

# Shaft Grounding Rings

Protecting VFD Driven Motors  
from Bearing Currents



# Variable Frequency Drives and Electric Induction Motors

When pulse width modulation (PWM) Variable Frequency Drives (VFDs) were developed using insulated gate bipolar transistors (IGBTs), this new technology was used to control electric induction motors in industrial and commercial applications. The advantages were obvious:

- *Torque and motor speed could now be precisely controlled to optimize both process and energy requirements.*
- *The potential to save energy by operating motors at only the needed speed while maintaining torque requirements could potentially result in a 20% to 50% energy savings.*
- *Processes could be optimized and controlled by computer processing systems to achieve productivity increases or energy savings.*

# Energy Savings through the use of Variable Frequency Drives

**The use of VFD's result in significant energy savings with payback periods often less than one year**

100% Speed  
100% Load  
100hp Induction Motor



*Cost per year \$27,000*

60% Speed  
22% HP  
100hp Induction Motor



*Cost per year \$6,000*

**Bearing Protection Helps Guarantee the savings**

Bearing failures are costly...take care of them...you don't want to deal with this...

Typical Bearing Failure Cost:	Small Motor 10 HP/215T	Large Motor 300 HP/449T
Rigging/Removal and replacement	\$1,000	\$2,000
Motor Repair	\$990	\$13,200
Production Downtime	<u>\$10,000</u>	<u>\$100,000</u>
Total	\$11,990	\$115,200
Cost of AEGIS™ installed on Marathon motor to Prevent Bearing Fluting Failure	\$456	\$1,327
Return on Investment	2629%	8681%

# Bearing Failure Reports

ABB Technical Guide No.5, 2000: *“Some new drive installations can have their bearings fail only a few months after start-up...”*

*Emerson (US motors), Product service bulletin, Vol.3, Dec/2002: “In the past few years, there has been a significant increase in motor problems associated with shaft voltages and currents.”*

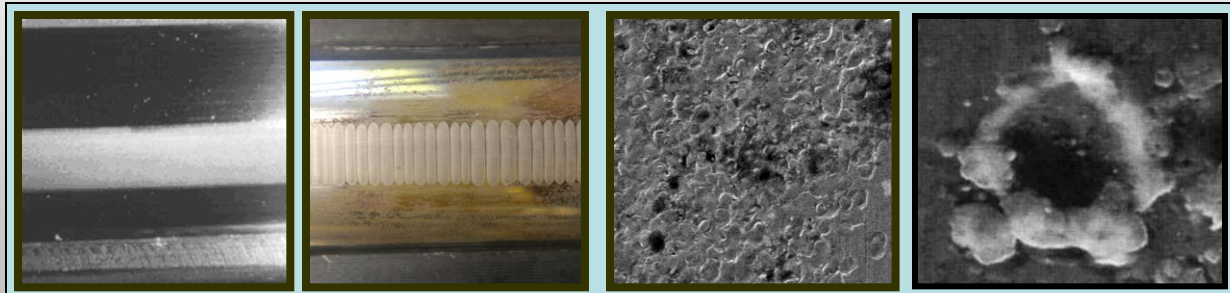
WEG Electric Motors, June/2003: *“Recently though, it has become apparent that these improvements have been bought at a price: IGBT technology has resurrected bearing problems due to electrical damage, creating a new challenge to manufacturers of electric motors...”*

IEEE 2004, IAS 2004, 0-7803-8486-5/04: *“The surfaces of the bearing races of bearings with operation time greater than 500 h are melted several times at the whole surface due to small craters.....”, A. Muetze, A.Binder, H.Vogel, J.Hering, “Experimental Evaluation of the Endangerment of Ball Bearings due to Inverter-Induced Bearing Currents”, pp. 1989 – 1995*

# Bearing Failure

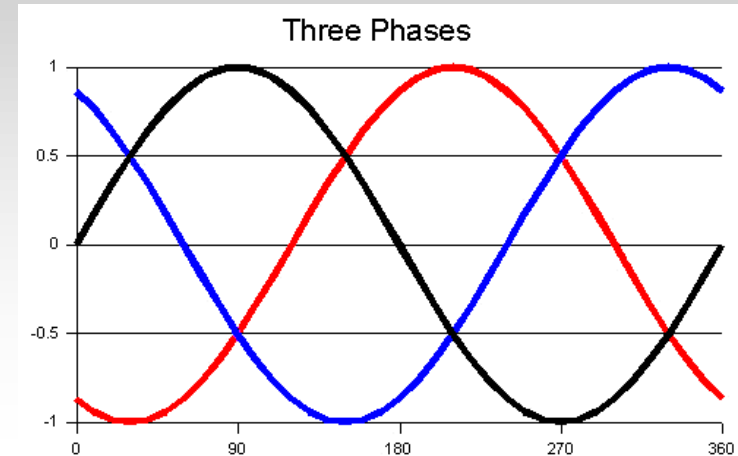
March 2005 Journal of Electrostatics “*Statistical model of electrostatic discharge hazard in bearings of induction motor fed by inverter*” by Adam Kempinski et. al. “*Electrical Discharge Machining (EDM) bearing currents have been found as the main cause of premature bearing damages in Pulse Width Modulation (PWM) inverter fed drives.*”

February 2007: Pump and Systems Magazine “*How to Prevent Electrical Erosion in Bearings*” by Daniel R. Snyder, P.E., SKF USA Inc. “*An estimated 50 percent of all electric motor failures are attributed to bearings, but the bearings themselves are not usually the root cause. Other forces are at work, such as the increasingly common problem of stray currents.*”



# Electric Motor Design

460 VAC  
60Hz



Most electric induction motors were designed for operation on 3 phase sine wave power – either 50 or 60 Hz.

The input power was balanced in frequency, phase (120 degrees apart) and in amplitude.

Common mode voltage – the sum of the 3 phases would always equal zero volts.

# Electric Motor Operation by VFD



When operated by VFD, the power to the motor is a series of pulses instead of a smooth sign wave.

The input power is never balanced because the voltage is either 0 volts, positive, or negative with rapid switching between pulses.

The Three phases of voltage pulses ensures that the common mode voltage is never equal to zero and instead is a “square wave” or “6 step” voltage.

