



PREVENTING VFD/AC DRIVE INDUCED ELECTRICAL DAMAGE TO AC MOTOR BEARINGS

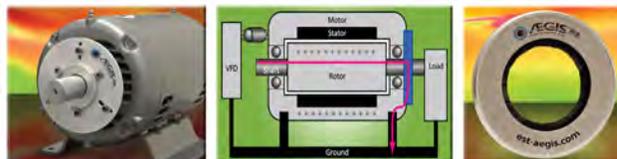
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EXECUTIVE SUMMARY:

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.



AEGIS SGR™ Prevents Electrical Bearing Damage

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.

This is not a small problem. Consider:

- Most motor bearings are designed to last for 100,000 hours, yet motors controlled by VFDs can fail within one month (720 hours).
- An HVAC system contractor recently reported that, of the 30-60 HP VFD-controlled vane axial fans he installed in a large building project, two failed within six months and 100% of the motors failed within one year.
- Several large pulp and paper companies surveyed noted that the VFD-controlled AC motors used in their plants typically fail due to bearing damage within six months.
- The largest motor manufacturer in the United States has cited eliminating drive-related motor failures as its number-one engineering challenge.
- Today, there are almost a dozen blogs on the Internet focused on discussing the problems presented by VFD-induced shaft currents, sharing information and experiences, and suggesting solutions.

- Motor failures caused by VFD-induced shaft currents result in hundreds of thousands of hours of unplanned downtime, in the United States alone, each year. In addition, these failures affect the performance and mean time between failure (MTBF) of the original equipment manufacturing (OEM) systems in which they are used.
- With recent motor-price increases (approximately 16% over last year) due to rising copper prices, this problem will become even more costly.

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].

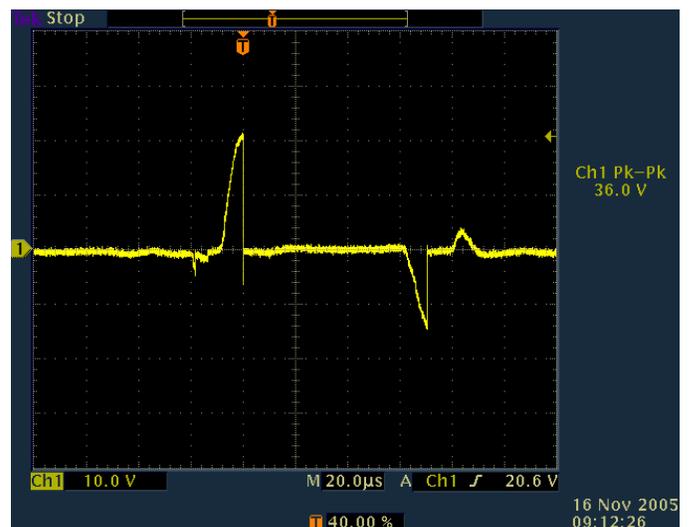


Figure 1

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 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 startup. 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. If half of all AC motor failures are due to bearing failure, almost 80% of these are caused by electrical damage to bearings.



Figure 2

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.

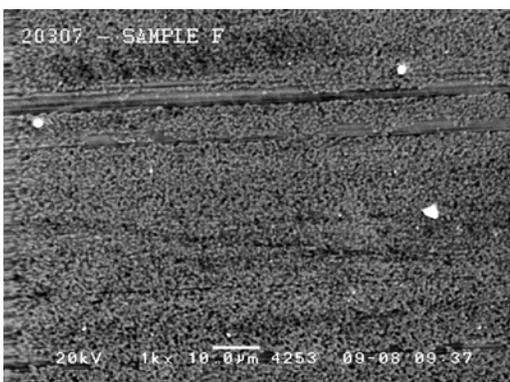


Figure 3

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.

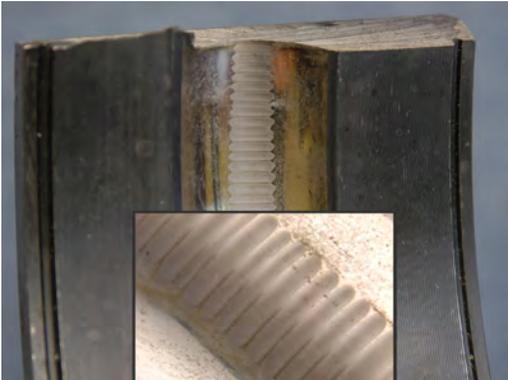


Figure 4

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.

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 tachometer or even the load. Due to the high cost of insulating the bearing journals, this solution is generally limited to larger-sized NEMA 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 NEMA-frame 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 patented Electron Transport Technology™ 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. The AEGIS SGR™ is a low-cost solution that can be applied to virtually any size AC motor in virtually any VFD application.

