Protecting VFD Driven Motors from Bearing Currents

Martin Deiss, EST Sales Manager Europe

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Topics

- Root causes of shaft voltage
- Impact on the bearings
- Possibilities to proof
- Mitigation strategies
- Application examples

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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.

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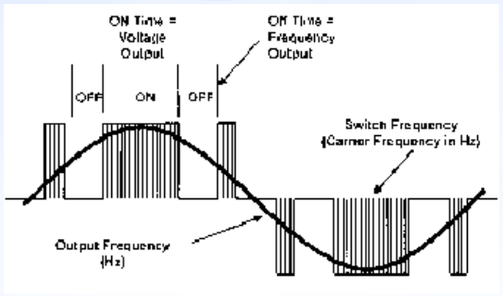
PWM Drives can cause



- **Winding failures:**

  High frequency transients (dv/dt) can break down the insulation between windings and cause corona discharge arcing which can short out the windings. This problem was resolved with class F or H insulation

- **Bearing failures:**

  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.

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Three Sources of Bearing Currents
Two Types

Capacitive Induced Voltage (want to go to ground)

- **Bearing Current A (from VFD):**
  Coming from the pulse width switching waveform produced by the variable frequency drive (VFD). This voltage present on the motor shaft can discharge in the motor's bearings or in the attached equipment.

Circulating Currents (circulating between rotor and stator)

- **Bearing Current B (from VFD)**
  High frequency circulating currents may flow due to a high-frequency flux produced by common-mode currents. High frequency inductive circulating currents from VFDs are in the KHz or MHz in motors over about 75 KW.
- **Bearing Current C (from line voltage)**
  50/60 Hz sine wave voltage sources in large machines can cause **extremely low frequency circulating currents** because of the motor's asymmetrical design and magnetic asymmetries.

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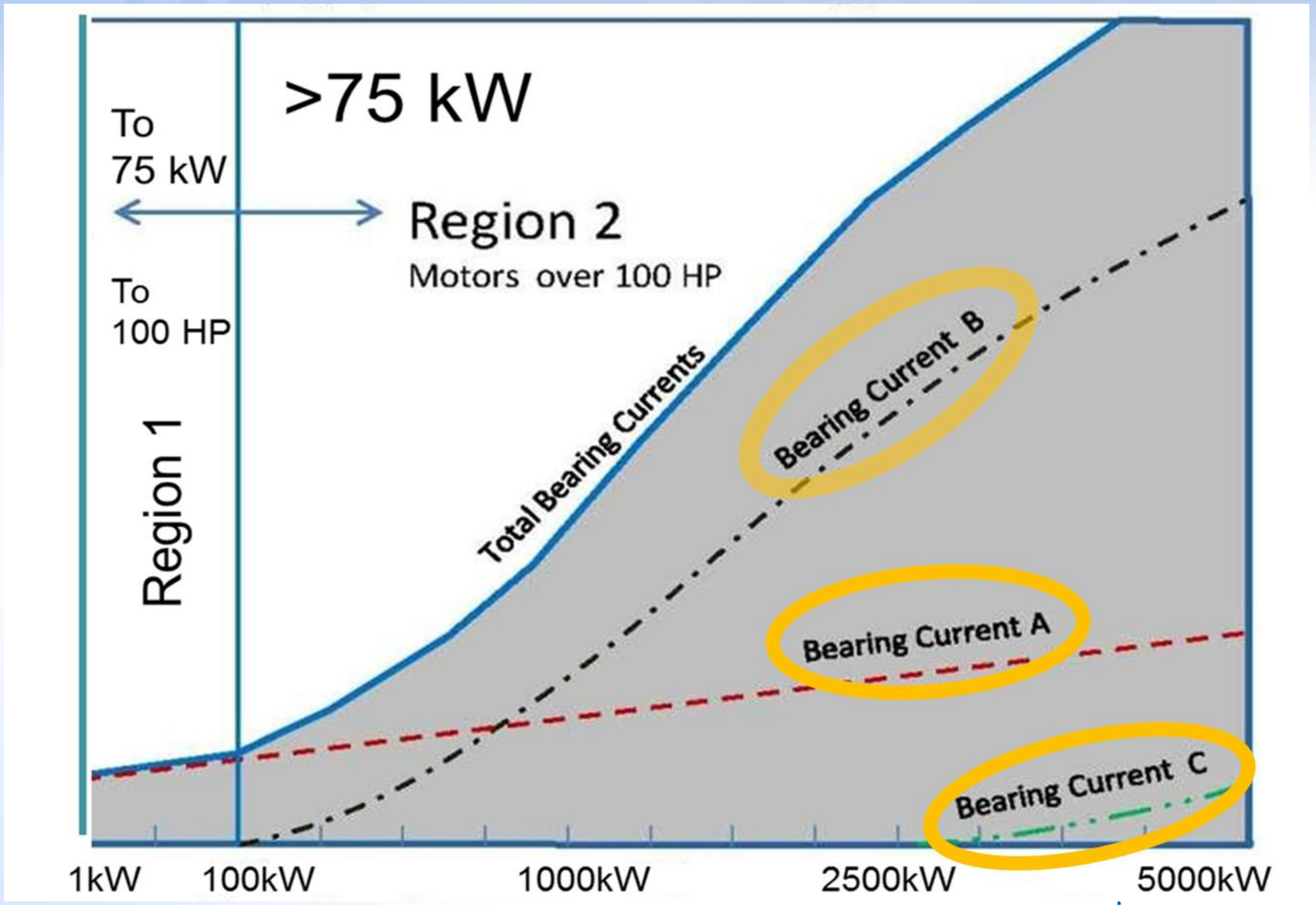
Three Sources of Bearing Currents



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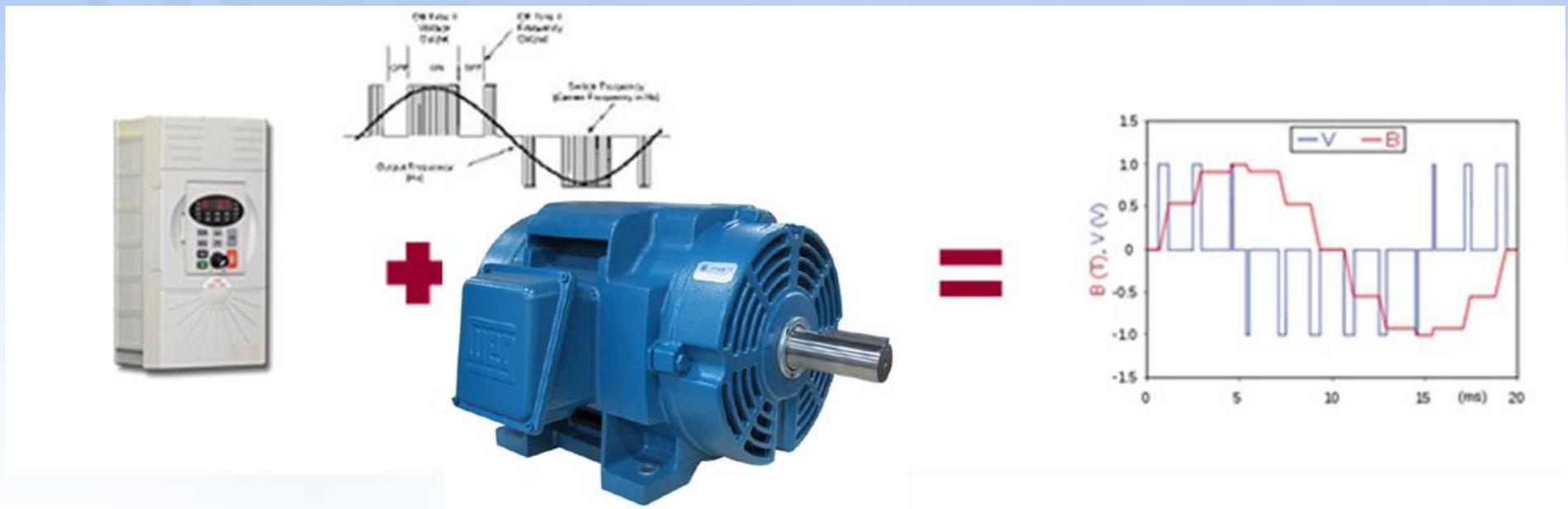
Motor Design

- Electric induction motors designed for operation on 3-phase sign wave power – either 50 or 60 Hz.
- The input power is balanced in frequency, phase (120 degree phase shift) and in amplitude.
- Common mode voltage – the sum of the 3 phases always equal zero volts when properly balanced.

Bearing protection generally not needed except for large frame motors.

Electric Motor Operation by VFD

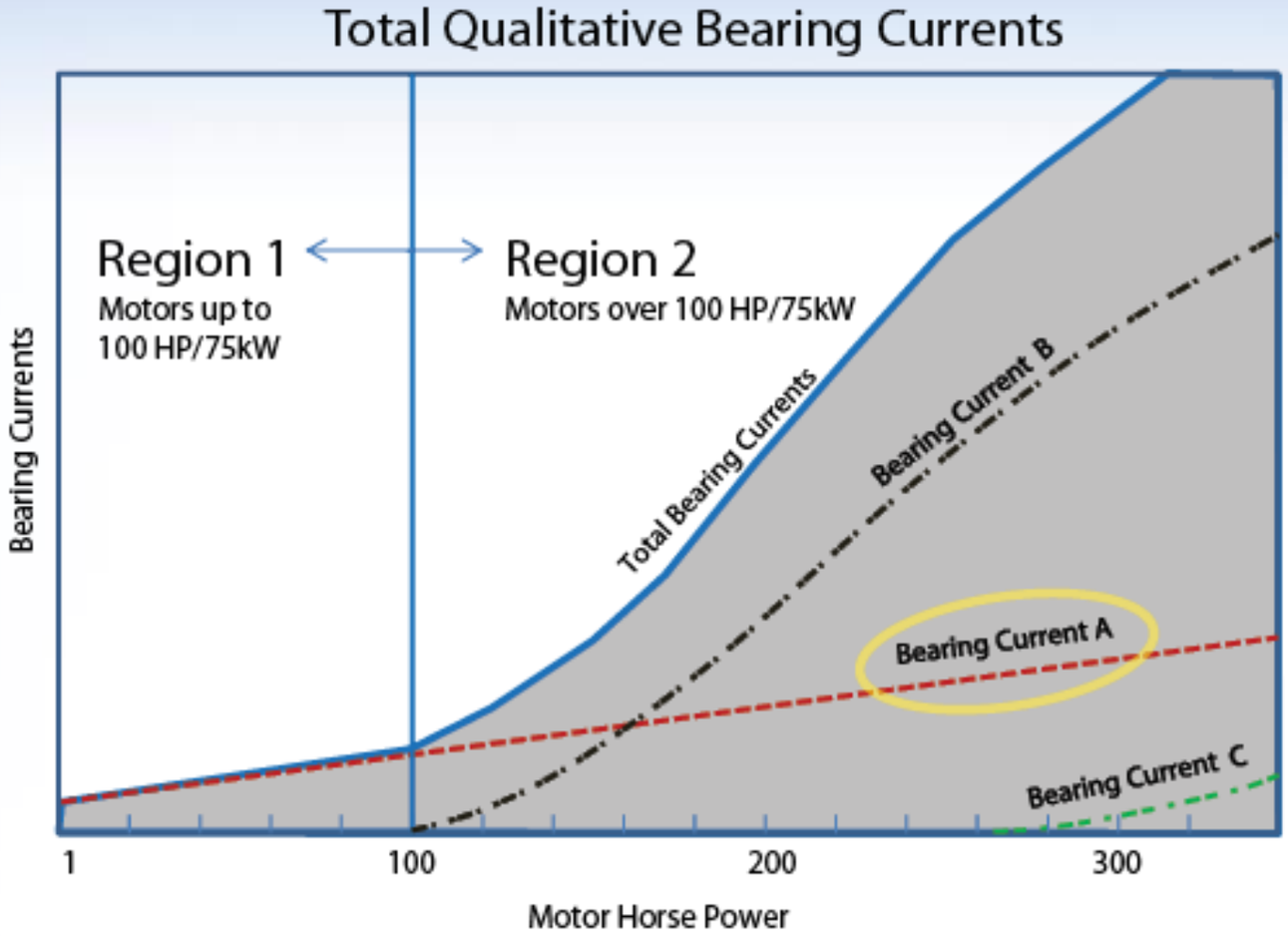


- When operated by VFD, the power to the motor is a series of pulses instead of a smooth sign wave.
- The input voltage is never balanced because the voltage is either 0 volts, positive, or negative with rapid switching between pulses in all three phases
- The common mode voltage is usually a “square wave” or “6 step” voltage wave form.

Bearing protection needed to mitigate electrical discharge machining (EDM) damage in bearings.

Capacitive Induced Shaft Voltage
Bearing Current A

- Capacitive induced shaft voltage that discharges in the motor bearings. Voltages are capacitive coupled from stator to rotor through parasitic capacitance and create the possibility of bearing currents.
- Virtually any motor from fractional HP to large motors may have bearing currents from this source.