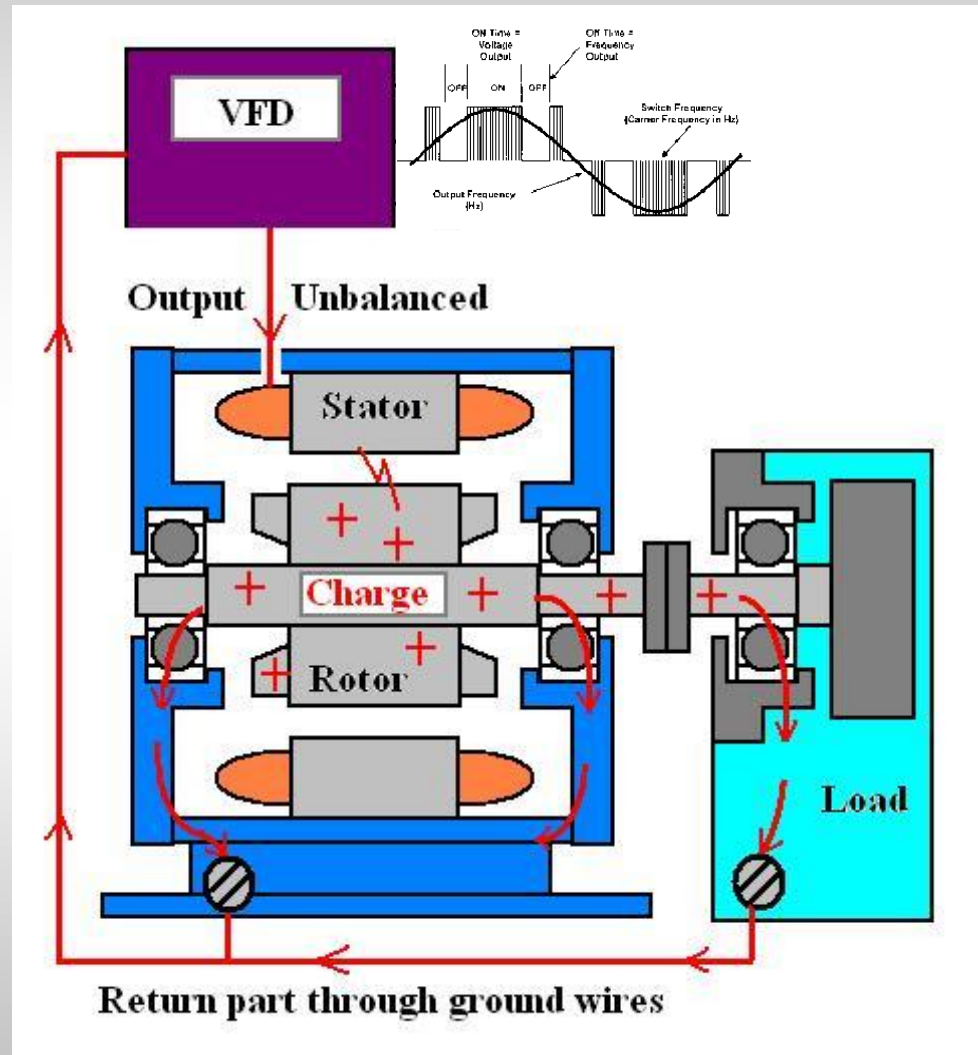


# An Electric Motor looks like a Capacitor

The Pulses to the motor from the VFD create a capacitively coupled common mode voltage on the motor shaft.

The voltage looks for a path to ground and breaks down the dielectric in the bearing.

The resulting discharge through the motor bearing creates a pit in the bearing race and over time the bearing degrades fails.

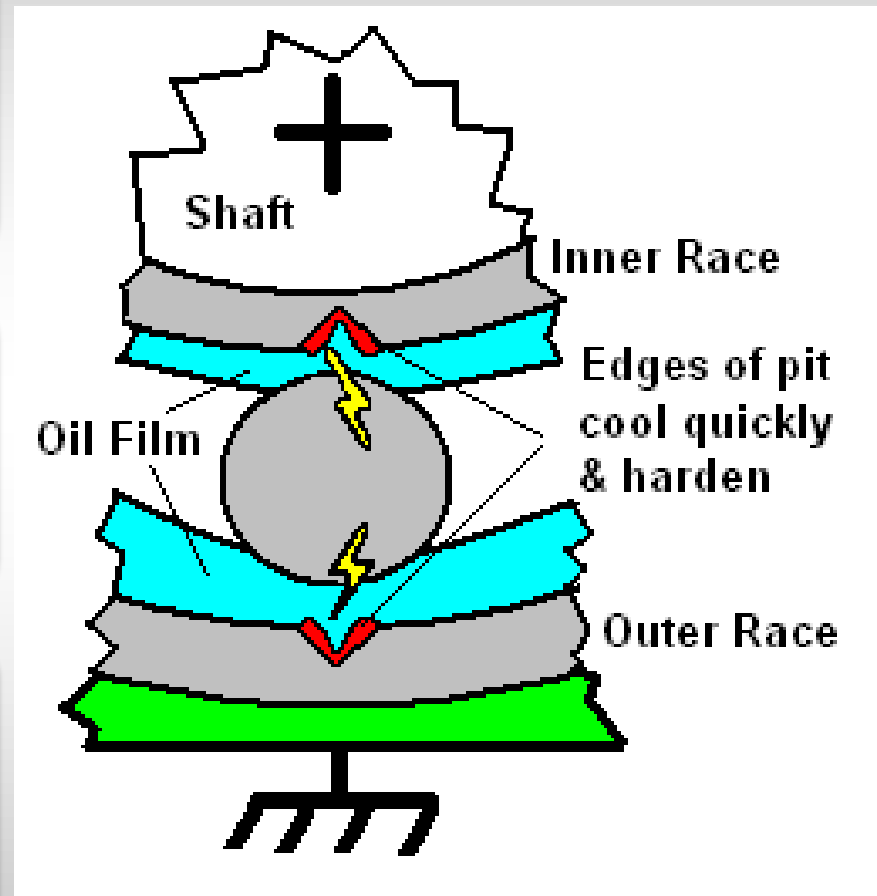


# What effect does this have on the bearings?

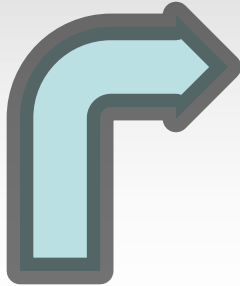
Voltage builds up until it exceeds the insulation level of the bearing's oil film layer – the “break-down” voltage of the bearing.

The voltage then arcs through the bearing creating an electrical discharge machining (EDM) pit from the rapid melting and cooling of the steel surface.

