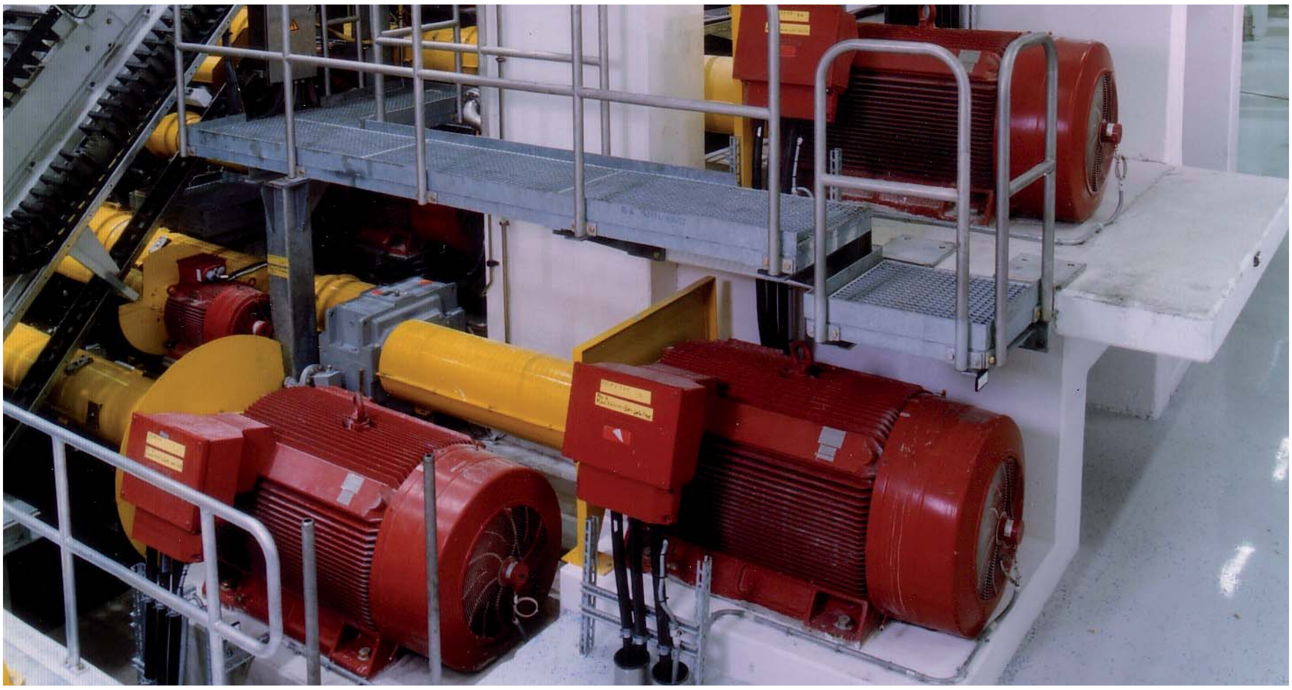
Shaft grounding for inverter driven motors



The use of variable-frequency drives (VFDs) to control AC motors has increased dramatically in recent years. In addition to their low operating cost and high performance, they save energy. Today, the challenge facing system designers and engineers is to minimize damage to AC motors from shaft current. From its first minute of operation, a VFD induces destructive voltages that build up on the motor shaft until they find discharge paths to the frame (ground). In most cases, the motor bearings present the path of least resistance. Once voltage is sufficient to overcome the resistance of the oil film layer in the bearing, shaft current discharges, causing electrical discharge machining (EDM) pits and fusion craters in the race wall and ball bearings. This phenomenon continues until the bearings become so severely pitted that fluting, excessive noise, and failure occur.

Mitigation of this damage is possible through various strategies. Some are narrow in application, and most are costly. Many are not technically feasible. However, a new technology employs a circumferential ring of conductive micro fibers to discharge harmful currents and provide a low-cost solution to the problem.

