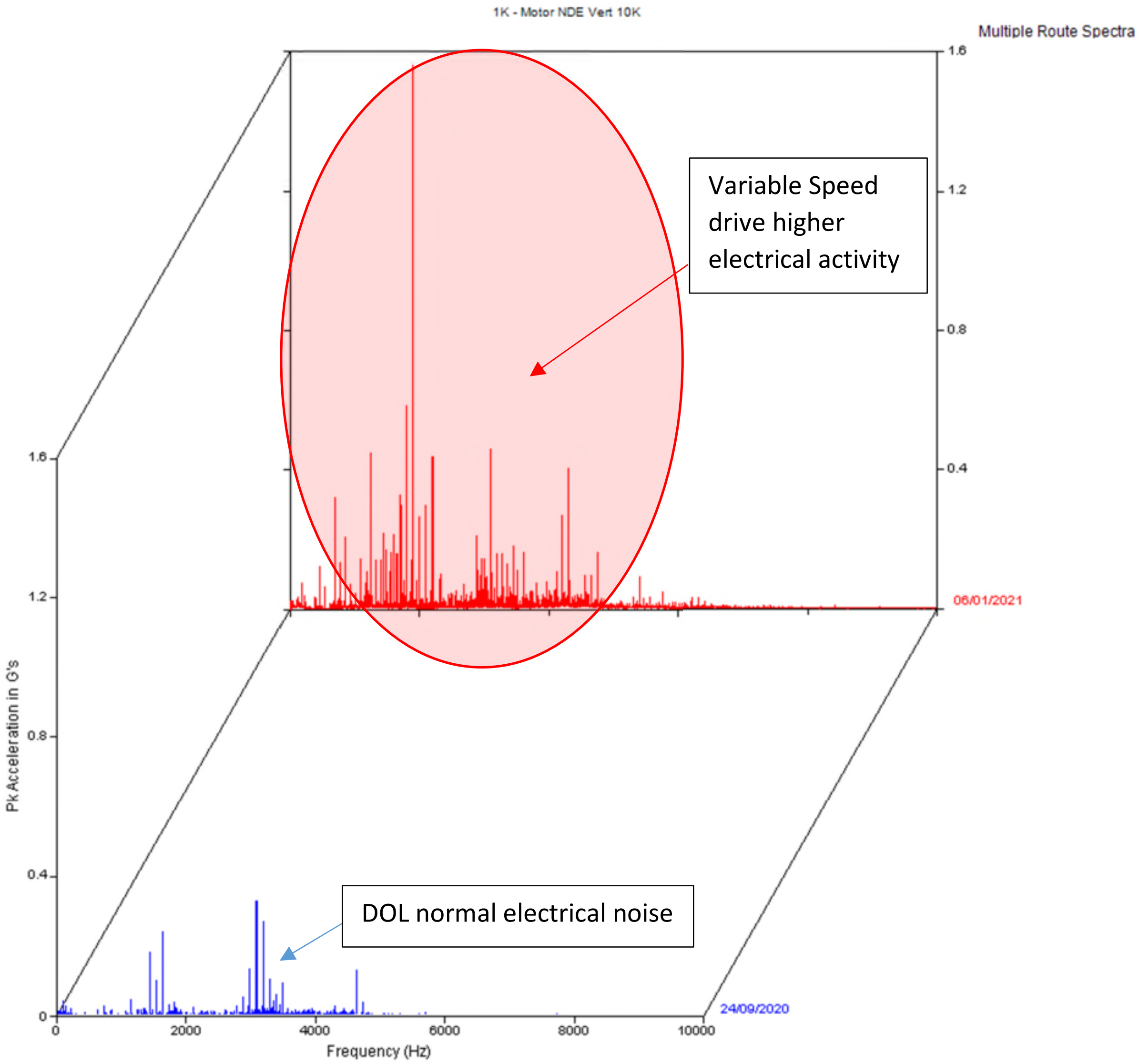
It has also been noted that since the variable frequency drives have been in operation the lubrication condition of the bearings have been deteriorating. This is an indication that the high frequency discharges are causing the grease to deteriorate.

Burnt Grease: Continuous electrical arcing in the motor bearings will often rapidly deteriorate the lubricating capability of the grease and cause bearing race damage. When an arc occurs, the oil component of the grease is heated beyond its temperature capacity.

This is a trend of the bearing PeakVue levels. This shows the high increase in the bearing levels once the drive was in operation.