Thousands of pits per second may be created and over time the ball rolling over the disturbed surface can cause what is known as “fluting damage”



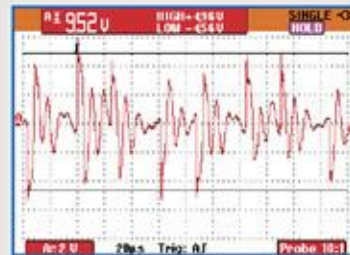
# Shaft Voltage Readings



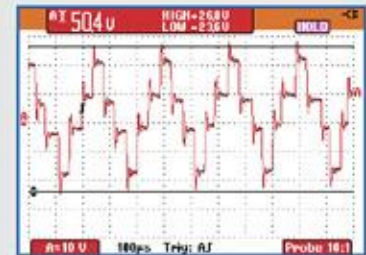
The following types of readings indicate potential bearing currents in your motor:



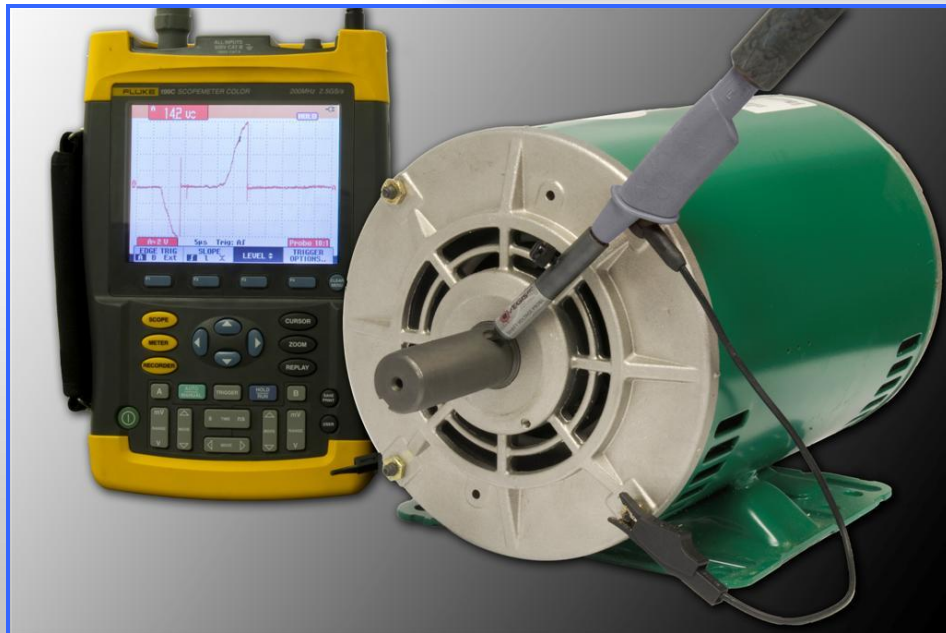
High amplitude EDM discharge pattern



Low amplitude voltage discharge pattern



High Peak to Peak common mode voltage



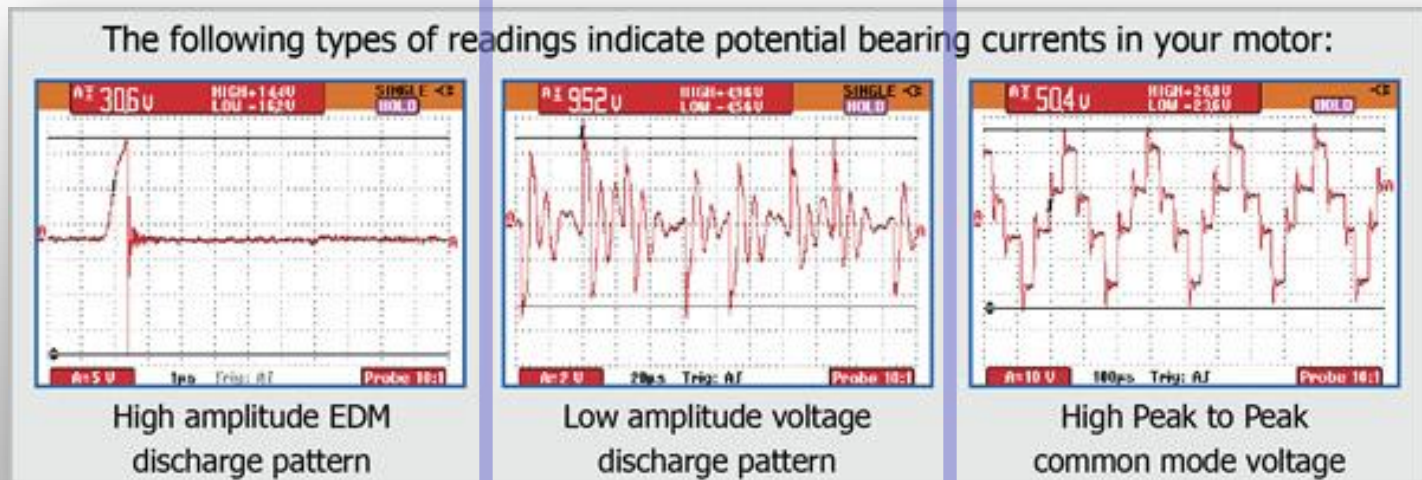
A number of different wave forms may be present...

# Shaft Voltage Readings

Typical Bearing discharge “EDM” pit created in the bearing race. Note the sharp voltage trailing edge.

The lower peak to peak voltage indicated continuous conductivity in the bearing.