Best Practice: Ground the motor shaft – best with the AEGIS® Shaft Grounding Ring to provide a path of least resistance to ground and divert current away from the motor's bearings and to protect attached equipment. (Ref: NEMA MG1 Part 31.4.4.3)

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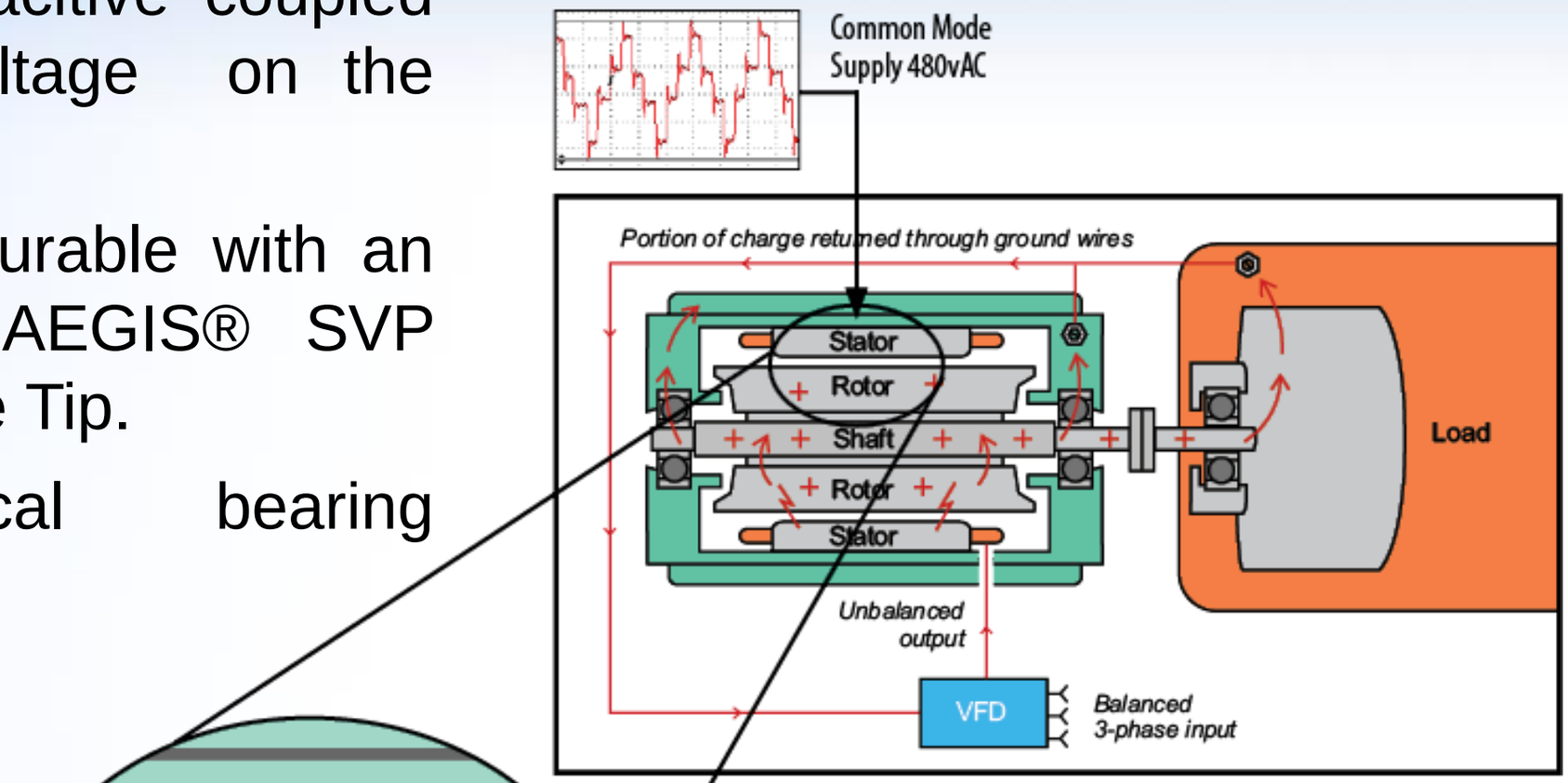
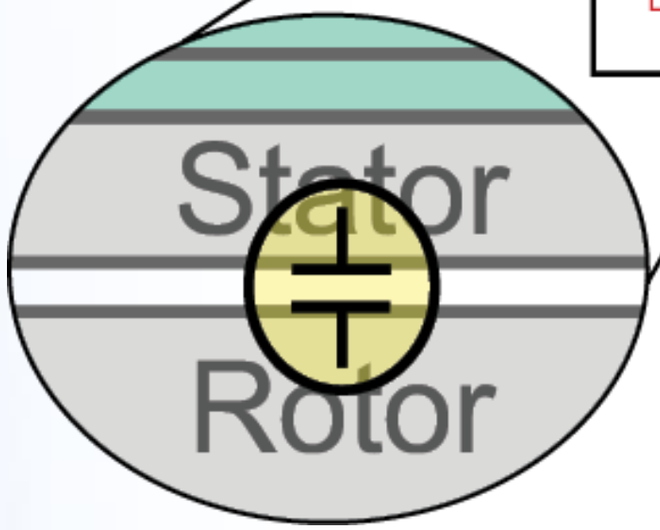
An Electric Motor looks like a Capacitor

- The Pulses to the motor from the VFD create a capacitive coupled common mode voltage on the motor shaft.
- Voltages are measurable with an oscilloscope and AEGIS® SVP Shaft Voltage Probe Tip.
- Creates electrical bearing discharge currents.





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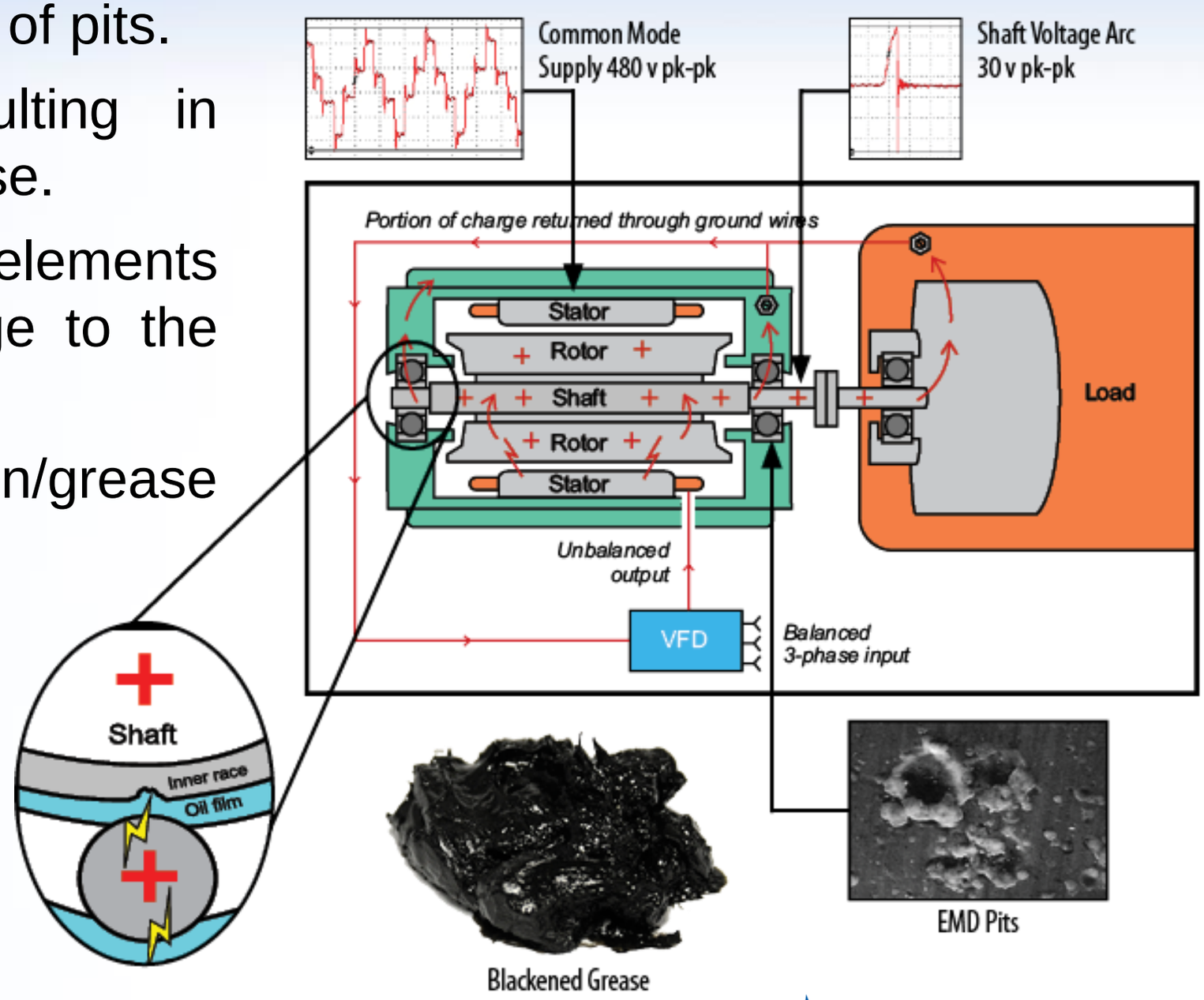
What effect does this have on the bearings?

- Electrical discharge machining (EDM) creates thousands of pits.
- Bearings degrade, resulting in increased friction and noise.
- Eventually, the rolling elements can cause fluting damage to the bearing races.
- Bearing lubrication/grease deteriorates/burns.
- Potential for costly unplanned downtime



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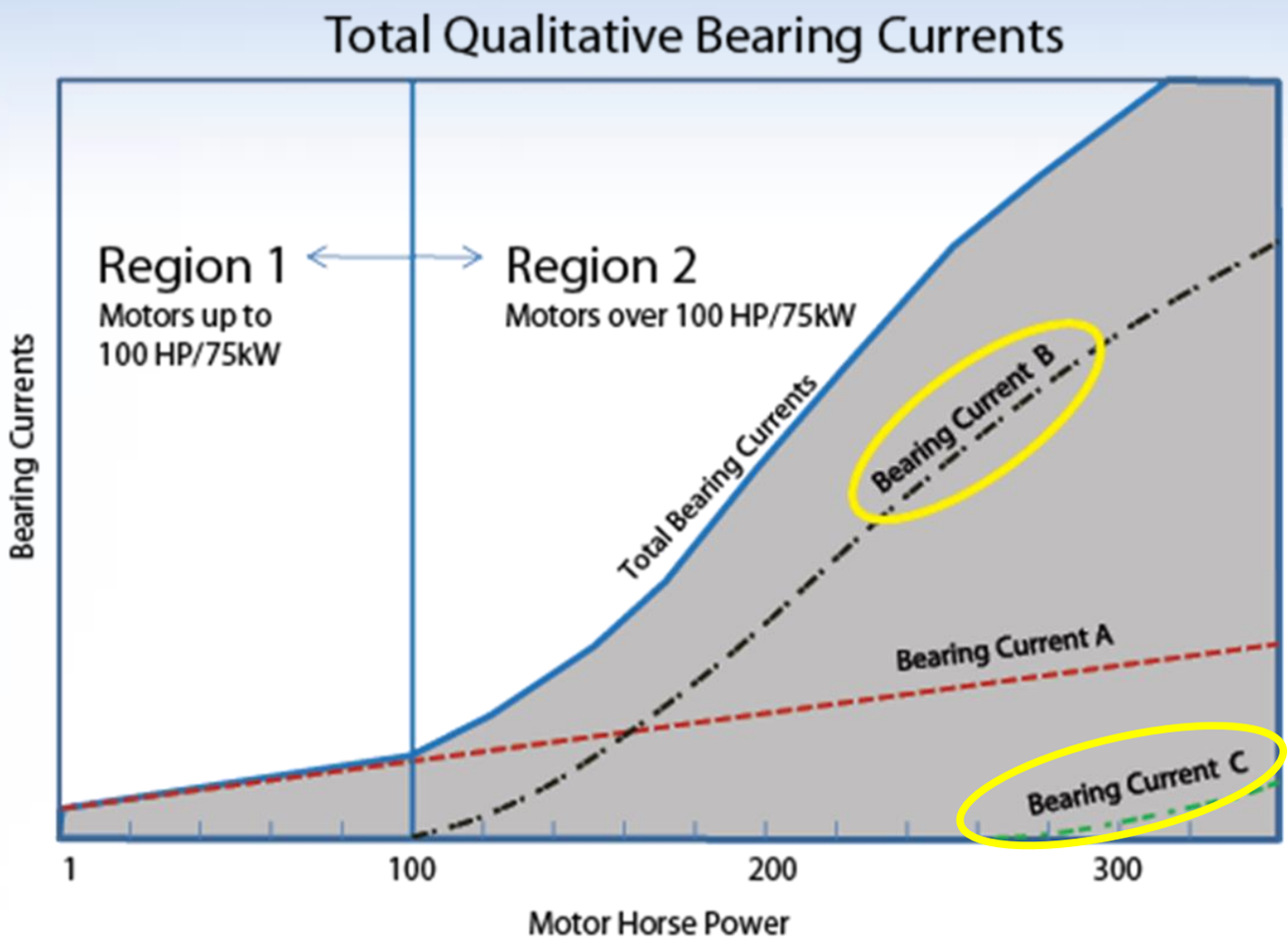
Circulating Currents
Bearing Current B (HF) and C (Line Voltage)

- High frequency circulating currents may flow due to a high-frequency flux produced by common-mode currents in KHz or MHz frequencies.
- Usually present in motors above 75 kW.
- Circulate through the motor bearings, shaft to frame



Best Practice: Interrupt the circuit by insulating one end (opposite to grounding side) – best with an insulated bearing.