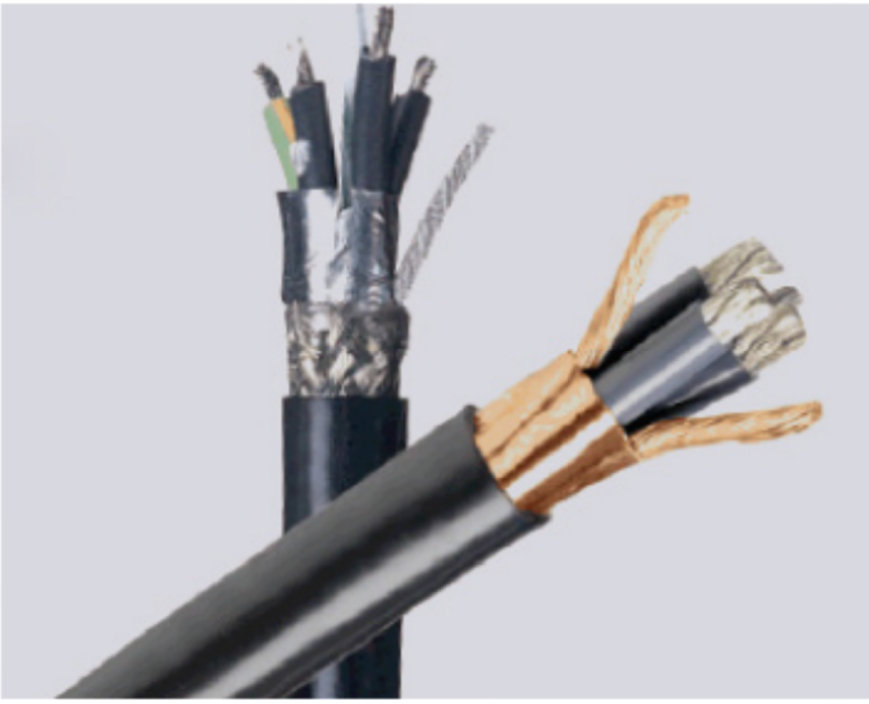
This is a comparison of the direct online (blue) and variable speed drive (red) vibration Acceleration spectra.



Solution(s):

The ideal solution to affect the high frequency bearing currents are a proper cabling and earthing system; breaking the bearing current loops; and damping the high frequency common mode current. This would require.

- Symmetrical multicore VFD motor cables. The earth connector arrangement in the motor cable must be symmetrical to avoid bearing currents at fundamental frequency. This is achieved by an earthing conductor surrounding all the phase leads or a cable that contains a symmetrical arrangement of three phase leads and three earth conductors.
- Short impedance path. The best and easiest way to do this is to use shielded motor cables, the shield must be continuous and of good conducting material and the connections at both ends needs to be made with 360º termination.
- Add high frequency bonding connections between the installation and known earthing reference points to equalise the potential of affected items use braided flat straps of copper 50-100mm wide.
- Fit an insulated bearing at the NDE



Example of VFD cabling

Where there are financial limitations to affect the correct solution the below can be used to mitigate this failure mode.