VARIABLE FREQUENCY DRIVES INDUCE SHAFT CURRENTS IN AC MOTORS

Due in large part to an increased focus on energy savings, the use of pulse-width-modulated (PWM) variable-frequency drives (VFDs) to control AC motors has grown dramatically over the last few years. While they offer low operating costs and high performance, VFDs are not without their problems.

Shaft currents induced by VFDs can lead to motor failures. Without some form of mitigation, shaft currents travel to ground through bearings, causing pitting, fusion craters, fluting, excessive bearing noise, eventual bearing failure, and subsequent motor failure.

ELECTRICAL DAMAGE TO BEARINGS

Due to the high-speed switching frequencies used in PWM inverters, all variable frequency drives induce shaft current 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 electromagnetic induction. These voltages, which can register 70 volts or more (peak-to-peak), are easily measured by touching an oscilloscope probe to the shaft while the motor is running [Figure 1].

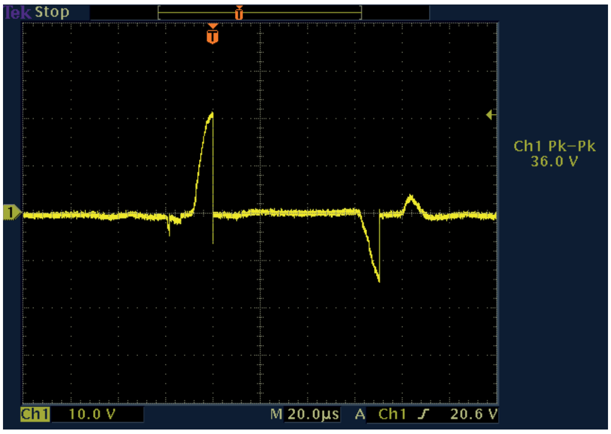


Figure 1.

Once these voltages reach a level sufficient to overcome the dielectric properties of the grease in the bearings, they discharge along the path of least resistance typically the motor bearings to the motor housing. (Bearings are designed to operate with a very thin layer of oil between the rotating ball and the bearing race.) During virtually every VFD cycle, induced shaft voltage discharges from the motor shaft to the frame via the bearings, leaving a small fusion crater in the bearing race.

These discharges are so frequent that before long the entire bearing race becomes marked with countless pits known as frosting. As damage continues, the frosting increases, eventually leading to noisy bearings and bearing failure. A phenomenon known as fluting may occur as well, producing washboard-like ridges across the frosted bearing race. Fluting can cause excessive noise and vibration that, in heating, ventilation, and air-conditioning systems, is magnified and transmitted by the ducting. 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 Euros in downtime and lost production.

New bearing race [Figure 2]: Viewed under a scanning electron microscope, a new bearing race wall is a smooth surface. As the motor runs, a track eventually forms where the bearing ball contacts the wall. With no electrical discharge damage, this type of mechanical wear would be the only cause of degradation.

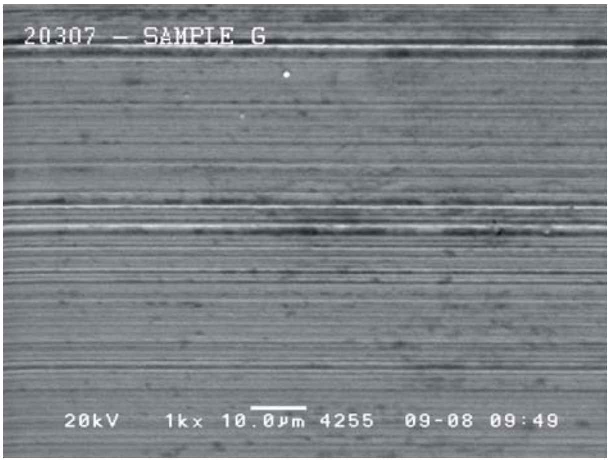


Figure 2. *New bearing race wall.*

Pitting [Figure 3]: Frosted bearing race wall after 5400 hours of continuous use in a VFD/AC motor system. Early damage typically takes the form of pitting. These fusion craters increase in number and size as each cycle of induced voltage discharges from the shaft through the bearings to the frame and ground. Soon the entire race is covered with millions of pits. As new fusion craters form over old ones, eventually a "frosted" surface easily visible to the naked eye appears.