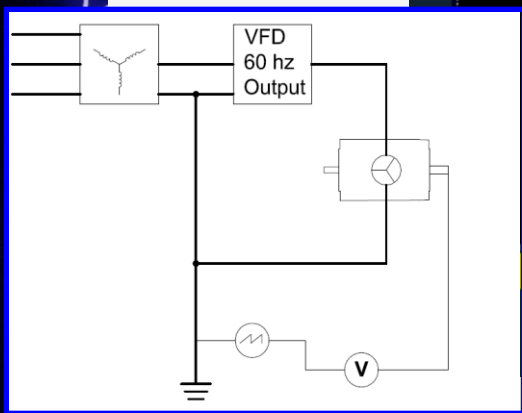
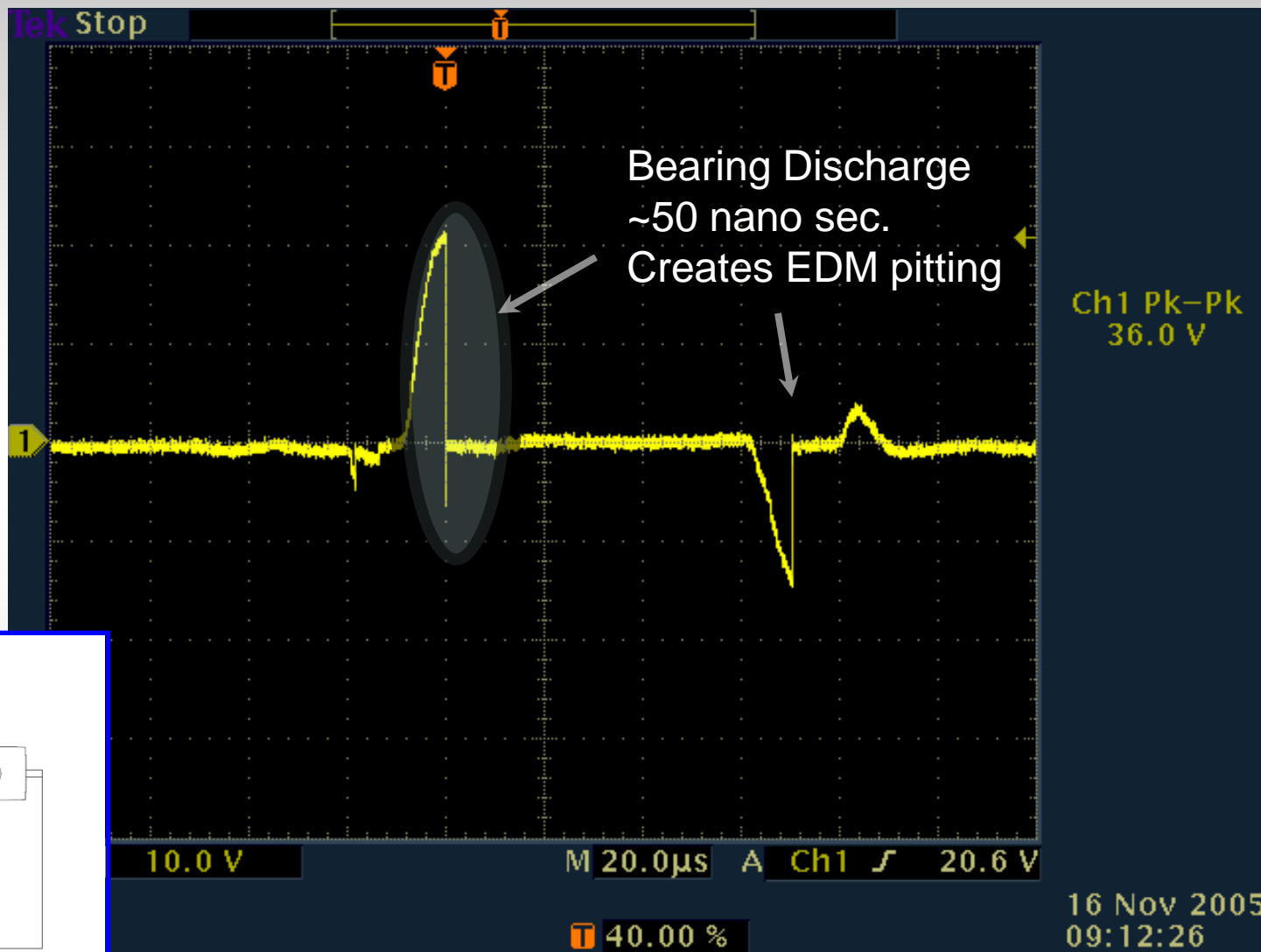
This wave form is typical before discharge takes place. Note the classic “6-step” wave forms.



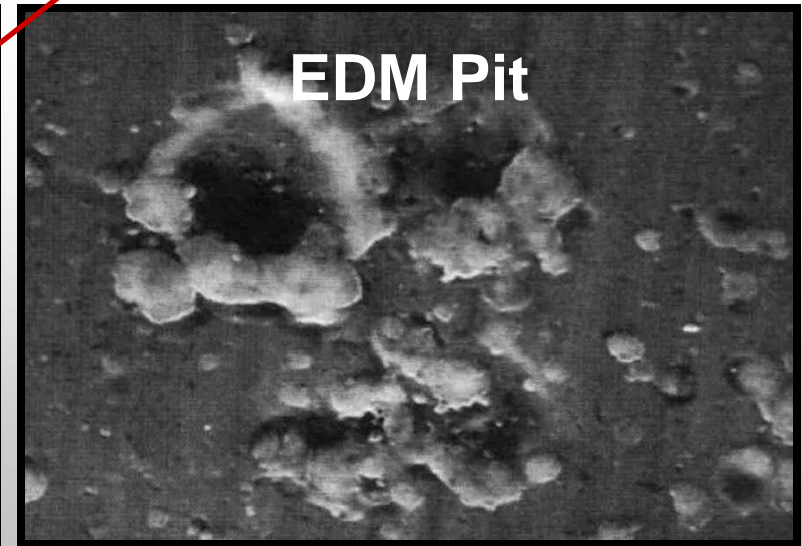
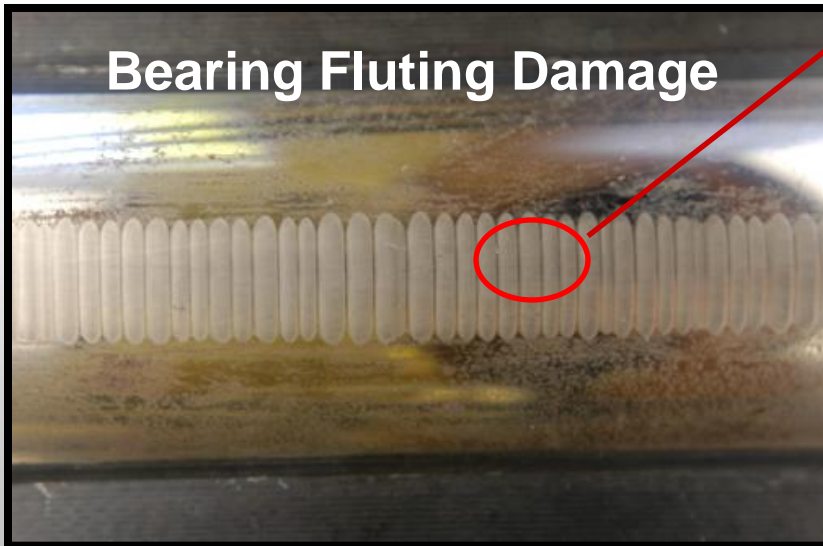
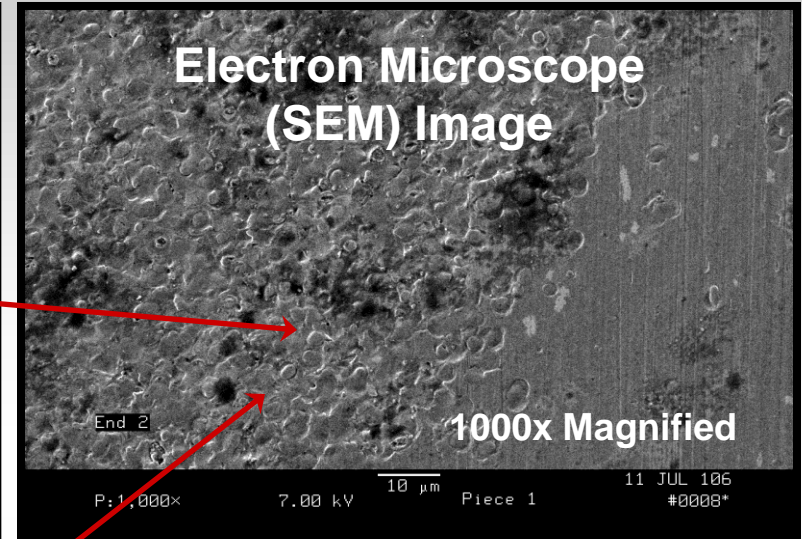
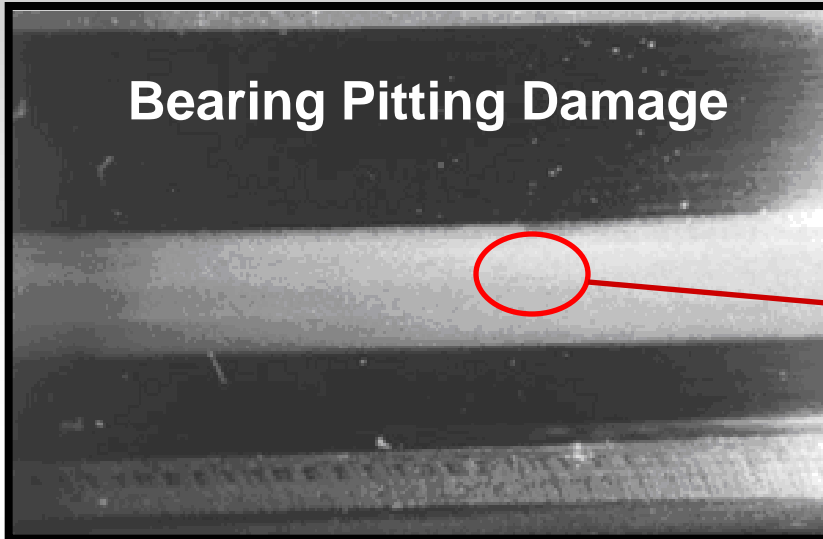
# Bearing Discharge Voltage Pattern