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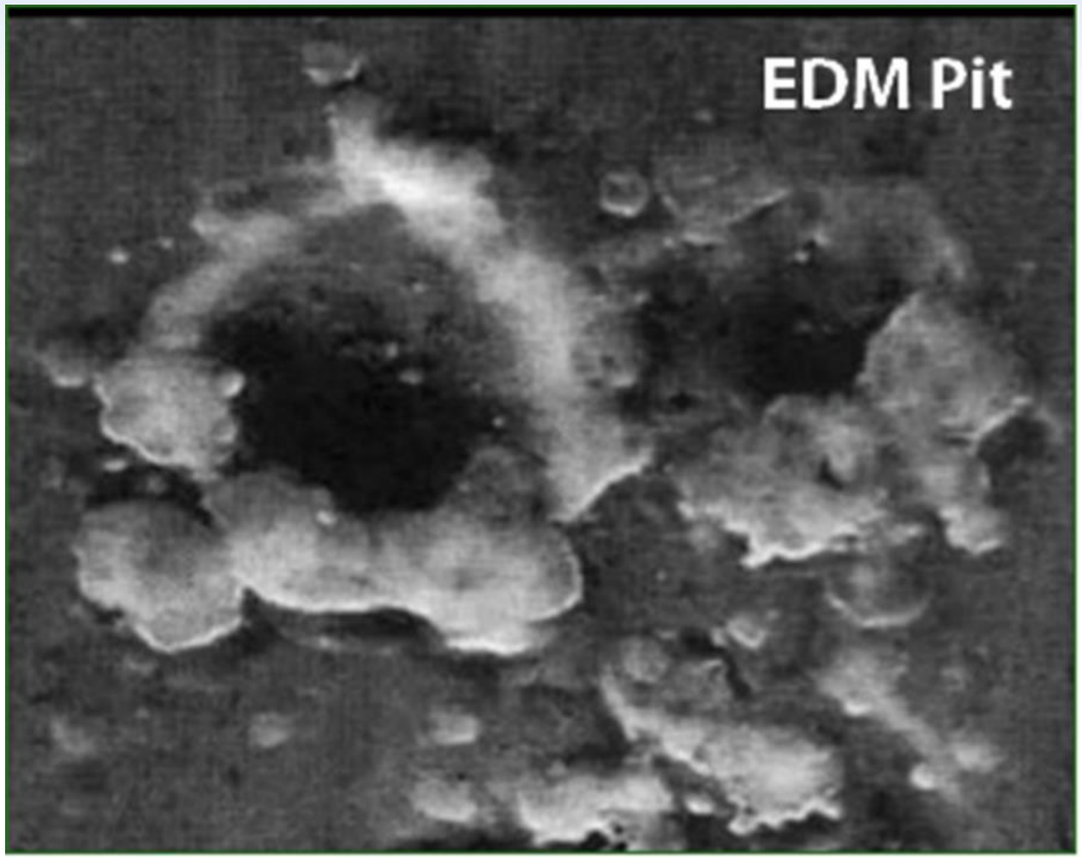
Bearing Damages

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



- When this event happens, temperatures are hot enough to melt bearing steel and severely damage the bearing lubrication.

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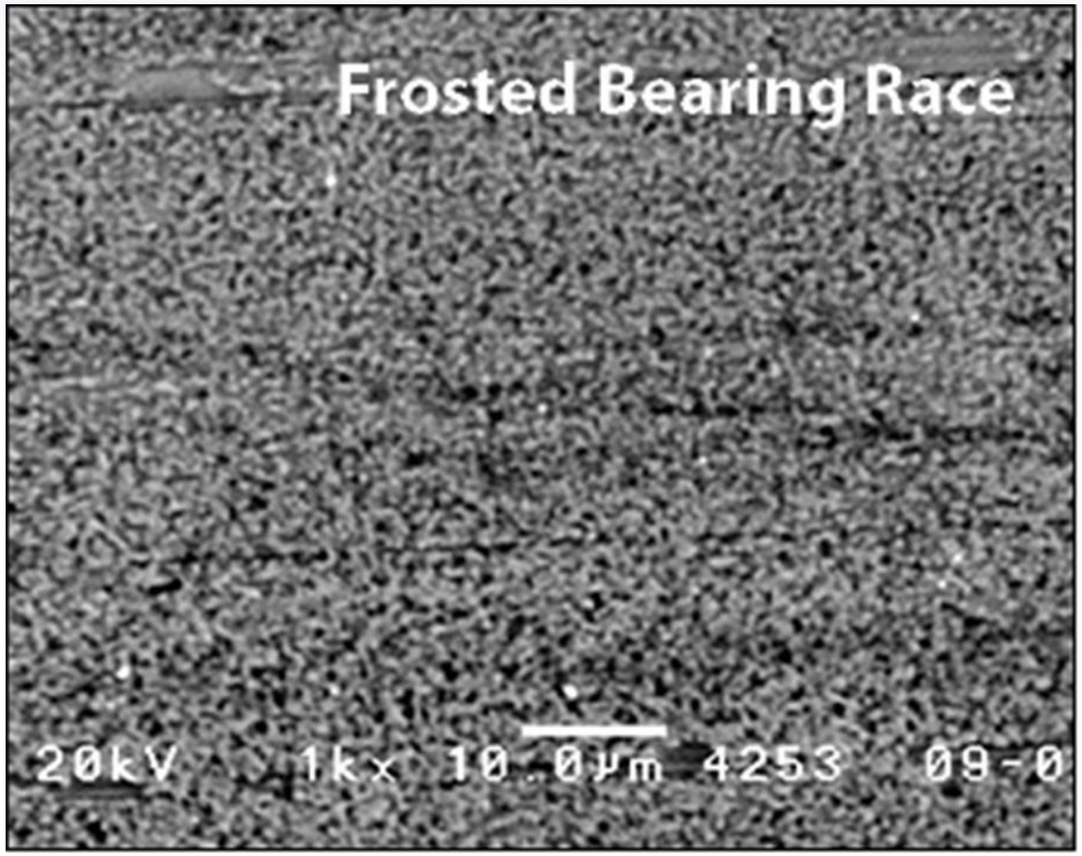
Bearing Damages

- These discharges are so frequent (millions per hour) that before long the entire bearing race becomes marked 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 excessive noise and vibration and in heating, ventilation, and air-conditioning systems, it is magnified and transmitted by the ducting.



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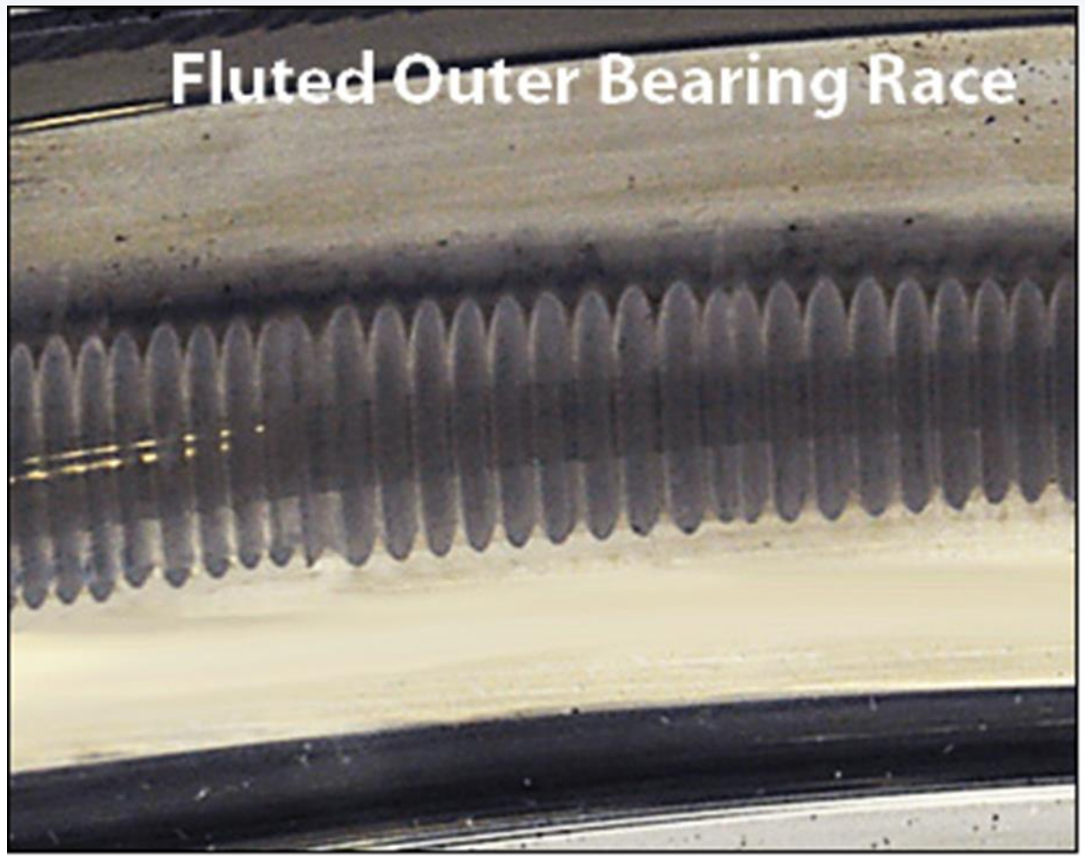
Bearing Damages

- Regardless of the type of bearing or race damage that occurs, the resulting motor failure often costs many thousands or even tens of thousands of dollars in downtime and lost production.
- Failure rates vary widely depending on many factors, but evidence suggests that a significant portion of failures occur only 3 to 12 months after system start-up.
- Because many of today's AC motors have sealed bearings to keep out dirt and other contaminants, electrical damage has become the most common cause of bearing failure in AC motors with VFDs.



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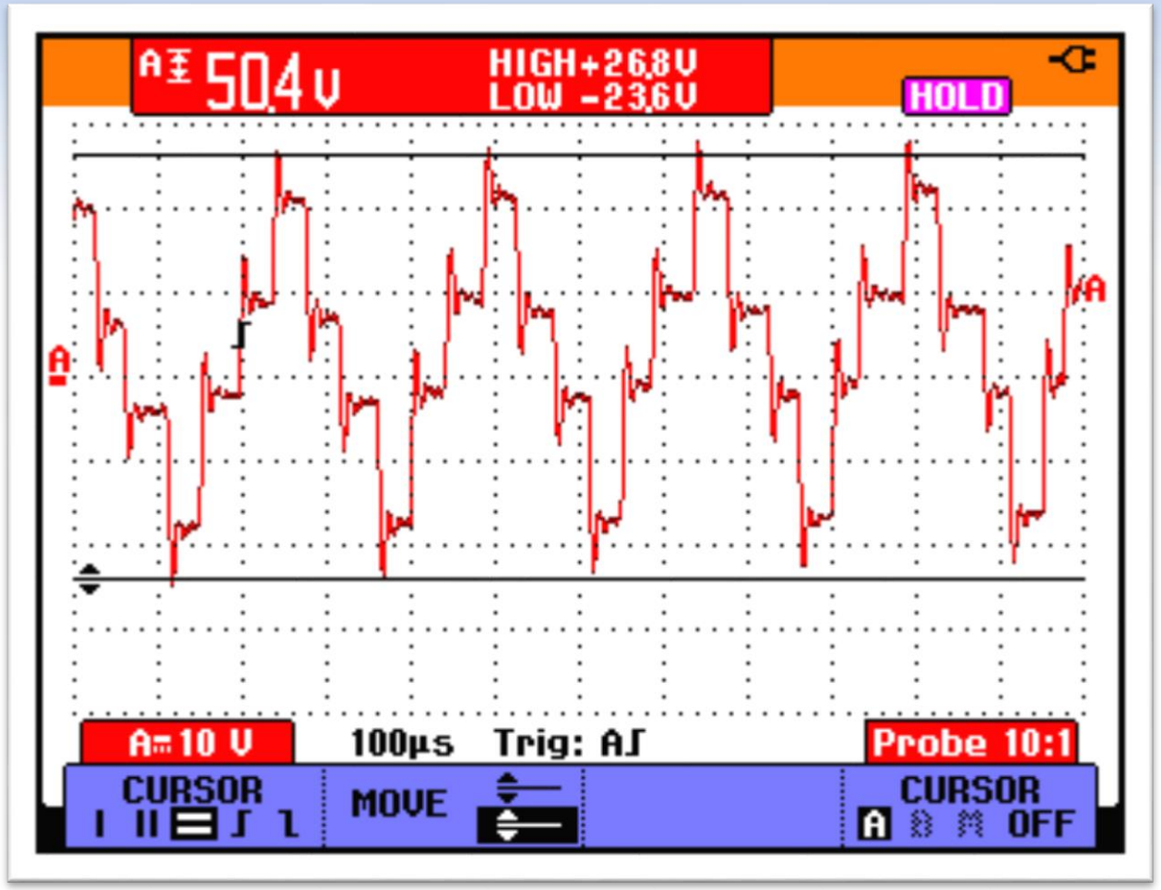
Taking the Measurements – Shaft Voltage

- Oscilloscope with 100MHz minimum bandwidth (Fluke ScopeMeter® 190 Series)
- 10:1 probe
- AEGIS® SVP KIT
- Magnetic base

Examples of Shaft Voltage Readings

High Peak to Peak Common Mode Voltage

Typically 20 to 120 volts peak to peak. 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 wave form looks like. Sometimes it will look like a square wave.