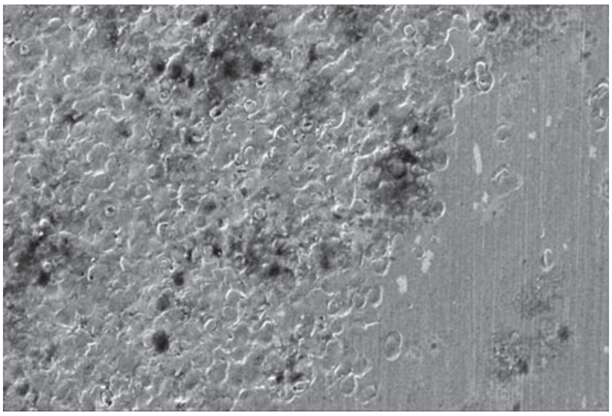


Figure 3. *Frosting.*

Fluting [Figure 4}: In a phenomenon known as fluting, the operational frequency of the VFD causes concentrated pitting at regular intervals along the bearing race wall, forming a "washboard" pattern. This pattern results in vibration and noise. In an HVAC system, this noise can be transmitted throughout a facility via air ducts.

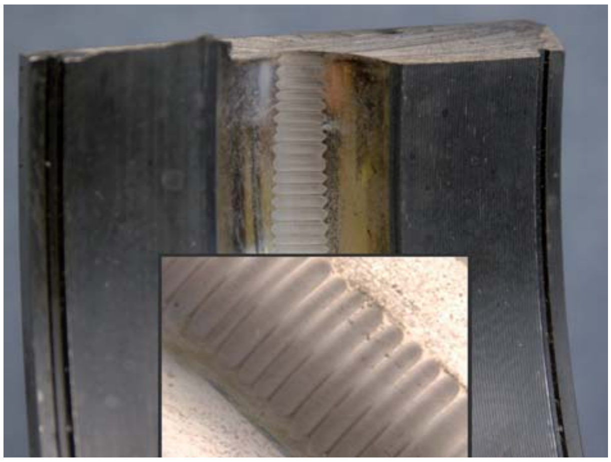


Figure 4. *Fluted bearing.*

STRATEGIES FOR MITIGATING SHAFT CURRENT DAMAGE

As demonstrated above, electrical damage to VFD/AC motor bearings begins at startup and grows progressively worse. As a result of this damage, the bearings eventually fail. To prevent such damage in the first place, the induced shaft current must be diverted from the bearings by insulation and/or an alternate path to ground.

Insulation: Insulating motor bearings is a solution that tends to shift the problem elsewhere as shaft current looks for another path to ground. Sometimes, because of the capacitive effect of the ceramic insulation, high-frequency VFD-induced currents actually pass through the insulating layer and cause bearing failure. If attached equipment, such as a pump, provides this path, the other equipment often winds up with bearing damage of its own. Insulation and other bearing-isolation strategies can be costly to implement.

Alternate discharge paths: When properly implemented, these strategies are preferable to insulation because they neutralize shaft current. Techniques range in cost and sometimes can only be applied selectively, depending on motor size or application. The ideal solution would provide a very-low-resistance path from shaft to frame, would be low-cost, and could be broadly applied across all VFD/AC motor applications, affording the greatest degree of bearing protection and maximum return on investment.

SHAFT CURRENT MITIGATION TECHNOLOGIES

Although there are a number of technologies now available to protect AC motor bearings from damage due to shaft currents, few meet all the criteria of effectiveness, low cost, and application versatility.