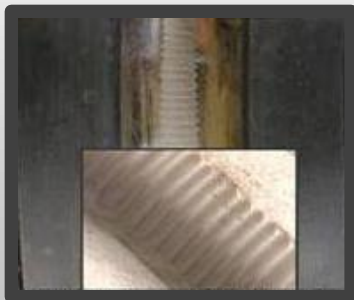
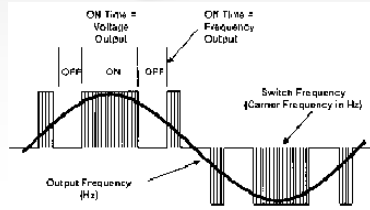
Voltage Increase & drop  
Signifying Current flow  
through Bearings



# Motor Bearing Damage from Electrical Currents Electrical Discharge Machining (EDM)



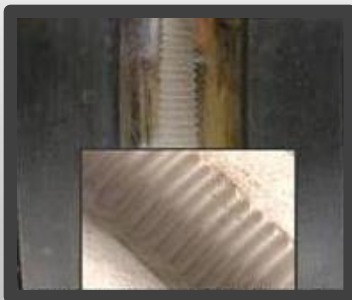
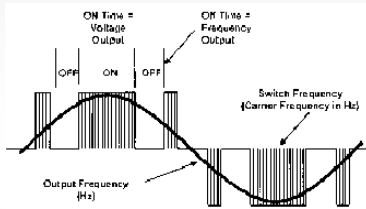
# PWM Drives Cause



1. High frequency transients ( $dv/dt$ ) can break down the insulation between windings and cause corona discharge arcing which can short out the windings.

2. Because of the inherent voltage imbalance and  $dv/dt$ , the voltage pulses are capacitively induced on the motor shaft and can overcome the dielectric of the oil film in the motor bearings. Electrical discharges result in pitting and fluting damage in the bearing, breakdown of lubrication, and fluting failure of the bearing.

# Motor Reliability for Inverter Driven Motors



**Motor Winding Problems** The motor winding insulation was changed to withstand the transient voltages and to prevent the corona discharges. NEMA MG1 specified motor design to meet what was known as “class F, G or H” insulation, and “corona resistant wire” was developed.

Motors with this upgraded wire were marketed as “inverter duty” or “inverter ready” by motor manufacturers...However

The problem of electrical bearing damage, while identified in the NEMA MG1, was not prevented in the design of the motor.

NEMA recommended to use either ceramic bearings or shaft grounding. Neither solution was included in the “inverter duty” motor designs.



# Construction Specification Institute

## CSI 23 05 13

CSI 23 05 13 PART 2 PRODUCTS 2.1.13.e Provide Shaft Grounding Kit for Field Installation

CSI 23 05 13 PART 3 EXECUTION 3.2 A. 9 Motors: Wire Shaft ground kit on motors for use with Variable Frequency Drives

## Motors Developed to IEEE standard 841

Section 5.3 - requires motors operated on adjustable speed drives to avoid the following condition: (9) VFD-induced “shaft-to-bearing voltages and/or currents resulting from common mode currents flowing through stray system capacitances to ground via the bearings.”

# NEMA MG1 section 31.4.4.3

## Motors below 500 Frame (NEMA 56 to 449T):

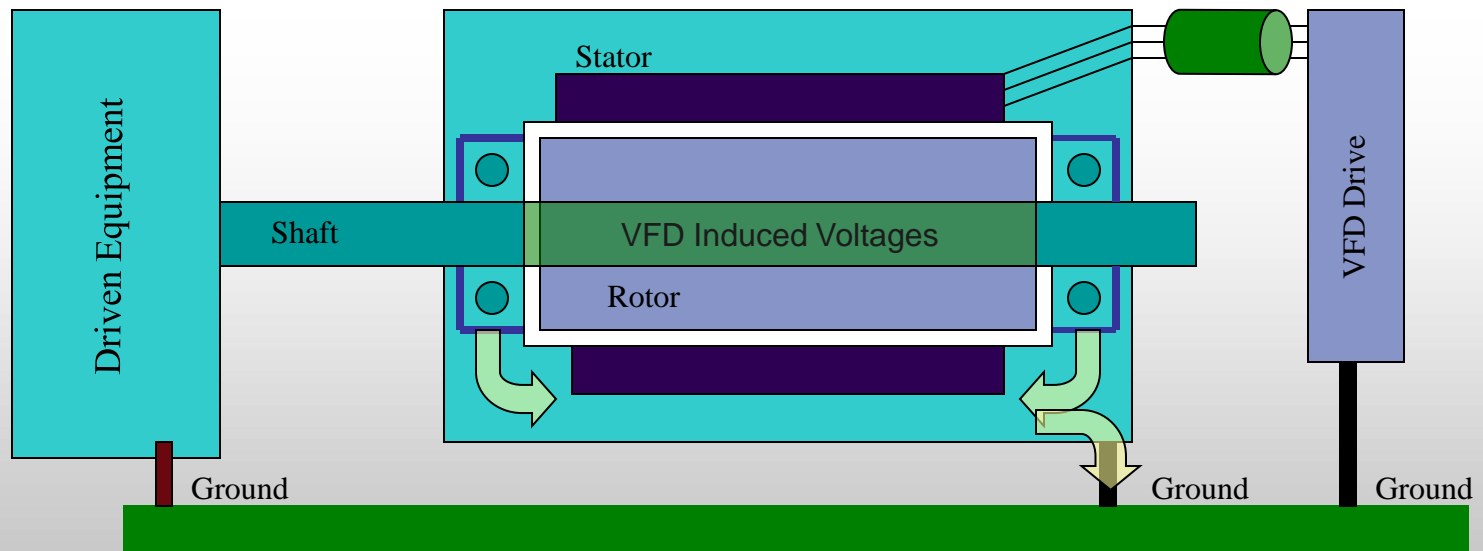
More recently...potentially destructive bearing currents have occasionally occurred in much smaller motors... These drives can be generators of a common mode voltage which...oscillates at high frequency and is capacitively coupled to the rotor. This results in peak pulses as high as 10-40 volts from shaft to ground... Interruption of this current therefore requires insulating both bearings.