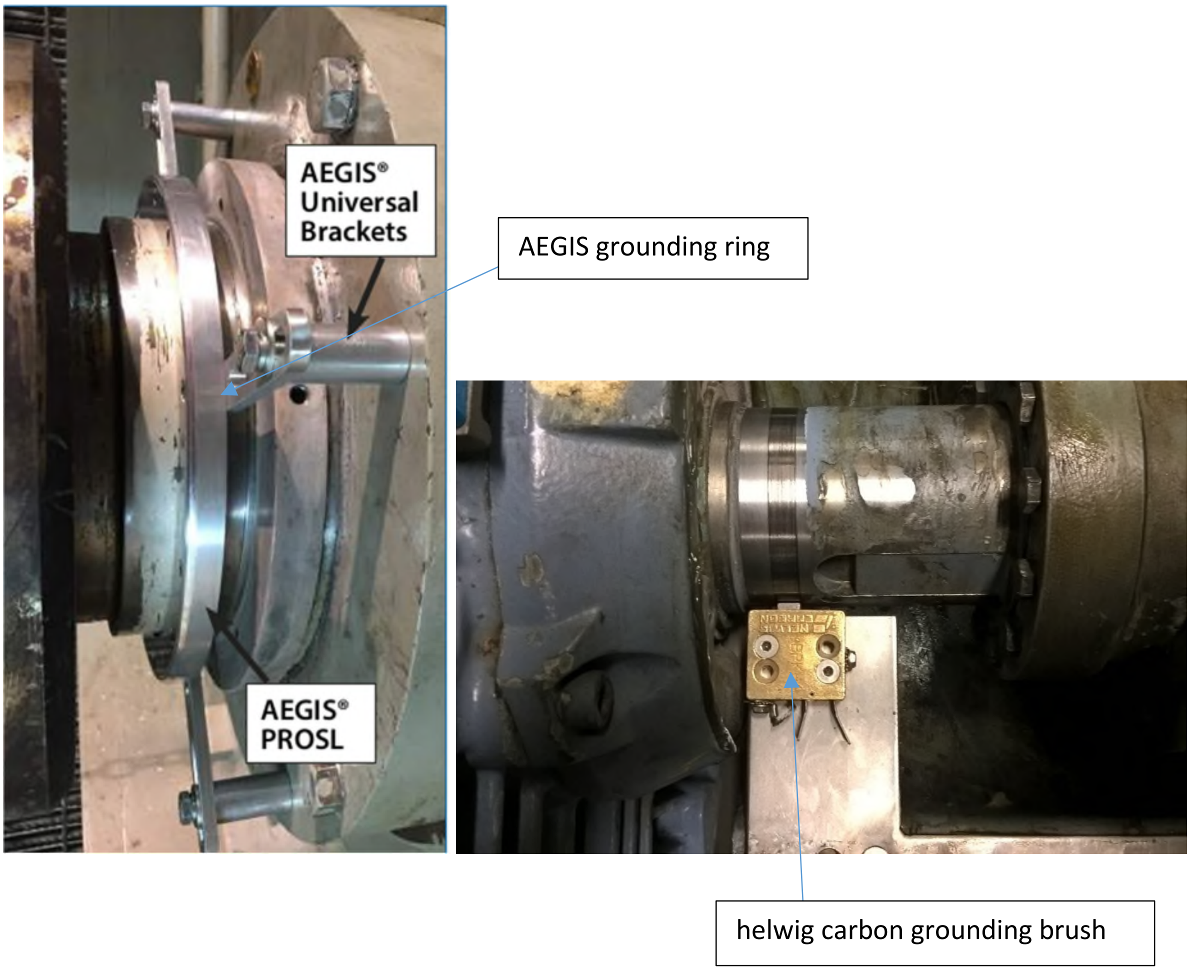
There are other approaches that can be installed and trailed to reduce the effect of the voltage discharge though the bearing, this comprises methods of earthing the motor DE shaft / filtering the signal

- Electrical filters
- Earthing rings
- Earthing brushes

In your application you would need to

- Fit an insulated bearing to the NDE of the motor
- Install proper high frequency grounding straps. Ideally from the motor terminal box to the back panel of the variable frequency drive main earth
- Install high frequency grounding staps across the asset to the local earth
- Install a shaft earthing solution at the DE

Shaft grounding is available in many versions, here are the most common solutions.