ELECTRON TRANSPORT TECHNOLOGY™

Electron Transport Technology was invented by engineer William Oh of Electro Static Technology (EST), an Illinois Tool Works company. EST is a leader in the development and application of passive ionization technology solutions for industry.

A MORE COMPLETE SOLUTION

The AEGIS SGR Conductive MicroFiber Bearing Protection Ring offers a unique combination of benefits unmatched by other technologies, including:

Scalability: AEGIS technology is scalable to all sizes of NEMA-frame and larger motors regardless of shaft size or application. Introduced to the market in May 2005, the SGR was designed for motors with shafts from 0.311" to 6.020" including NEMA and IEC frames as well as high-

horsepower AC and DC motors with shaft diameters up to 30". AEGIS SGRs have been applied to power generators, gas turbines, wind turbine generators, AC traction and break motors, cleanrooms and HVAC systems, and a long list of other industrial and commercial applications.

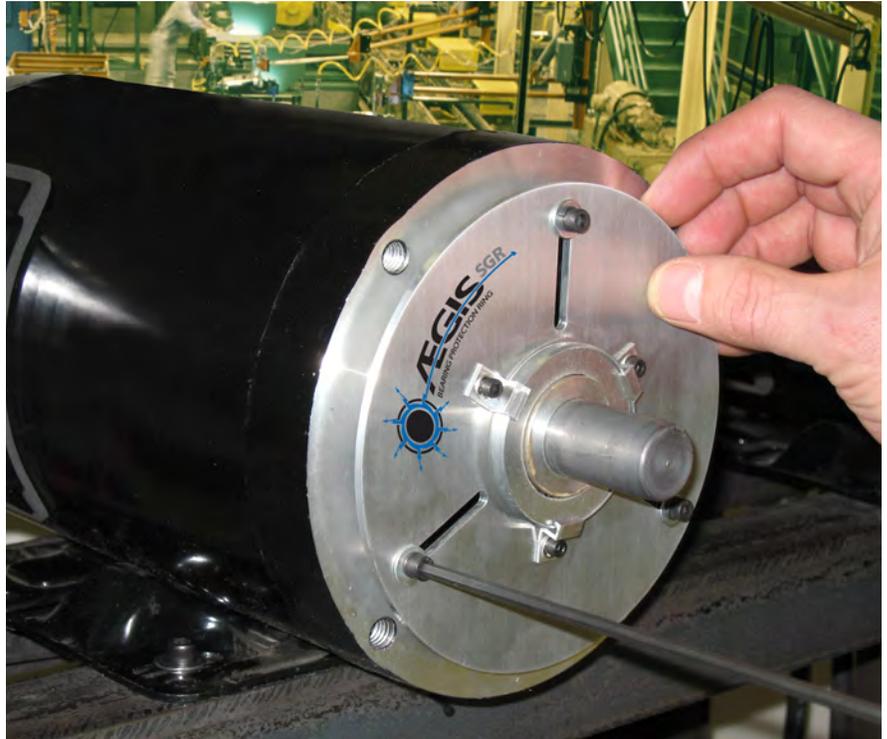
Installation and maintenance:

The SGR is easily installed by sliding the ring over either end of the motor shaft and locking it in place with simple screw-on mounting brackets. Because no machining is required, the SGR can be installed in minutes — even in the field. Once installed, the AEGIS SGR requires no maintenance. With no parts to wear out, the SGR lasts as long as the bearings. A split-ring design allows installation around the shaft without disassembling attached equipment.

Low cost and high return on investment: One of the key goals in the design of the AEGIS SGR was to create a true value for the customer. Typically, an AC motor coupled with a VFD costs from \$2,400 to \$100,000 or more and may be part of a manufacturing process that generates revenues from \$10,000 to \$1,000,000 or more per hour. The cost of installing an AEGIS SGR in a VFD/AC motor system is very low when compared to the cost of the overall system, usually less than 1% of the equipment cost.

By preventing electrical damage to bearings, the SGR protects the VFD system from the costly downtime of unplanned maintenance. In some production applications, even a momentary stoppage due to motor failure can cost more than \$250,000, excluding the cost of repairing the motor.

Motor manufacturers and process engineers in industries where VFDs are used are keenly aware of the problems



The AEGIS™ SGR™ with NEMA adaptor plate

and expense caused by electrical damage to bearings. They have expended significant time, effort, and money to find a solution to this problem. The AEGIS SGR™ Conductive MicroFiber Bearing Protection Ring is the most effective and universally applicable solution to date.

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