Alternately, shaft grounding brushes may be used to divert the current around the bearing.

It should be noted that insulating the motor bearings will not prevent the damage of other shaft connected equipment.

# Capacitive Induced VFD Shaft Voltages and Bearing Currents in All AC Motors

- ✓ **VFD induced capacitive voltages** from the high switching speed of the pulse width modulation (PWM) drives discharge through motor bearings and cause electrical discharge machining (EDM) effect in the bearing race.
- ✓ **Rotor ground currents** generated by PWM Drive will partly flow as rotor ground current through the bearings of the motor. These currents are caused by the rotor being connected to common ground with a significantly lower impedance path than the ground of the stator housing.



# NEMA MG1 section 31.4.4.3

Large Frame Motors (500 frame or larger): ...voltages may be present under sinusoidal operation and are caused by magnetic dissymmetry's in the construction of these motors...current path...is from the motor frame through a bearing to the motor shaft, down the shaft, and through the other bearing back to the motor frame. This type of current can be interrupted by insulating one of the bearings.

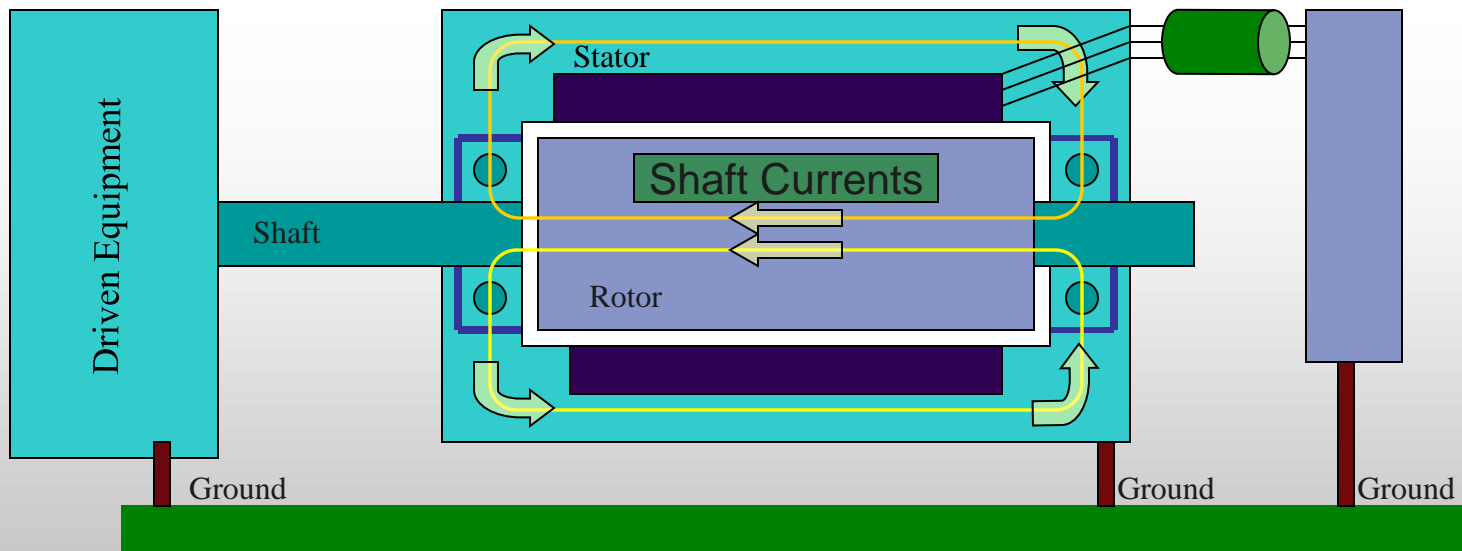
When VFD is used, the circulating currents described above increase from 60 Hz to KHz or MHz frequencies and may effect motors rated at 150 kW (200 HP). This is referred to as “High Frequency Circulating Current”

**Reference:**

A. Muetze, A. Binder, H. Vogel, J. Hering, [“What can bearings bear? – How much current is too much? How much current reduction enough?”](#) *IEEE Magazine on Industry Applications*, vol. 12, no. 6, pp. 57-64, November/December 2006.

# High Frequency Circulating Currents in Large Motors & Generators

- ✓ Induced by the magnetic flux imbalance around the motor shaft from the stator windings, these currents circulate through the motor bearings. Circulating currents are a problem in large AC and DC motors of over 100 hp.
- ✓ Because these currents circulate through the motor via the shaft and bearings, the current flow must be either broken or an alternate path established to prevent bearing failures.



High Frequency Flux encircling the rotor causing shaft bearing currents

# True Inverter Duty Motors Have Inverter Rated Windings and Bearing Protection to Improve Reliability and Prevent Downtime



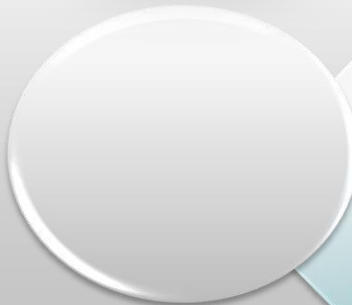
# Mitigation Strategies



**Insolate the shaft from the frame of the motor:** Use insulated sleeve on the bearing journal ceramic coated or ceramic ball bearings. Protect the motor but not attached equipment. Best used to prevent circulating currents in motors above 100 HP