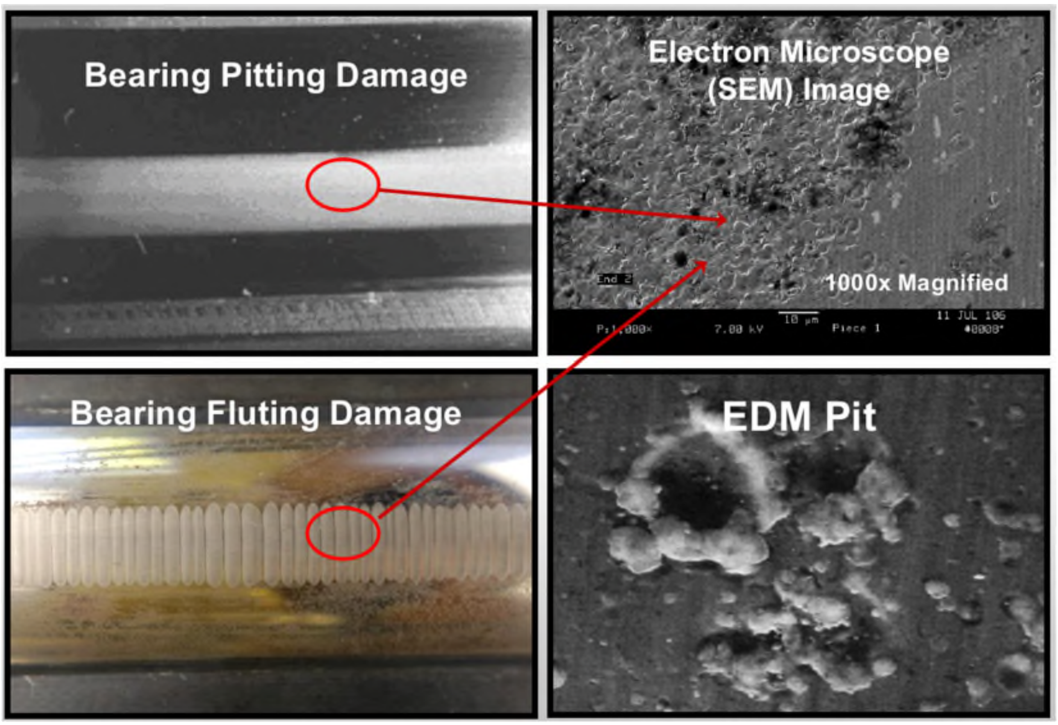


Appendix A: Aegis 'What is EDM Electrical Discharge Machining?'

Because of the high-speed switching frequencies in Pulse Width Modulation (PWM) inverters, variable frequency drives induce capacitively coupled shaft voltages in the electric motors they control. The high frequency switching speed of insulated-gate bipolar transistors (IGBT) used in these drives produce common mode voltages on the motor's shaft during normal operation through parasitic capacitance between the stator and rotor. These voltages, which can register 10-40 volts peak, are easily measured by touching an AEGIS® Shaft Voltage Probe™ to the motors shaft while the motor is running. A Digital Oscilloscope allows the voltages to be viewed and recorded for analysis.

Once these voltages reach a level sufficient to overcome the dielectric properties of the bearing grease, they arc through the motor's bearings, discharging along the path of least resistance to the motor's housing. During virtually every VFD switching cycle, induced shaft voltage discharges from the motor's shaft to the frame via the bearings, leaving a small fusion crater (fret) in the bearing race.

These discharges are so frequent (potentially millions per hour) that before long the entire bearing race surface becomes damaged with countless pits known as frosting. A phenomenon known as fluting may occur as well, producing washboard-like ridges across the frosted bearing race. Fluting causes audible noise and vibration and is an indication of a catastrophic failure mode. Regardless of the type of rolling element or raceway damage that occurs, the resulting motor failure often costs thousands of pounds in downtime and equipment failure related repair or replacement costs.



Failure rates vary widely depending on many factors, but evidence suggests that a significant portion of failures occur in only 3 to 12 months after system start-up. All AC and DC motors operated by electronic drives or inverters have the potential of developing this failure in their bearings regardless of motor frame size or horsepower.

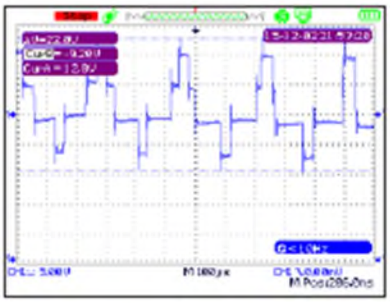
Typically, EDM discharges can occur from 20 to 80 volts peak to peak (10 to 40 volts peak) depending on the motor, the type of bearing.

Reference: Aegis Handbook

Appendix B: Aegis 'Examples of Shaft Voltage Discharge'

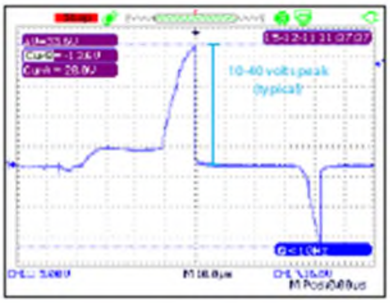
High Peak to Peak common mode voltage –
Typically 20 to 120 volts peak to peak (10 to 60 volts peak). The waveform image shows the capacitive coupled common mode voltage on the shaft of the motor. The "six-step" wave form is the result of the 3 phases of pulses from the VFD. The timing of the pulse width modulation (PWM) pulses to the motor from the drive determines what the waveform looks like. Sometimes it will look like a square wave.