Important note: 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 it’s maximum level. The continued voltage will eventually overcome the dielectric in most bearings and begin discharging.

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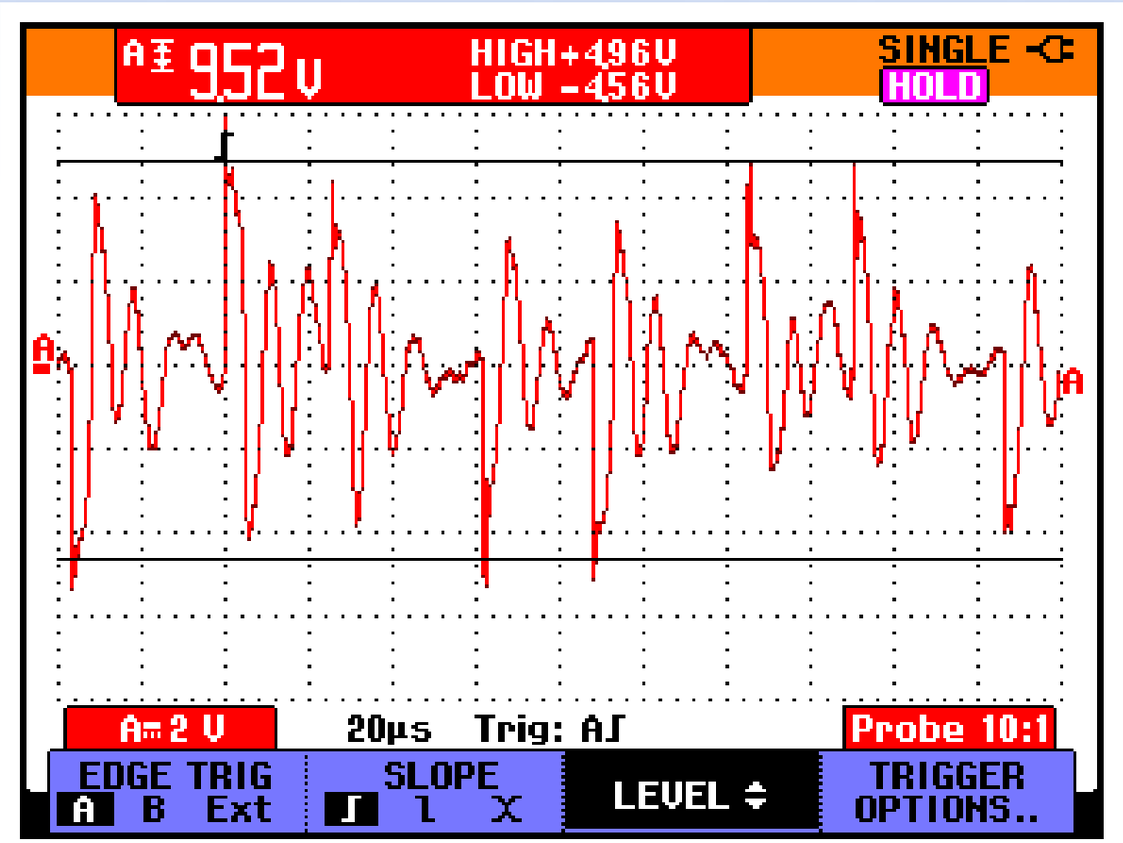
Examples of Shaft Voltage Readings

Low amplitude voltage discharge pattern

Typically the peak to peak voltages are 4 to 15 volts peak to peak. The waveform image shows a more continuous discharge pattern with lower dv/dt frequencies between 30 KHz to 1 MHz. The lower voltage is due to greater current flow in the bearings which is the result of the bearing lubrication becoming conductive.



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.

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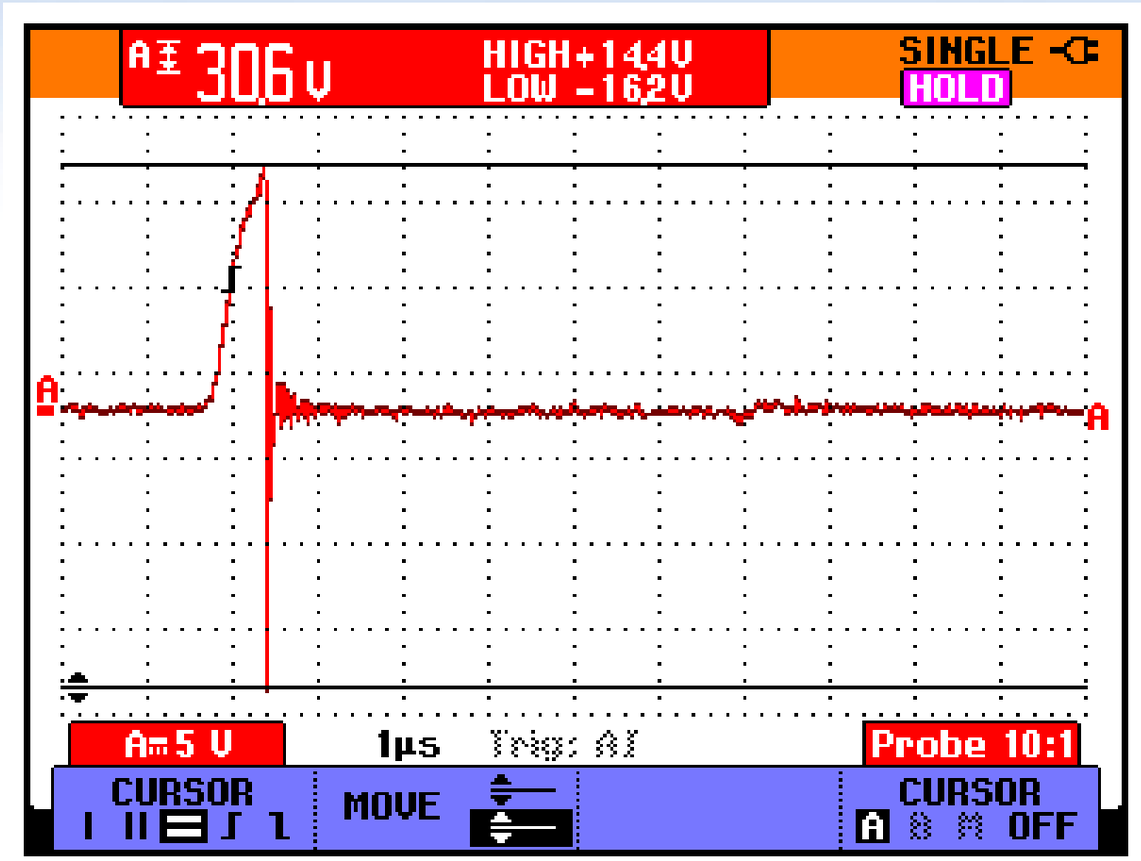
Examples of Shaft Voltage Readings

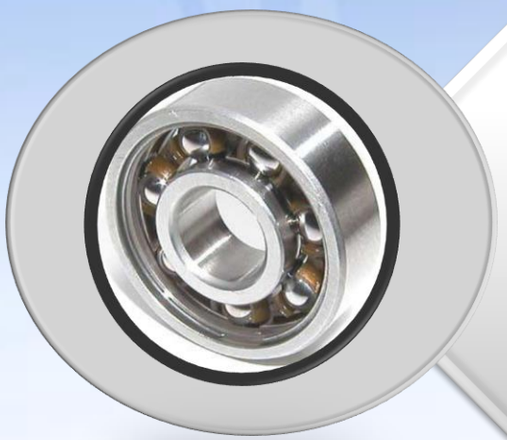
Electrical Discharge Machining (EDM)

- Because of the high-speed switching frequencies in PWM inverters, variable frequency drives induce shaft currents in AC motors.
- The switching frequencies of insulated-gate bipolar transistors (IGBT) used in these drives produce voltages on the motor 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 oscilloscope probe to the shaft while the motor is running. *Reference: NEMA MG1 Section 31.4.4.3*

Mitigation Strategies

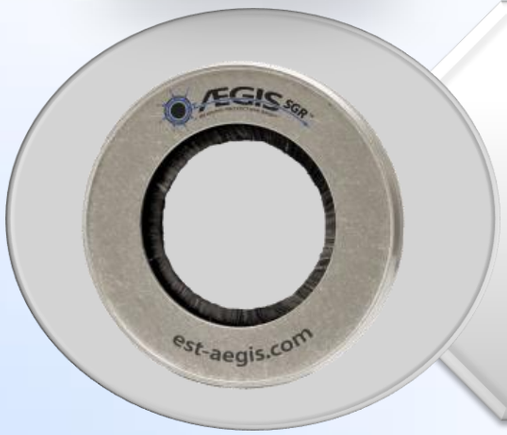


Insolate the shaft from the frame of the motor:

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 75 kW.

“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:

AEGIS® Shaft Grounding Ring of conductive micro fibres for voltage discharge. Maintenance free, works in oil/grease/dust, lasts for service life of motor.

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AEGIS® BEARING PROTECTION RINGS

New Conductive Microfiber Shaft Grounding Technology

Design Difference

100%	Only 4%
• Full 360º degrees around shaft • Designed for VFD currents • Larger Shaft = more current capability • Contact and Nanogap Contact	• Limited shaft coverage • Small contact area • Friction contact only • Wear and replacement • Not suitable for VFD currents
	

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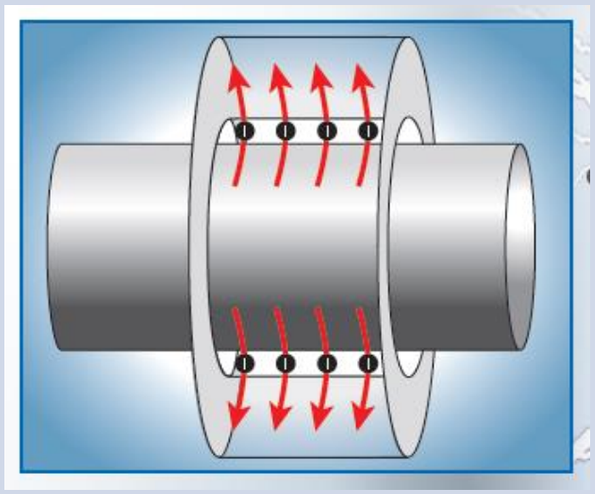
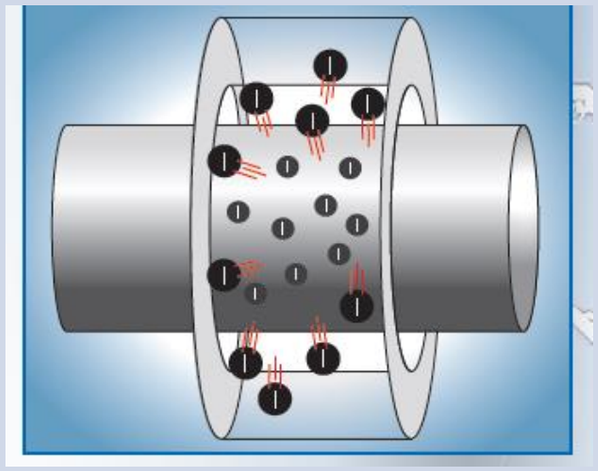
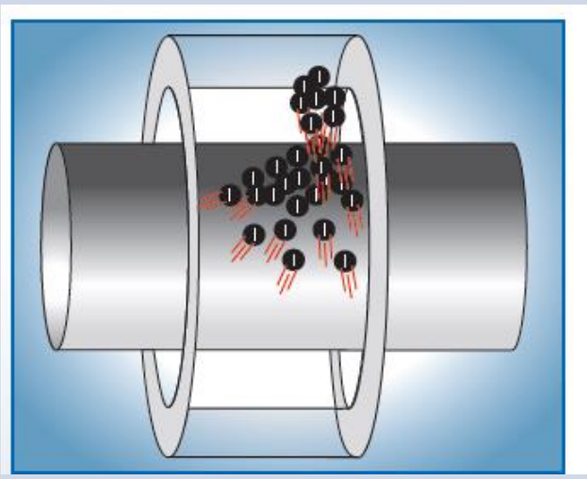
AEGIS® BEARING PROTECTION RINGS

Patented AEGIS® NanoGap Contact Technology

Tunneling of Electrons when Fibers are <2nm	Field Emissions of Electrons when Fibers are 2nm -5um	Townsend Avalanche of Gaseous Ions when Fibers are >5um
		