1. Faraday shield: The shield prevents the VFD current from being induced onto the shaft by effectively blocking it with a capacitive barrier between the stator and rotor. However, this solution is extremely difficult to implement, very expensive, and has been generally abandoned as a practical solution.

2. Insulated bearings: Insulating material, usually a nonconductive resin or ceramic layer, isolates the bearings and prevents shaft current from discharging through them to the frame. This forces current to seek another path to ground, such as through an attached pump or encoder or even the load. Due to the high cost of insulating the bearing journals, this solution is generally limited to larger-sized motors. Sometimes, high-frequency VFD-induced currents actually pass through the insulating layer and cause bearing damage anyway. Another drawback is the potential for contaminated insulation, which can, over time, establish a current path through the bearings.

3. Ceramic bearings: The use of nonconductive ceramic balls prevents the discharge of shaft current through this type of bearing. As with other isolation measures, shaft current will seek an alternate path to ground. This technology is very costly, and in most cases motors with ceramic bearings must be special ordered and have long lead times. In addition, because ceramic bearings and steel bearings differ in compressive strength, ceramic bearings must be resized in most cases to handle mechanical static and dynamic loadings.

4. Conductive grease: In theory, because this grease contains conductive particles, it would provide a lower-impedance path through the bearing and would bleed off shaft current through the bearing without the damaging discharge. Unfortunately, the conductive particles in these lubricants increase mechanical wear to the bearing, rendering the lubricants ineffective and often causing premature failures. This method has been widely abandoned as a viable solution to bearing currents.

5. Grounding brush: A metal brush contacting the motor shaft is a more practical and economical way to provide a low-impedance path to ground, especially for larger motors. However, these brushes pose several problems of their own:

a. They are subject to wear because of the mechanical contact with the shaft.
b. They collect contaminants on their metal bristles, which destroys their effectiveness.
c. They are subject to oxidation buildup, which decreases their grounding effectiveness.
d. They require maintenance on a regular basis, increasing their cost.

6. Bearing Protection Ring (SGR): This innovative new approach involves the use of a ring of specially engineered conductive micro fibers to redirect shaft current and provide a reliable, very low impedance path from shaft to frame, bypassing the motor bearings entirely. The ring's uses the principles of ionization to boost the electron-transfer rate and promote extremely efficient discharge of the high-frequency shaft currents induced by VFDs. With hundreds of thousands of discharge points, the SGR channels shaft currents around the AC motor bearings and protects them from electrical damage.

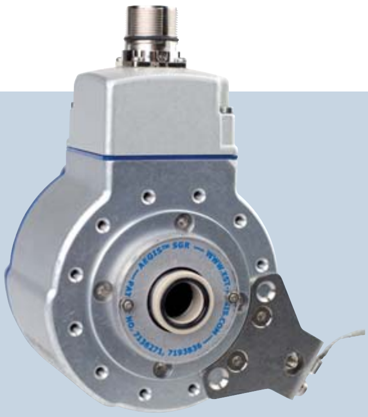


Figure 5. *Encoder with mounted AEGIS™ SGR.*

Availability of SGR's on Leine & Linde encoders

As an option are the heavy duty encoders in Leine & Lindes 800 series available with AEGIS™ shaft grounding rings. The encoder need to be pre-prepared with a special encoder shaft in order to permit the mounting of a SGR. As the SGR is somewhat subject to wear are they always mounted outside the encoders enclosure [Figure 5] and can therefore easily be replaced. Thus preventing current paths being built up thru the encoder to ground, the SGR's effectfully dispatch the currents in a controlled manner saving costs in plants all around the world.

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Mr. Oh has extensive design and application experience in both automation and product development, specializing in passive dissipative technology for mitigating unwanted electrical currents. He has developed products and manufacturing equipment for several companies and is a member of the Illinois Tool Works Patent Society.

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