This six-step or square wave is what is seen when there is no bearing discharge and the peak to peak shaft voltage is at its maximum level. The voltage level may eventually overcome the dielectric in non-isolated bearings and begin discharging.

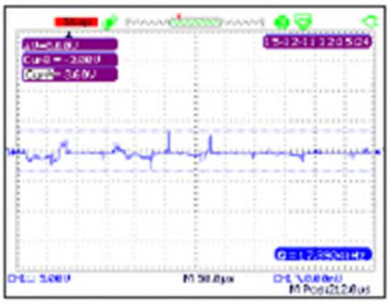


High amplitude EDM discharge pattern –
Typically EDM discharges can occur from 20 to 80 volts peak to peak (10 to 40 volts peak) depending on the motor, the type of bearing, the age of the bearing, and other factors. The waveform image shows an increase in voltage on the shaft and then a sharp vertical line indicating a voltage discharge. This can occur thousands of times in a second, based on the carrier frequency of the drive. The sharp vertical discharge at the trailing edge of the voltage is an ultra high frequency dv/dt with a typical "discharge frequency" of 1 to 125 MHz (based on testing results in many applications).

Reference: NEMA MG1 Section 31.4.4.3

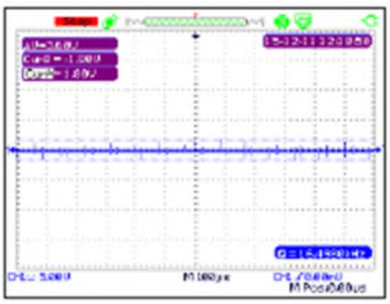


Low amplitude voltage discharge pattern –
Typically the voltages are 4 to 15 volts peak to peak (2 to 8 volts peak). The waveform image shows a more continuous discharge pattern with lower dv/dt frequencies. The lower voltage may be due to greater current flow in the bearings which is the result of the bearing lubrication becoming conductive or could be a function of the motor's drive, speed, loading or other factors. As discharges occur in the bearings, the lubrication is contaminated with carbon and metal particles. The lower impedance to the shaft voltages results in lower peak to peak voltages. This condition is usually found in motors that have been in operation for many months or years.



Peak to Peak voltage with AEGIS® ring installed –
With the AEGIS® ring installed, a bare steel shaft will typically show shaft voltages of 2 to 10 volts peak to peak (1 to 5 volts peak) depending on the power of the motor, ground noise, the conductivity of the shaft and other factors. The voltage readings may be decreased further with the application of AEGIS® Colloidal Silver Shaft Coating which allows for higher shaft surface conductivity and a more efficient electron transfer to the conductive micro fiber tips.

The waveform image shows the low peak to peak waveform of a motor with the AEGIS® SGR ring installed and discharging the shaft voltages normally.



Reference: Aegis Handbook

Appendix C: ABB Technical Guide 5 'Bearing currents in modern AC drive systems'

General

Some new drive installations can have their bearings fail only a few months after start-up. Failure can be caused by high frequency currents, which flow through the motor bearings. While bearing currents have been around since the advent of electric motors, the incidence of damage they cause has increased during the last few years. This is because modern variable speed drives with their fast-rising voltage pulses and high switching frequencies can cause current pulses through the bearings whose repeated discharging can gradually erode the bearing races. To avoid damage occurring, it is essential to provide proper earthing paths and allow stray currents to return to the inverter frame without passing through the bearings. The magnitude of the currents can be reduced by using symmetrical motor cables or inverter output filtering. Proper insulation of the motor bearing construction breaks the bearing current paths.

How are HF bearing currents generated?

The source of bearing currents is the voltage that is induced over the bearing. In the case of high frequency bearing currents, this voltage can be generated in three different ways. The most important factors that define which mechanism is prominent, are the size of the motor and how the motor frame and shaft are grounded. The electrical installation, meaning a suitable cable type and proper bonding of the protective conductors and the electrical shield, plays an important role. This is indicative a damaged bearing outer raceway though EDM discharge.

How does the current flow through the system?

The return path of the leakage current from the motor frame back to the inverter frame consists of the motor frame, cable shielding or PE-conductors and possibly steel or aluminium parts of the factory building structure. All these elements contain inductance. The flow of common mode current through such inductance will cause a voltage drop that raises the motor frame potential above the source ground potential at the inverter frame. This motor frame voltage is a portion of the inverter's common mode voltage. The common mode current will seek the path of least impedance. If a high amount of impedance is present in the intended paths, like the PE connection of the motor frame, the motor frame voltage will cause some of the common mode current to be diverted into an unintended path, through the building. In practical installations several parallel paths exist. Most have a minor effect on the value of common mode current or bearing currents but may be significant in coping with EMC requirements.