“NanoGap Electron Transfer”

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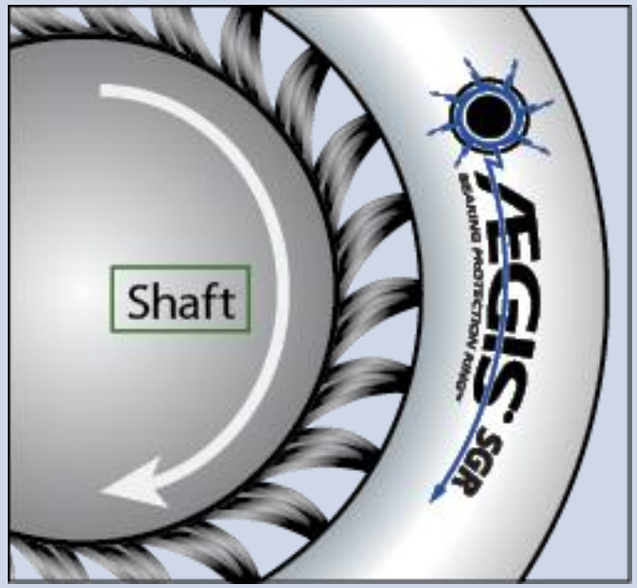
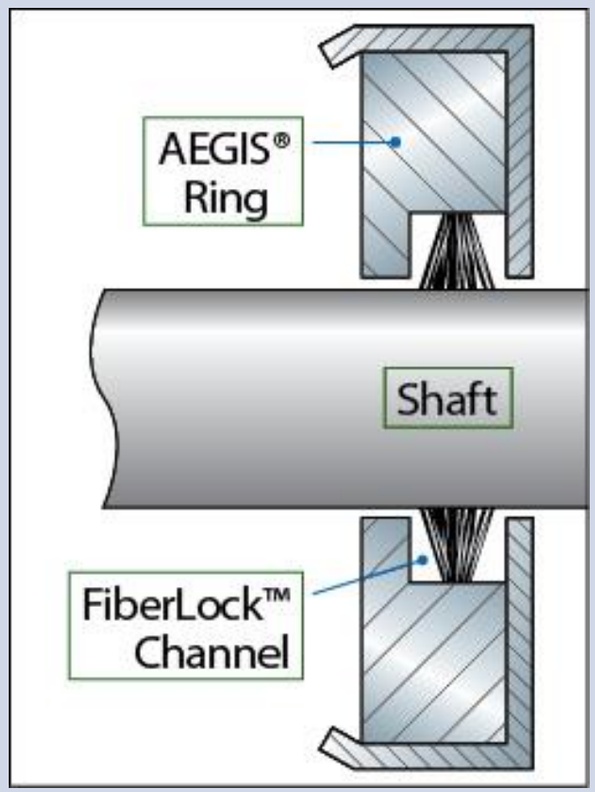
AEGIS® BEARING PROTECTION RINGS

Patented AEGIS® Ring Design

Specially Designed Microfibers Flex Without Breaking – Ultra Low Friction	Patented FiberLock™ Channel Secures and Protects Fibers
	

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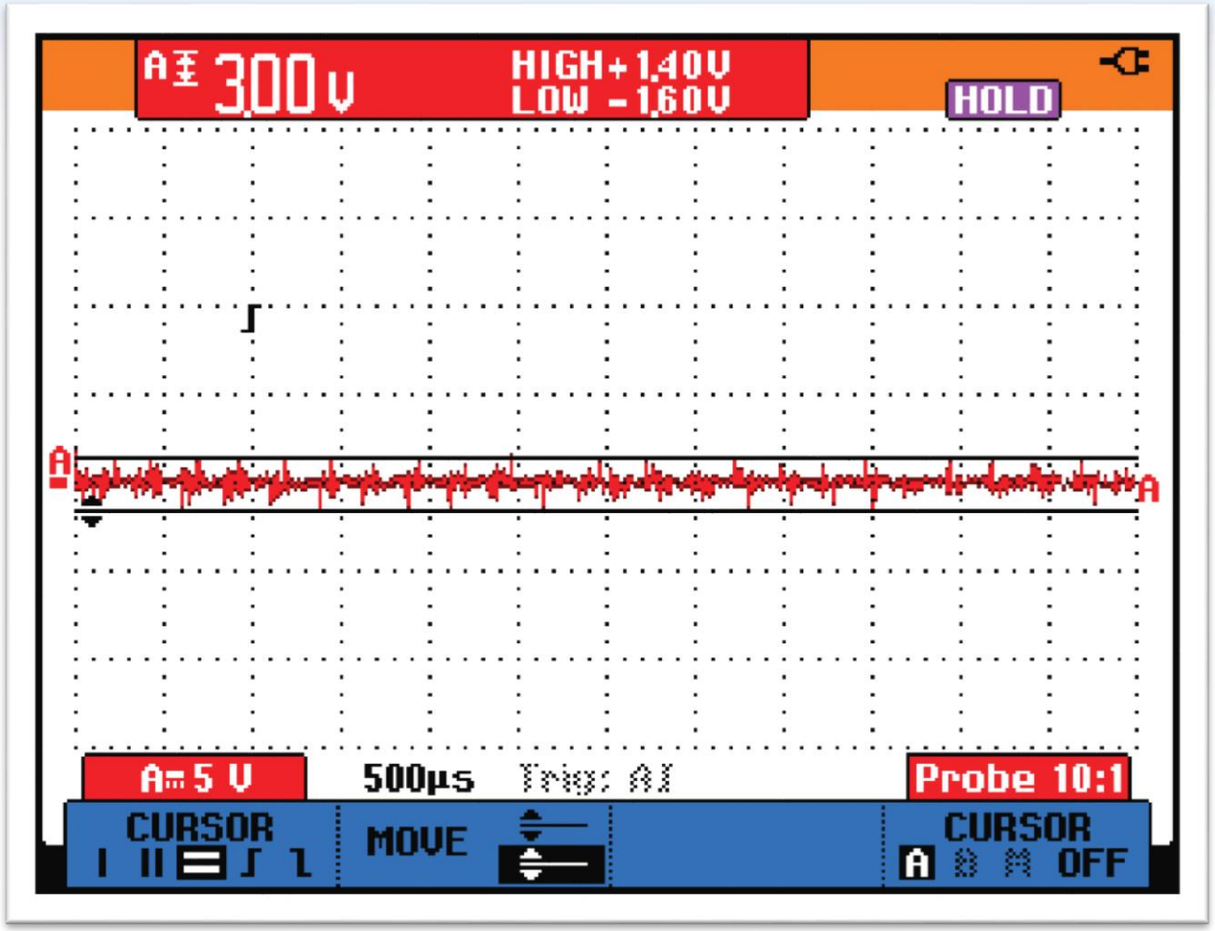
Typical Shaft Voltage Readings

Peak to Peak voltage with AEGIS® SGR installed

With the AEGIS® ring installed, you will typically see discharge voltage peaks around 2 to 3 volts on a bare steel shaft surface. The voltage readings may be decreased with the application of AEGIS® Colloidal Silver Shaft Coating which allows for a more efficient electron transfer to the conductive micro fibre tips. The waveform image shows the low peak to peak waveform of a motor with AEGIS® SGR discharging the shaft voltages.



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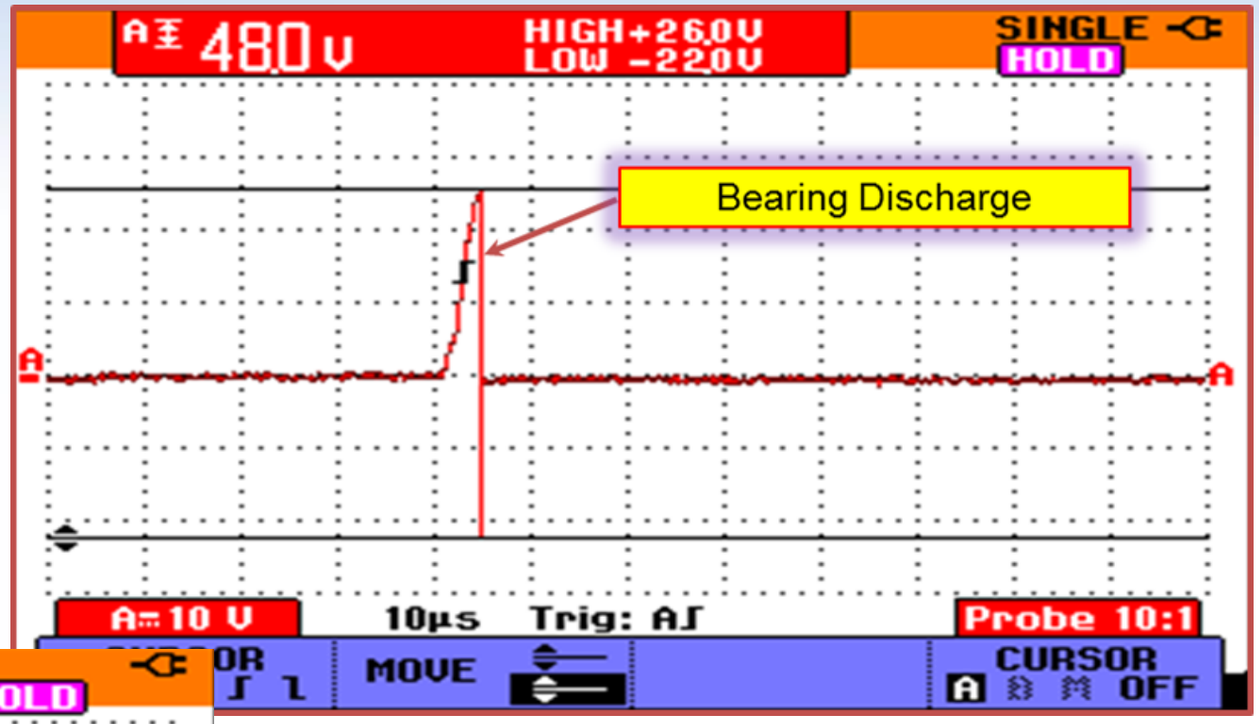
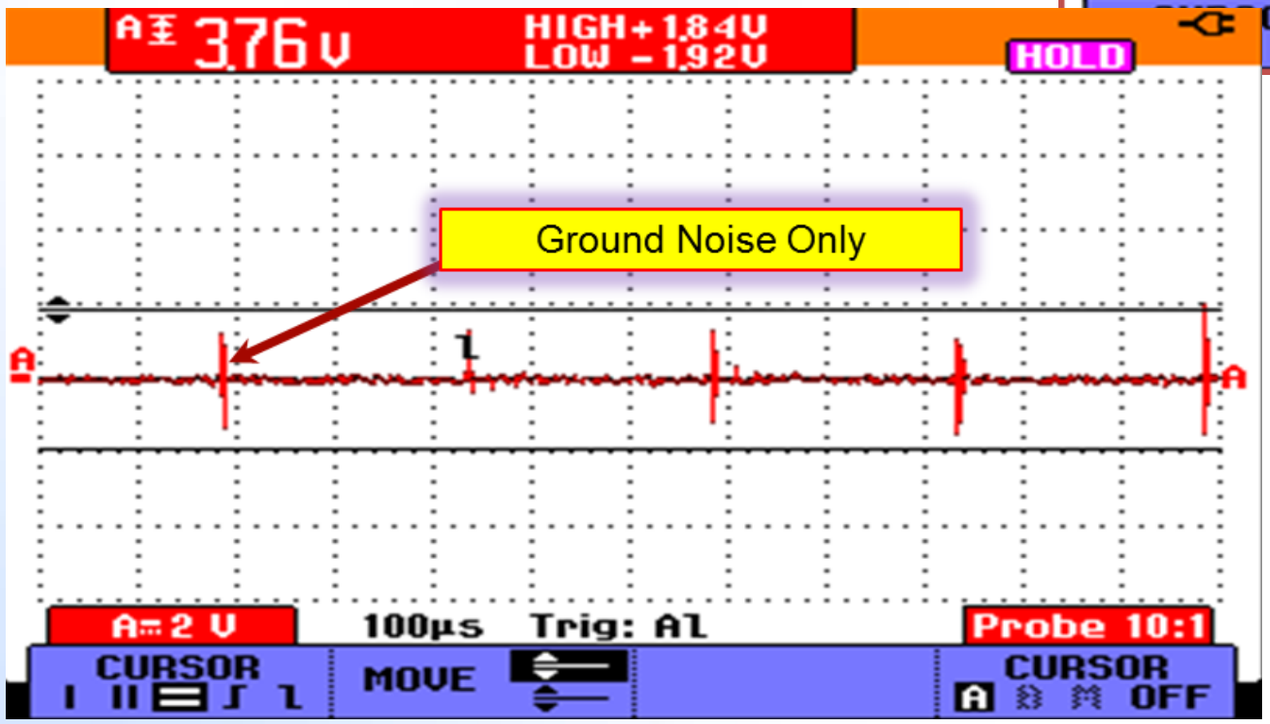
AEGIS® BEARING PROTECTION RINGS