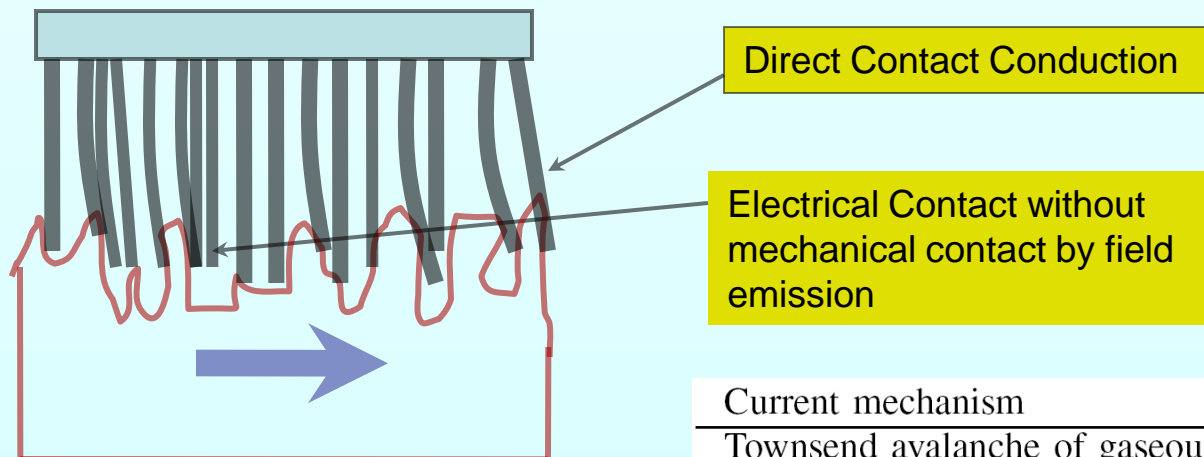
**Old Technology:** Legacy shaft grounding with spring pressure brushes. **Not effective because of wear, maintenance and contamination.** Usually a copper phosphor or bronze metal brush or carbon block brush.



**New Technology:** Shaft Grounding Ring of conductive micro fibers for voltage discharge. *Maintenance free, works in oil/grease/dust, lasts for service life of motor.*

# New Conductive Microfiber Shaft Grounding Technology

Uses several methods to transfer electrical currents\*

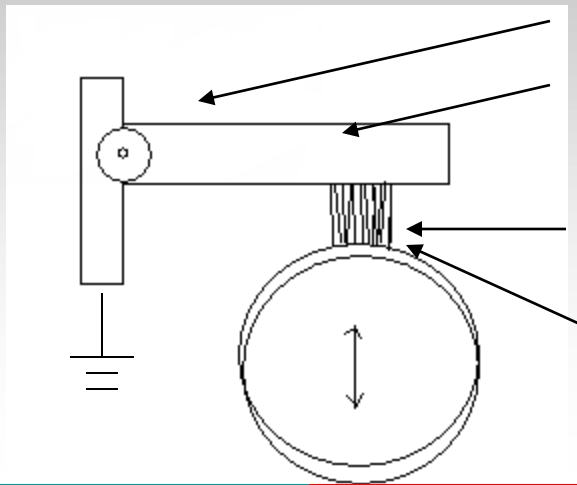


Current mechanism	Gap distance
Townsend avalanche of gaseous ions	$> 5\mu\text{m}$
Field emission of electrons	2nm to $5\mu\text{m}$
Tunneling of electrons	$< 2\text{nm}$

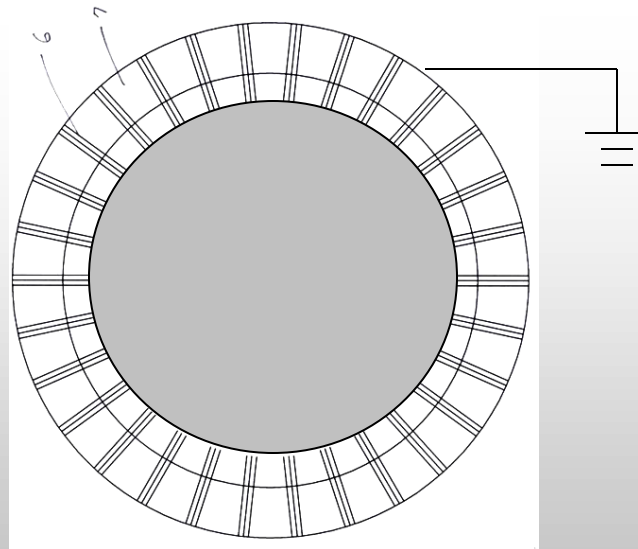
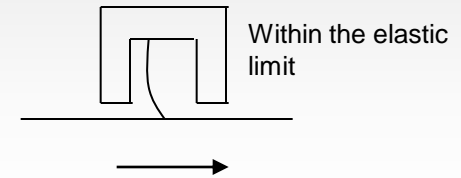
\*IEEE paper, September 2007: *Design Aspects of Conductive Microfiber Rings for Shaft Grounding Purposes*, by Dr. Annette Muetze et. Al.



# New Approach to Electrical Current Transfer

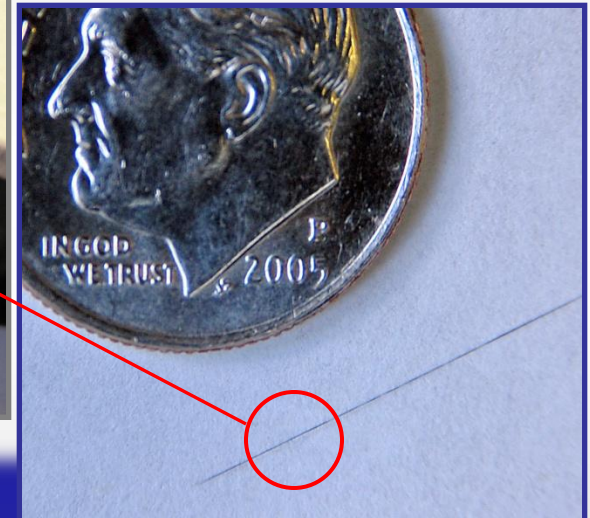


- Installation Difficulty
- Vibration due to “stick-slip”
- Material Wear (not suitable at high surface rate)
- “Shaft run-out” is compensated by spring load
- Not effective above 2MHz signal



- No Spring load
- Negligible wear of micro-fibers even high surface rate
- Continuous contact despite “shaft run-out”
- Easy Installation
- Low cost
- Maintenance Free