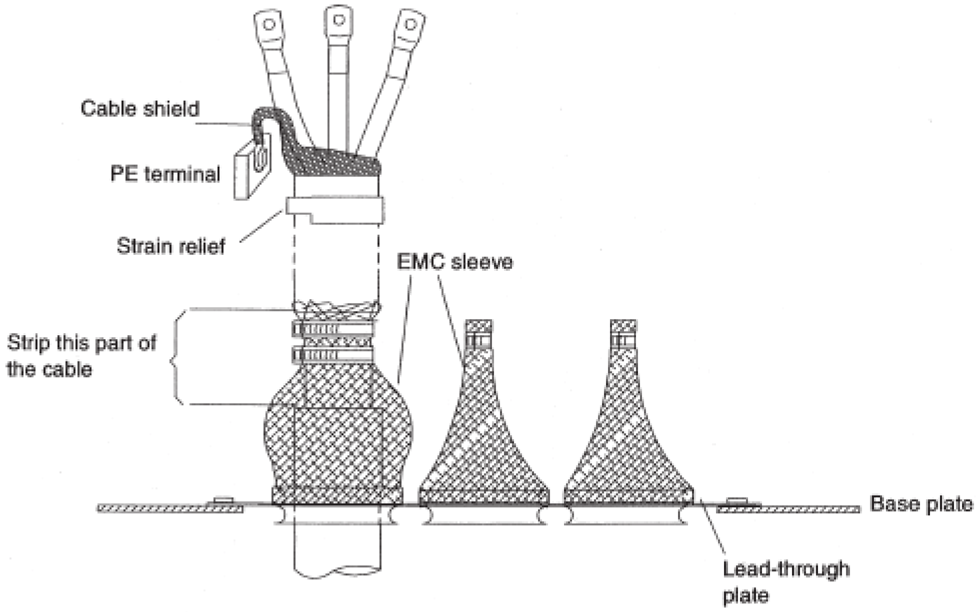
Preventing high frequency bearing current damage.

There are three approaches used to affect high frequency bearing currents: a proper cabling and earthing system; breaking the bearing current loops; and damping the high frequency common mode current. All these aims to decrease the bearing voltage to values that do not induce high frequency bearing current pulses at all or damp the value of the pulses to a level that has no effect on bearing life. For different types of high frequency bearing currents, different measures need to be taken. The basis of all high frequency current mastering is the proper earthing system. Standard equipment earthing practices are mainly designed to provide a sufficiently low impedance connection to protect people and equipment against system frequency faults. A variable speed drive can be effectively earthed at the high common mode current frequencies.

JPS Reliability
A Reliable Plant is a Profitable Plant

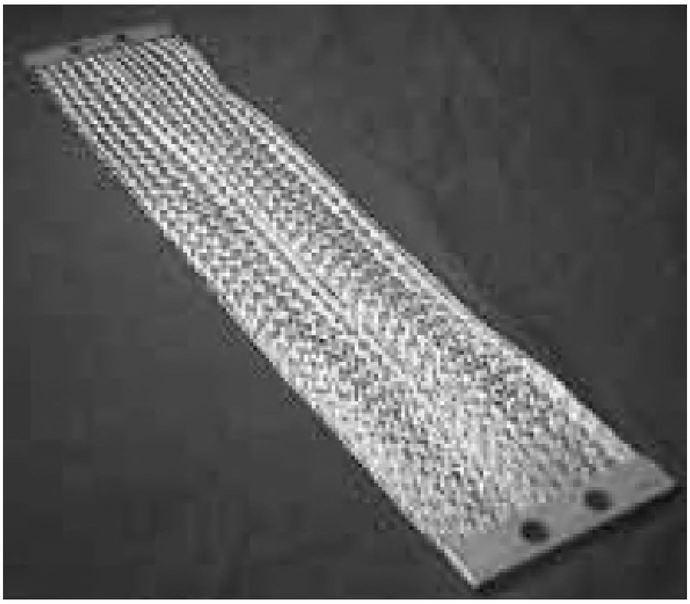
Short impedance path.