Typical Shaft Voltage Readings
Before and after installation of AEGIS® SGR

Shaft Voltage Reading:
48 V p-p



Equipment:
Motor: Baldor 15 HP
VFD: ABB



Shaft Voltage Reading:
3,76 V p-p

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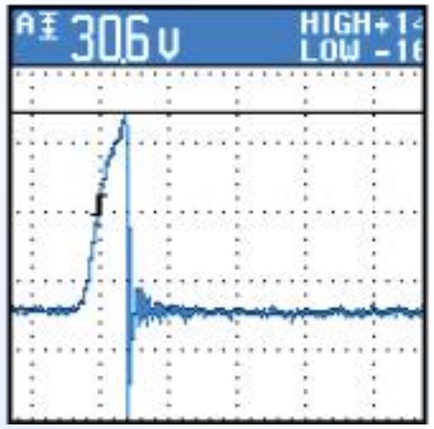
Bearing Protection – Best Practices



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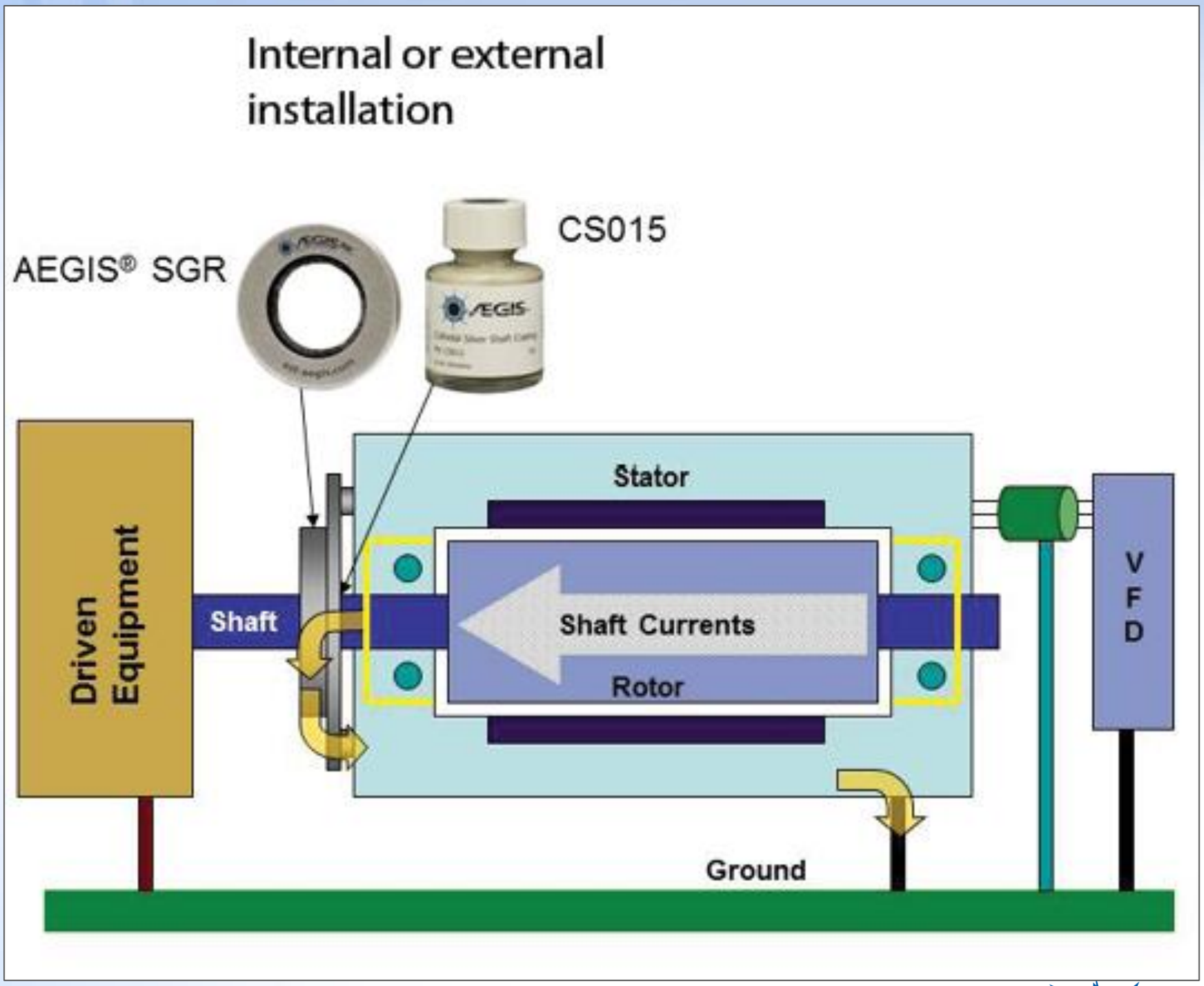
Motors up to around 75 kW



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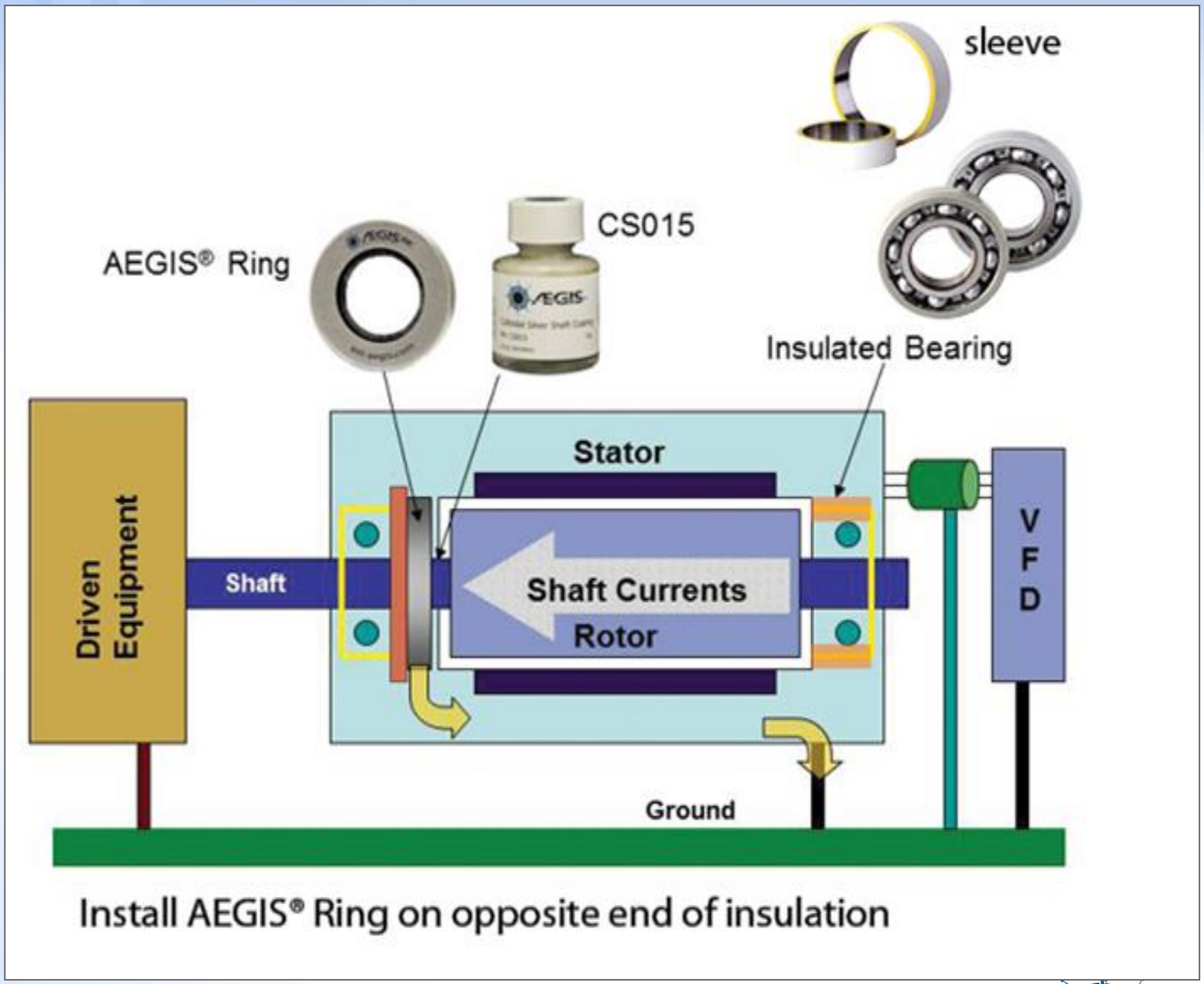
Motors above around 75 kW
low and medium voltage



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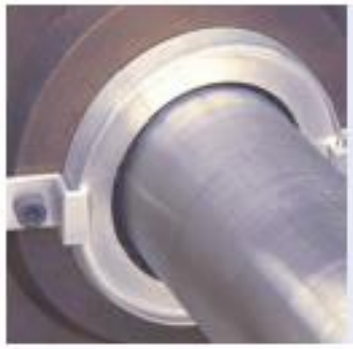
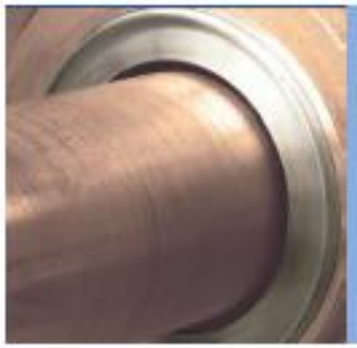
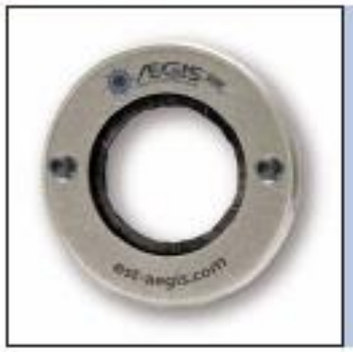
AEGIS® SGR Types



Standard mounting brackets with brackets
Shaft diameter: 8 mm to 153 mm
Delivery unit with mounting brackets, bolts and washers
Fast and easy mounting, generally on the exterior of the housing



Mounting by pressing
Shaft diameter 8 mm to 153 mm
0.102 mm manufacturing accuracy of the moulded part
Variable manufacturing size



Mounting with holes and countersunk screws
Shaft diameter: 8 mm to 153 mm
M3 x 14 countersunk screws
2 holes for shaft diameters up to 99 mm
3 holes for larger diameter

Split design
Shaft diameter: 8 mm to 153 mm
4-6 mounting brackets, screws and washers
Mounting without dismantling the motor

NEW: AEGIS standard and split version for fitting with conductive epoxy bond instead of screws
- Dimensions are the same as standard and split rings

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AEGIS® BEARING PROTECTION RINGS

AEGIS® PRO for high current application

- 50 to 800 mm shaft diameter
- 6 rows of fibers for to discharge up to 120 A
- Split version possible
- Customized design possible

Application areas

- Medium voltage motors
- AC and DC motors
- Generators

AEGIS® BEARING PROTECTION RINGS

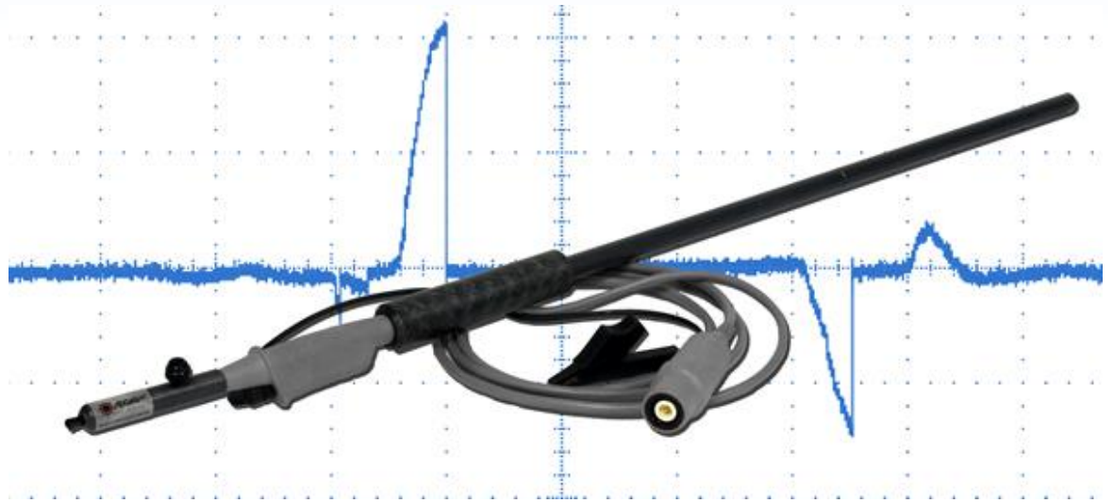
AEGIS® SVP Measurement Kits

Specially made for Fluke 190 series. Also suitable for other oscilloscopes.

Including tips, probe holder and two piece extension rod.

Suitable for all standard magnetic holders.

Easy in handling.



