

Preventing VFD/AC Drive-Induced Electrical Damage to AC Motor Bearings

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Overview

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 bearing 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 voltage discharges, causing electrical discharge machining (EDM) pits — 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.



Variable Frequency Drives Induce Bearing Currents in AC Motors

Due in large part to an increased focus on energy savings, the use of pulse-width-modulated (PWM) 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 voltage induced by VFDs can lead to motor failures. Without some form of mitigation, shaft voltage discharges by arcing through bearings, a process also known as bearing current. These currents cause pitting, fusion craters, fluting, excessive bearing noise, eventual bearing failure, and subsequent motor failure. This is not a small problem. Consider:

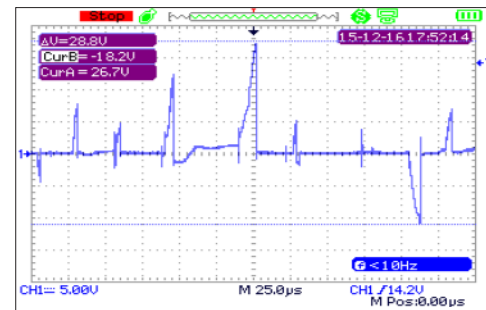
- Most motor bearings are designed to last for 100,000 hours, yet motors controlled by VFDs can fail within one month (720 hours).
- An HVAC system contractor recently reported that, of the 30-60 HP VFD-controlled vane axial fans he installed in a large building project, two motors failed within six 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 dozens of published articles discussing the problems presented by VFD-induced bearing currents, sharing information and experiences, and suggesting solutions.
- Motor failures caused by VFD-induced bearing currents result in hundreds of thousands of hours of unplanned downtime, in the United States alone, each year. In addition, these failures decrease their performance and mean time between failure of the systems in which they are used.
- With motor price increases, this problem will become even more costly.

Electrical Damage to Bearings

Figure 1

Voltage repeatedly builds up on the shaft of a VFD-controlled motor, then discharges through bearings, damaging them and shortening motor life.

Due to the high-speed switching frequencies used in PWM inverters, all variable frequency drives induce shaft voltage in AC motors. During normal operation, the switching frequencies of the insulated-gate bipolar transistors (IGBTs) used in these drives produce voltages on the motor shaft through electrostatic 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 it is running (Figure 1).



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

These discharges are so frequent that before long the entire bearing race becomes marked with countless microscopic pits, which cause bearing 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 thousands or even tens of thousands of dollars in downtime and lost production.

Figure 2

Under an electron microscope, a new bearing race is smooth, showing only the typical grooved track where the bearings contact to the wall.

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 one of the most common causes of bearing failure in VFD-driven AC motors.

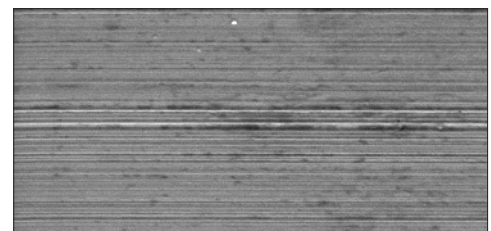


Figure 3

Pitting occurs after 5400 hours of continuous operation of a VFD-driven motor. Eventually, the entire bearing race will be covered with millions of pits, giving the appearance of a frosted surface.

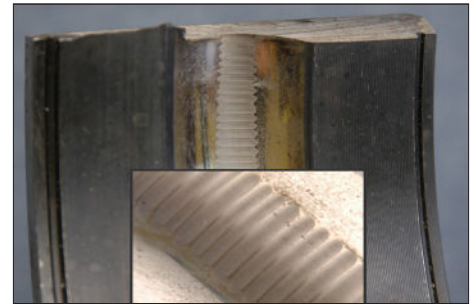
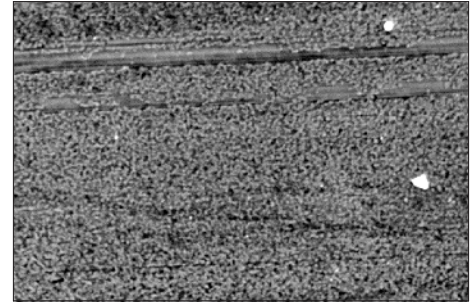
Figure 4

VFDs cause concentrated pitting at regular intervals along the bearing race wall, forming a “washboard” pattern known as fluting.

New Bearing Race: Viewed under a scanning electron microscope, a new bearing race wall is a smooth surface (Figure 2). 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.

Pitting: Early damage typically takes the form of pitting (Figure 3). 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. Eventually, as new fusion craters form over old ones, a “frosted” surface—visible to the naked eye—appears.

Fluting: In a phenomenon known as fluting concentrated pitting occurs at regular intervals along the bearing race wall, forming a “washboard” pattern (Figure 4). 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

Electrical damage to the bearings of VFD-controlled motors 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, either the bearings must be shielded or a non-destructive path to ground for the discharge currents must be created.

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

1. Faraday shield: The shield prevents the VFD current from being induced on 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 voltage 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 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: Nonconductive ceramic balls prevent the discharge of shaft voltage through this type of bearing, forcing the current to 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, in many cases ceramic bearings must be resized to handle mechanical static and dynamic loadings.

4. Conductive grease: In theory, because this grease contains conductive particles, it should provide a lower-impedance path through the bearing and should bleed off shaft current through the bearing without damaging discharges. 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 limit their effectiveness.
- c. They are subject to oxidation buildup, which further decreases their grounding effectiveness.
- d. They require maintenance on a regular basis, which increases their cost.

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A More Complete Solution

6. Shaft Grounding Ring: This innovative new approach involves the use of a ring of specially engineered conductive microfibers 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 voltage induced by VFDs. With hundreds of thousands of discharge points, the SGR channels shaft current away from AC motor bearings, protecting 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.

The AEGIS® Ring offers a unique combination of benefits unmatched by other technologies, including:

Scalability: AEGIS® technology is scalable to any size motor regardless of motor frame or shaft size, or application. Introduced to the market in May 2005, the AEGIS® Shaft Grounding Ring 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® Shaft Grounding Rings 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 AEGIS® Ring 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 or conductive epoxy. Because no machining is required, the ring can be installed in minutes — even in the field. Once installed, the AEGIS® Ring requires no maintenance. With no parts to wear out, the AEGIS® Ring 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® Ring was to create true value for the customer. Typically, an AC motor coupled to 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® Ring 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 AEGIS® Ring 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 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® Conductive Microfiber Shaft Grounding Ring is the most effective and universally applicable solution to date.

AEGIS® Shaft Grounding Rings outlast and outperform virtually all other shaft grounding technologies. Their microfiber brushes surround motor shafts with a full 360° of conductive microfibers that provide millions of contact points for superior grounding protection. Maintenance-free, they last for the full L-10 life of motor bearings, will not clog or jam, and are unaffected by moderate contamination.

William Oh, the author of this paper and the General Manager of Electro Static Technology, has extensive design and application experience in both automation and product development, specializing in passive dissipative technology for mitigating unwanted electrical currents. Mr. Oh is also the inventor of the Electron Transport Technology on which AEGIS® Shaft Grounding Rings are based.

Electro Static Technology, an Illinois Tool Works company, is a leader in the development and application of passive ionization technology solutions for industry.

**AEGIS® Rings Outperform
Other Shaft Grounding
Technologies**



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