Define a short, low impedance path for common mode current to return to the inverter. The best and easiest way to do this is to use shielded motor cables. The shield must be continuous and of good conducting material, i.e., copper or aluminium and the connections at both ends need to be made with 360° termination.



High frequency bonding connections.

Add high frequency bonding connections between the installation and known earth reference points to equalise the potential of affected items, using braided straps of copper 50 - 100mm wide; flat conductors will provide a lower inductance path than round wires. This must be made at the points where discontinuity between the earth level of the inverter and that of the motor is suspected. Additionally, it may be necessary to equalise the potential between the frames of the motor and the driven machinery to short the current path through the motor and the driven machine bearings.



CXT SY Cable Glands.

This gland provides an environmental seal on the outer sheath and internal mechanical retention of wire braid that has been teased and placed into the slot running down the thread which is then held by the locknut.

Reference: ABB Technical Guide 5 ‘Bearing currents in modern AC drive systems’

Appendix D: Wiring and Grounding for Pulse Rockwell Automation Width Modulated (PWM) AC Drives Publication DRIVES-IN001Q-EN-P - June 2019

This publication for Allen Bradley drives, chapter 6 covers the common mode voltage and the issues with electromagnetic interference due to the drive operation. In addition, from the publication for the Wiring and Grounding for Pulse Width Modulated (PWM) AC Drives. It states unshielded cable is ok where the electrical drive noise does not interfere with the operations of other drives, unfortunately in this installation it does.

Unshielded Cable

Properly designed multi-conductor cable can provide excellent performance in wet applications, significantly reduce voltage stress on wire insulation, and reduce cross coupling between drives.

Cables without shielding is acceptable for installations where electrical noise that the drive creates does not interfere with the operation of other devices, such as communication cards, photoelectric switches, weigh scales, and others. Verify that the installation does not require shielded cable to meet specific electromagnetic compatibility (EMC) standards for CE, RCM, or FCC requirements. Cable specifications depend on the installation type.

Shielded Cable

Shielded cable contains the general benefits of multi-conductor cable with the added benefit of a copper-braided shield that can contain much of the noise generated by a typical AC drive. Use shielded cable for installations with sensitive equipment, such as weigh scales, capacitive proximity switches, and other devices affected by electrical noise in the distribution system. Applications with large numbers of drives in one location, imposed EMC regulations, or a high degree of communication/networking, are also good candidates for shielded cable.

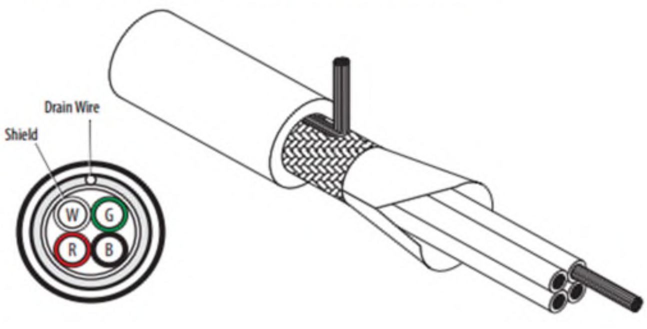
Shielded cable can also help reduce shaft voltage and induced-bearing currents for some applications. Also, the increased size of shielded cable can help extend the distance between the motor and the drive without the addition of motor protective devices, such as terminator networks. See Chapter 5 for information regarding reflected wave phenomena.

Consider the general specifications dictated by the environment of the installation, including temperature, flexibility, moisture characteristics, and chemical resistance. In addition, include a braided shield specified by the cable manufacturer as having coverage of at least 75%. An additional foil shield can greatly improve noise containment.

Type 1 Installation

Shielded cable for Type 1 installations has four XLPE insulated conductors with a 100% coverage foil and an 85% coverage copper braided shield (with drain wire) surrounded by a PVC jacket. For detailed specifications and information on Type 1 installations, see Table 1 on page 17.

Figure 7 - Type 1 Installation — Shielded Cable with Four Conductors



Additional:
In the interests of reliability and case history, we would appreciate feedback on work undertaken and the details of components used.

We trust that this will be acceptable to your requirements, however, should you require any additional information please contact the undersigned.

Kind Regards

Technician

Technician
Reliability Services

JPS Reliability
A Reliable Plant is a Profitable Plant

M: +44 (0)7387 986 454
E: info@jpsreliability.com
LI: https://uk.linkedin.com/in/vibration
W: https://jpsreliability.com