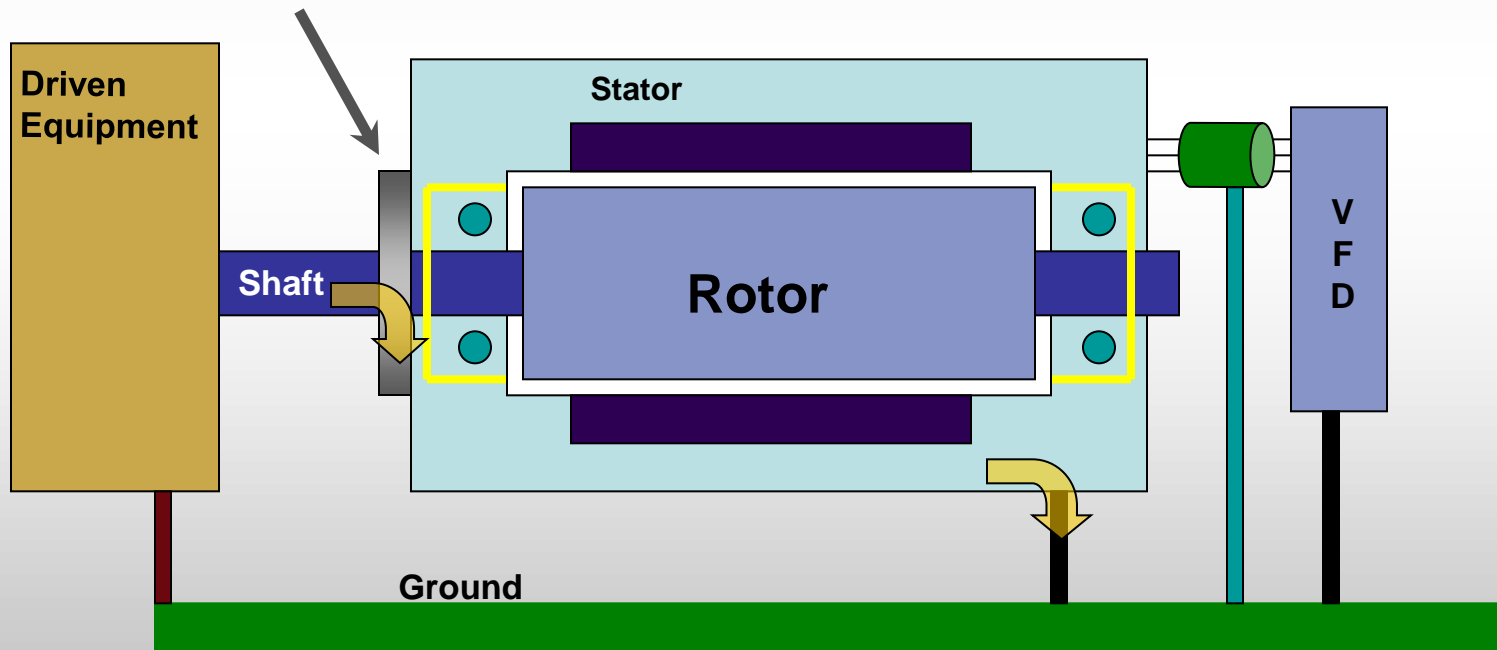
# Shaft Grounding Ring Construction



## Unique Characteristics

- ✓ Encircles complete 360 degree shaft area
- ✓ Unaffected by dirt and grease providing continuous grounding
- ✓ No maintenance required after installation

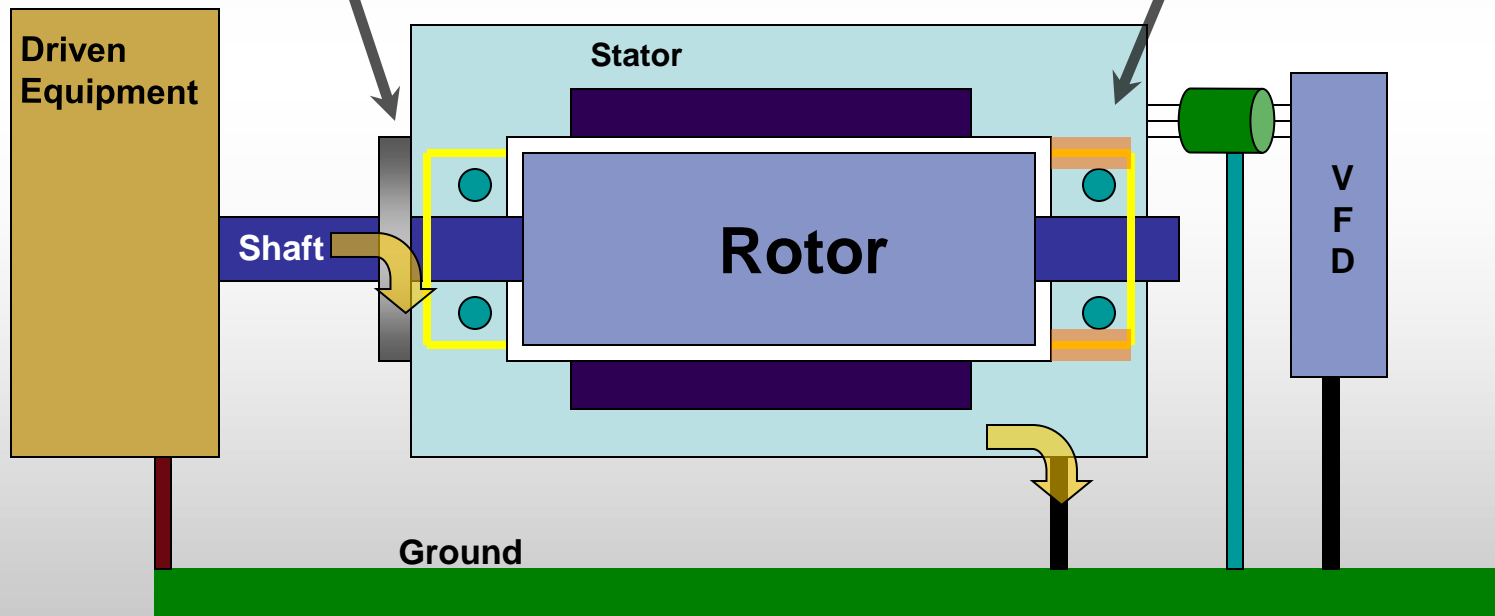
# Shaft Grounding Ring Bearing Current Mitigation motors to 100 HP



# Large Low and Medium Voltage Motors over 100 HP to Above NEMA Frames

Shaft  
Grounding  
Ring on DE

Insolated bearing  
or Insulation on  
NDE



### **Standard Mounting Brackets**

Shaft diameters: 0.311" to 6.02" (8mm to 153mm)  
Ships with mounting brackets, screws and washers  
Quick and easy installation to most surfaces

### **Split Ring**

Shaft diameters: 0.311" to 6.02" (8mm to 153mm)  
4 to 6 mounting brackets, screws and washers  
Installs without decoupling motor

### **Bolt Through Mounting**

Shaft diameters: 0.311" to 6.02" (8mm to 153mm)  
M3 x 14 socket head cap screws and lock washers  
2 mounting holes up to shaft size 99mm  
4 mounting holes for larger sizes

### **Press Fit Mounting**

Shaft diameters: 0.311" to 6.02" (8mm to 153mm)  
Clean dry 0.102mm press fit  
Custom sizes available

### **NEMA-IEC Mounting Kits**

Shaft diameters: see chart for standard kits  
Custom kits available for other shaft diameters  
Clears any slinger, shaft shoulder or protrusion

# *Easy To Install*



# Conclusions

Use of VFD is increasing to save energy in HVAC/R systems

VFD induced motor bearing currents may cause unplanned motor failures, decrease reliability and result in increase operating costs

All VFD driven motors should have bearing protection to ensure reliability

Bearing Protection Ring implements bearing current mitigation technology to ensure the goals of reliability, maintenance free operation and long service life.