Application areas

- Measurement of shaft voltage
- Diagnose the cause of EDM Bearing Failure
- Predictive maintenance

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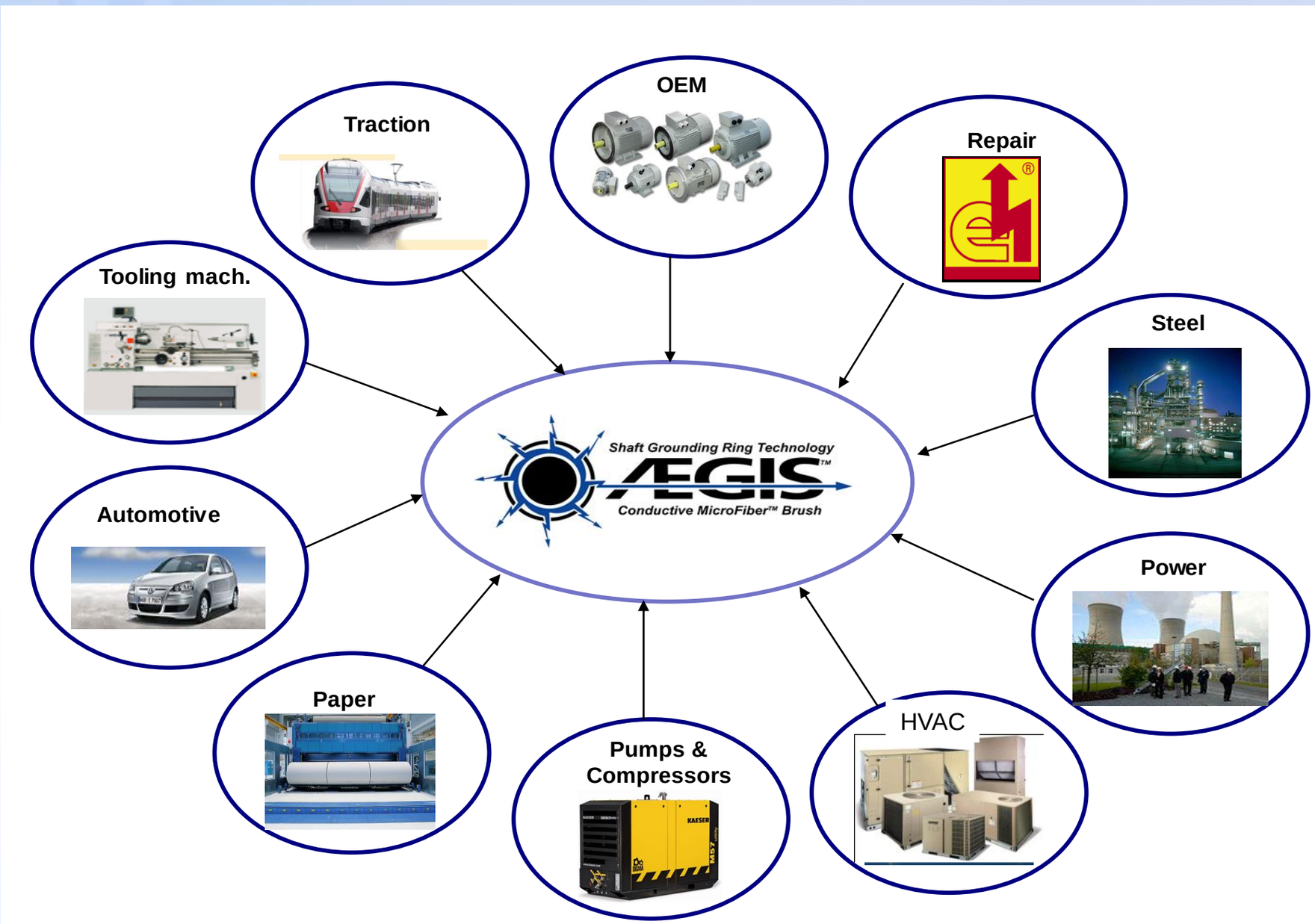
Application Areas for AEGIS® SGRs



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AEGIS® BEARING PROTECTION RINGS

OEM

GE Energy

New Products

A$D Ultra Motor
Section 4.0
The latest addition to the Ultra family of NEMA Premium Efficient motors designed for constant torque variable speed applications and protected against electrical bearing damage by an **internally** mounted Aegis SGR on the drive end bearing. See inside for more details.

Test and Warranty *(see Internet)*

….

• **Extended AEGIS® bearing guarantee** on motors up to and including 100 HP:
a. Direct drive applications: 15 years or 130,000 hours
b. …

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AEGIS® BEARING PROTECTION RINGS

OEM

Super-E® HVAC Motors with AEGIS™ Shaft Grounding Ring 1 – 50 HP 143T thru 326T

BALDOR

Aegis SGR™ guarantees the prevention of bearing damage caused by drive-induced currents

AEGIS SGR BEARING PROTECTION RING
AEGIS INSTALLED

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AEGIS® BEARING PROTECTION RINGS

OEM

- **ATB Schorch, D** - for large drives, AEGIS® for serial demand
- **Baumüller, D** - serial demand for two motor types
- **Oswald, D** - AEGIS® for special drives (Motor test rigs)
- **GE Converteam, F** - AEGIS® for special drives
- **T-T Electric, F** - Serial demand for all motor types
- **Leroy Somer, F** - Motors for electrical cars
- **WEG, Mexico and PT** - serial demand for some motor types
- **EMOD, D** - serial demand for motors >110 kW
- **Regal, US** – Marathon Motors
- **Baldor, US** – Super E Series
- **GE, US** – A$D Ultra Series

AEGIS® BEARING PROTECTION RINGS

Paper

UPM Schongau
D-86956 Schongau, Germany

Paper dust / high humidity
AEGIS® in use since 11/2007

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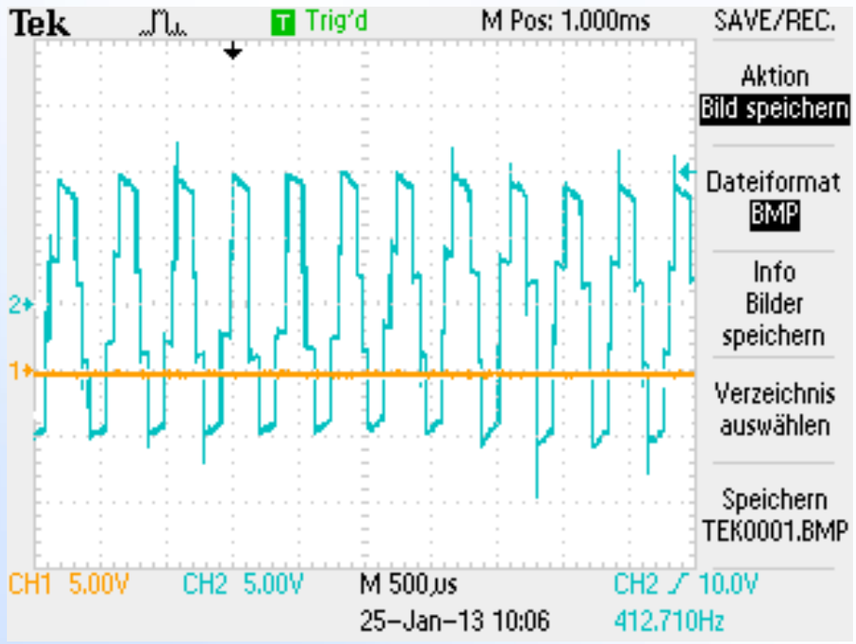
Traction

VBZ Zürich, Switzerland
Bombardier Bautzen, Germany

Proof of effectiveness of AEGIS® SGR in traction motors

Motor: TSA, type 4WXA2544E
95 kW, 420 V, 198A



- Channel 1 (blue) without AEGIS® installed about 30 V pp
- Channel 2 (yellow) with AEGIS® installed below 5 V pp

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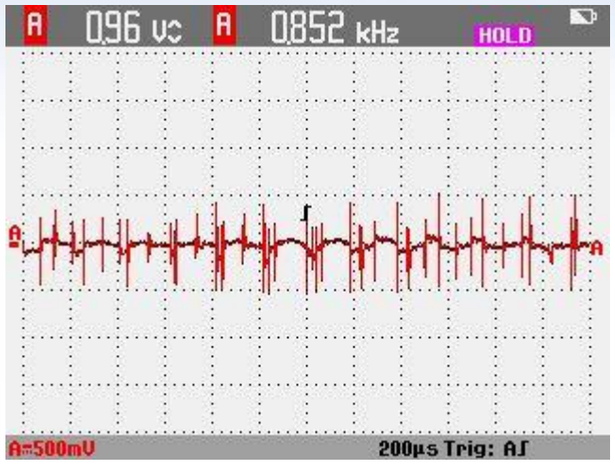
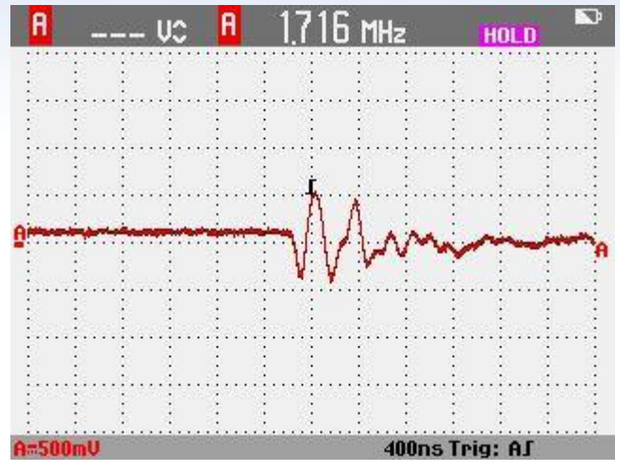
Traction

De Lijn Oost-Vlaanderen and Antwerp, Belgium

HermeLijn trams (MGT6, joint enterprise of Siemens AG and Bombardier)





AEGIS® SGR-11.2-2 ring mounted in the end cap of the gear box in 2009. Measurements in 2014 proved the effectiveness of the solution - <1 V pp

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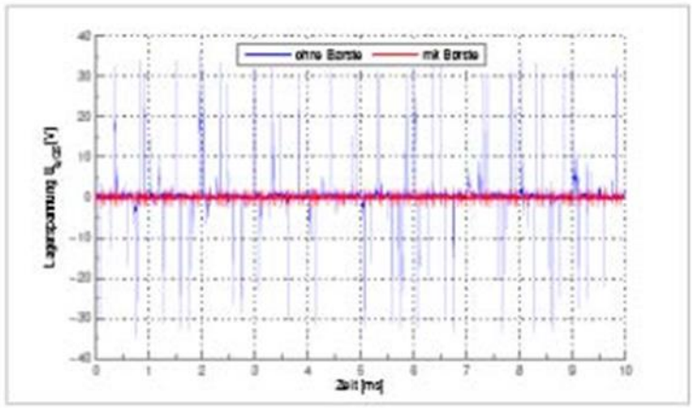
AEGIS® BEARING PROTECTION RINGS

Traction

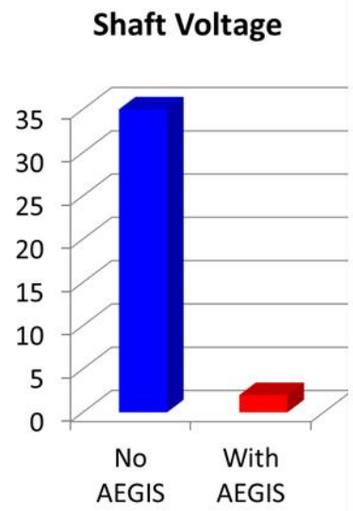
Stadler AG, Switzerland

1. **Measure result in a dry area :**

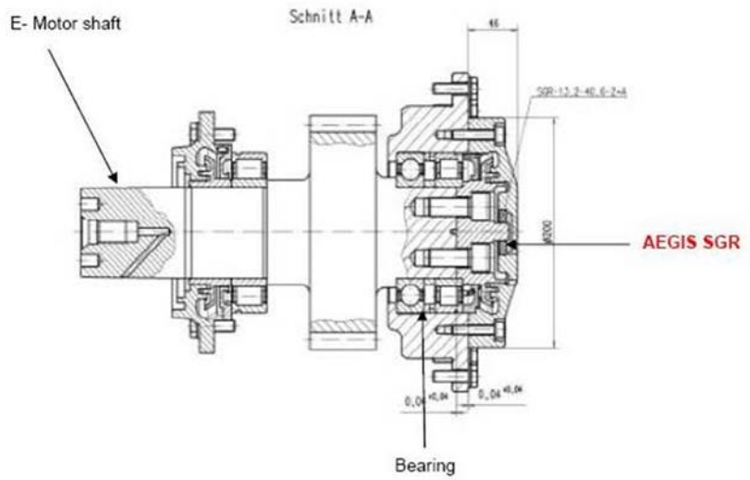


without SGR Volts 35 V pk – pk

with SGR Volts 2 V pk – pk



Drawing detail :



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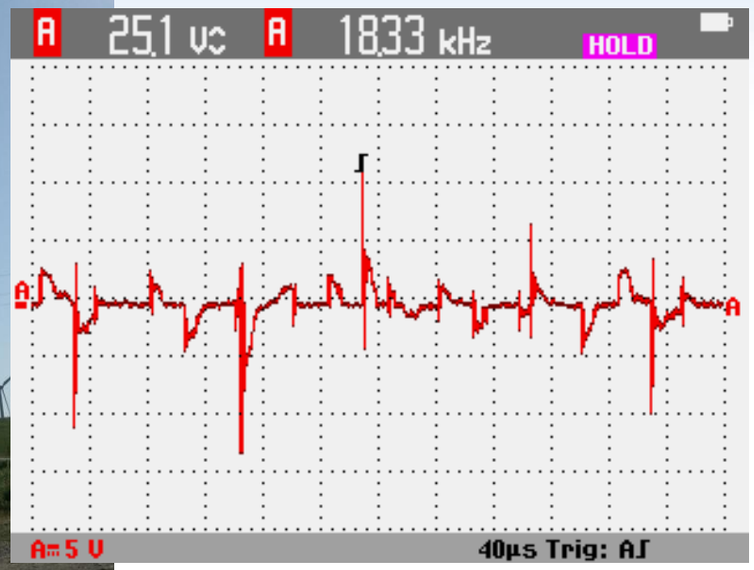
AEGIS® BEARING PROTECTION RINGS

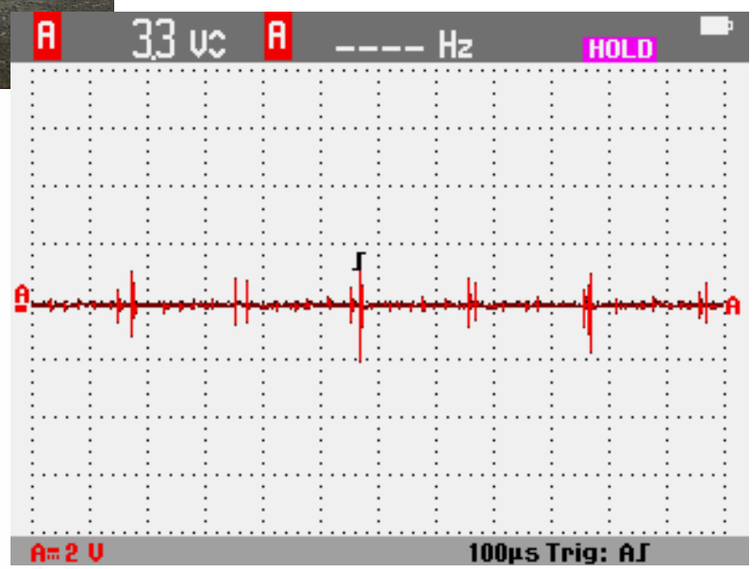
Wind

Montemurro Wind Farm, Italy

Measurements at Vestas V52 with Weier generator 850 kW



Without AEGIS® installed
25,1 V pp



With AEGIS® installed
3,3 V pp

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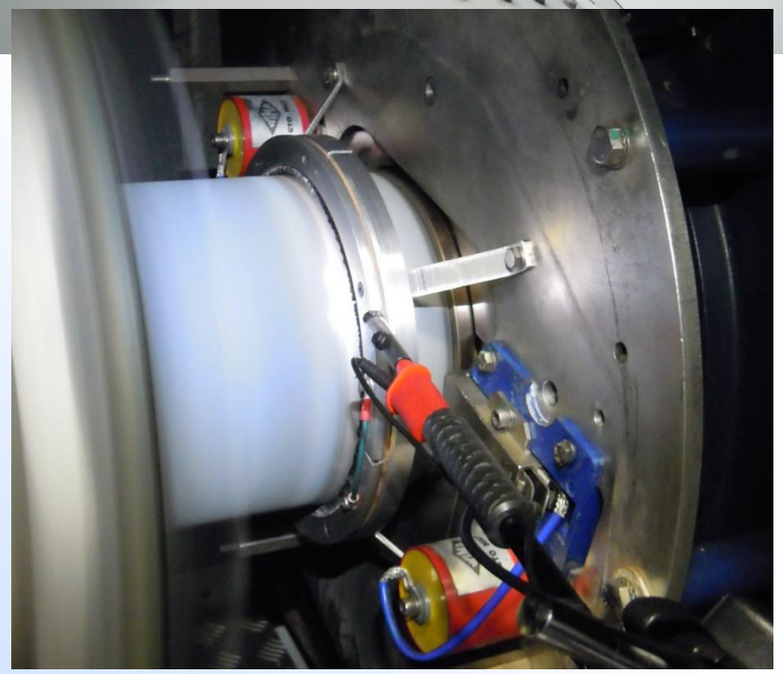
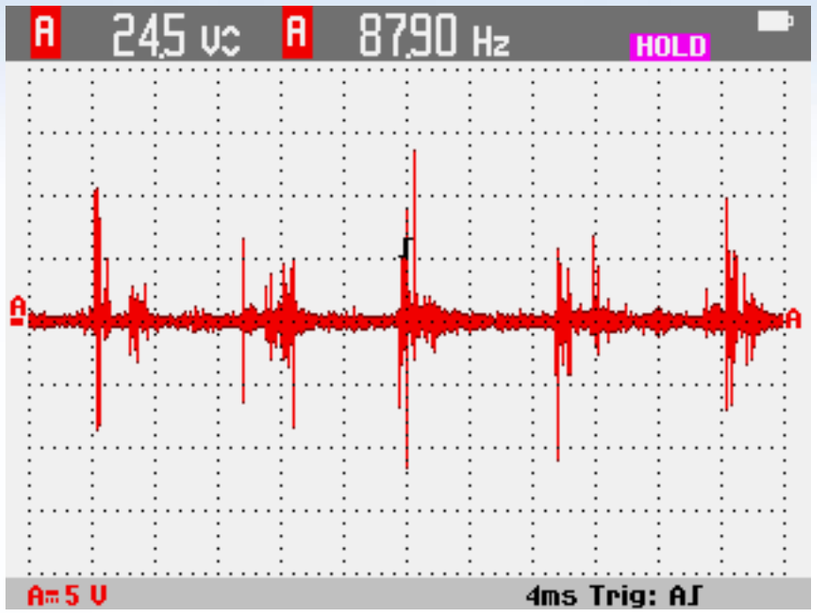
AEGIS® BEARING PROTECTION RINGS

Wind

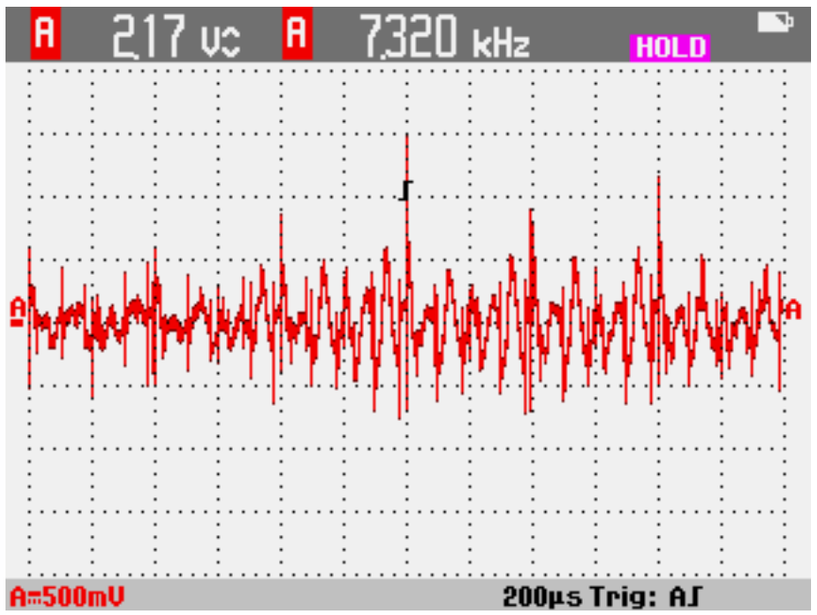
Windpark Langwedel (Deutsche Windtechnik), Germany

Measurements at Vestas V90 with ABB generator, 2 MW





Without AEGIS®,
power 277,2 kW,
1.138,3 Rpm
24,5 V pp



With AEGIS®
power 323,4 kW,
1.465,8 Rpm
2,2 V pp

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AEGIS® BEARING PROTECTION RINGS

Power

- **Coal power plant İskenderun Enerji Üretim Ve Tic.AŞ, Turkey**
  Water feeding pumps, Motor 3.5 MW

- **Nuclear power plants**
  - Gösgen (CH), Water feeding pumps
  - Mühleberg (CH), Water feeding pumps
  - Grundremmingen (DE), Emergency generators
  - Grafenrheinfeld (DE), Emergency generators

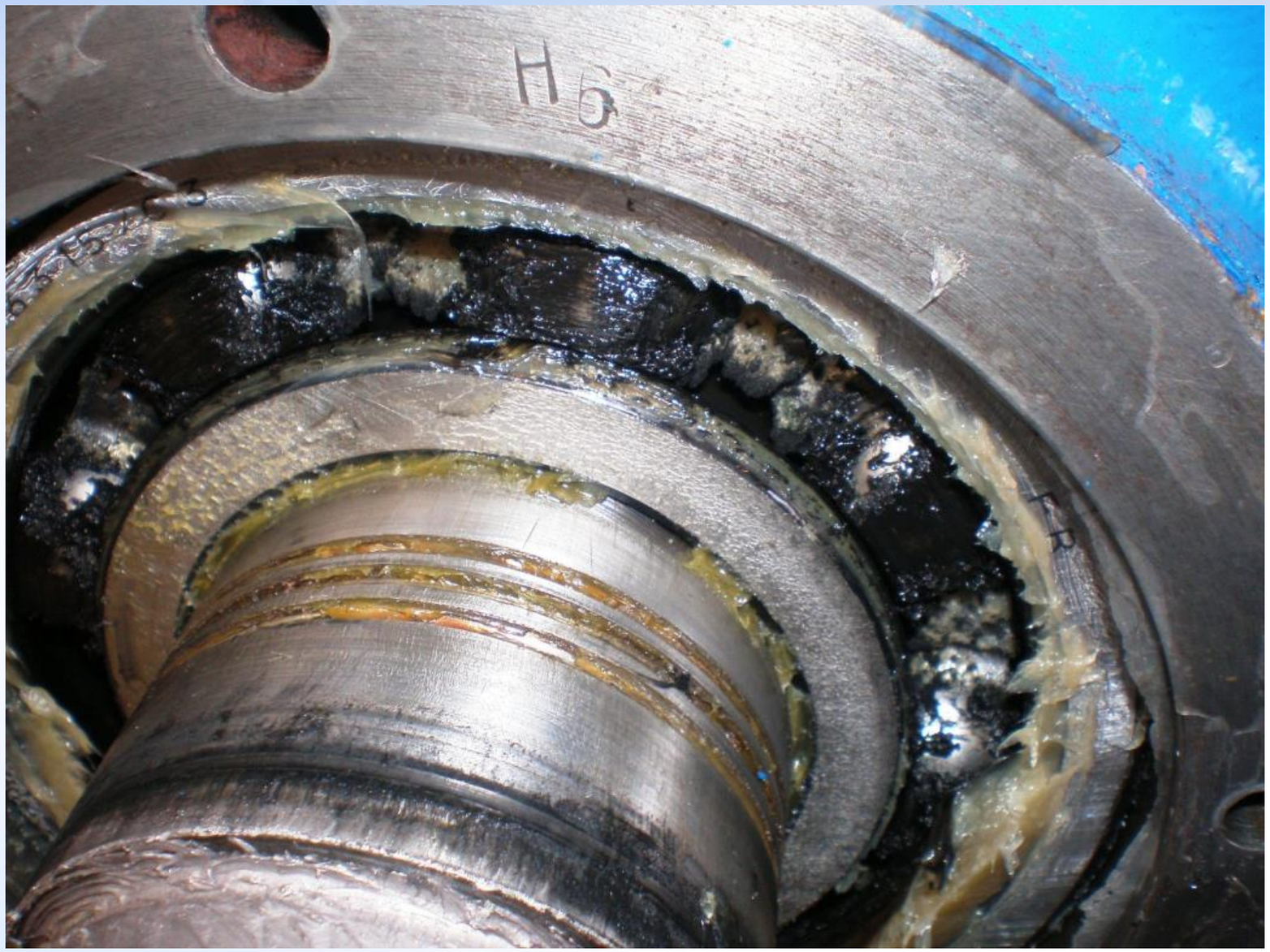
- **AREVA Nuclear Power**
  Recommend AEGIS® for emergency generators

- **Sulzer Pumps**
  Water feeding pumps world wide

- **Alstom Power UK**
  Generator application

AEGIS® BEARING PROTECTION RINGS

Repair



Typical example of burnt grease caused by current discharge (drive of an extruder)

AEGIS® BEARING PROTECTION RINGS

Automotive

- **Test rigs**
  AEGIS® with Rhodium-coated surfaces for to reduce EDM
  AEGIS® for bearing protection

- **Electrical drives**
  AEGIS® with Silver-coated surfaces for to reduce EDM and for bearing protection
  - Existing serial applications in electrical cars in US and Europe (well known brands)
  - Ongoing developement with well known car manufacturers for serial use in electro and hybrid cars

Thank You

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