Bearing damage: A lurking problem in electric cars

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Electric cars are news. Every major automaker has introduced some electric vehicle, and the trend seems to be toward greater reliance on electric motors. The “Holy Grail” is a battery electric vehicle (BEV, a car powered solely by electricity) with an extended driving range, at a reasonable price.

But the greater the reliance on electric motors, the greater the potential for electrical bearing damage. At the heart of every BEV and hybrid is an alternating-current (AC), 3-phase traction motor/generator. Since batteries provide direct current (DC), inverters (also known as variable frequency drives, or VFDs) are needed to convert the DC to AC. These inverters have an unfortunate side effect: They induce unwanted voltages on motor shafts. Without effective, long-term grounding, this shaft voltage will erode and eventually destroy motor bearings.

Reliability is crucial

For many Americans, the impetus to purchase a BEV or hybrid is a financial one — the ever-increasing price of gasoline. Still, most drivers are likely to hold onto their money until further advances in battery technology bring about longer all-electric driving ranges and lower sticker prices.

Even if reasonably priced and with longer driving ranges, BEVs are not likely to catch on unless consumers perceive them as reliable. In fact, for the trend toward these vehicles to continue, they must truly be reliable. How ironic it would be for sales to peak, then drop precipitously if people began to think of electric cars as having high maintenance costs.

Bearings in mind

Because electrical bearing damage is a lurking problem in electric cars, automotive design engineers face a new set of challenges. Inverter-induced shaft voltages jump to the path of least resistance wherever it leads, so partial mitigation measures such as insulated motor bearings can just shift the damage to other components, such as gearbox bearings, transmission gears, or wheel bearings. Even the bearings of a hybrid’s gasoline engine are vulnerable to such damage

when the vehicle is operating in electric mode.

To nip the problem of electrical bearing damage in the bud, automotive engineers need only look to other industries that have sought to be “green.” For years, design and maintenance engineers and contractors in manufacturing, processing, HVAC, and materials handling have turned to inverters as a way of controlling the speed of AC motors and thereby saving on their energy costs. These engineers found that — without an effective method of channeling inverter-induced shaft voltages safely to ground — any savings due to reduced energy consumption could quickly be wiped out by the high maintenance costs of replacing damaged motor bearings.

In short, an effective, long-term method of grounding motor shafts is needed to make inverter-driven systems reliable. Industrial engineers learned that a shaft-grounding device installed on a motor can divert harmful currents before they can cause bearing damage. Applied to the traction motor in a BEV or hybrid, such a device should prevent bearing damage and guarantee overall vehicle reliability.

One of the most reliable and cost-effective grounding devices is a ring that fits over the motor’s shaft [Figure 1]. Engineered with specially designed conductive microfibers, the AEGIS SGR Bearing Protection Ring safely channels damaging currents to ground, bypassing the bearings entirely. Scalable to any NEMA or IEC motor regardless of shaft size or horsepower, the ring has been installed successfully on motors powering pumps, fans, turbines, conveyors, etc., in hundreds of thousands of installations worldwide. More recently, the AEGIS ring has proven itself effective in the inverter-controlled traction motors of electric trucks, trains, trolleys [Figure 2], and construction equipment. It is now being tested by several auto manufacturers, though quietly, due to non-disclosure agreements.

Figure 1. This all-electric tram in Halle (Saale), Germany, suffered bearing damage from inverter-induced voltages until the problem was solved in 2007 with the installation of an AEGIS SGR Bearing Protection Ring (inset) on the shaft of every traction motor in the fleet. The city has had an electric tram system since 1891.

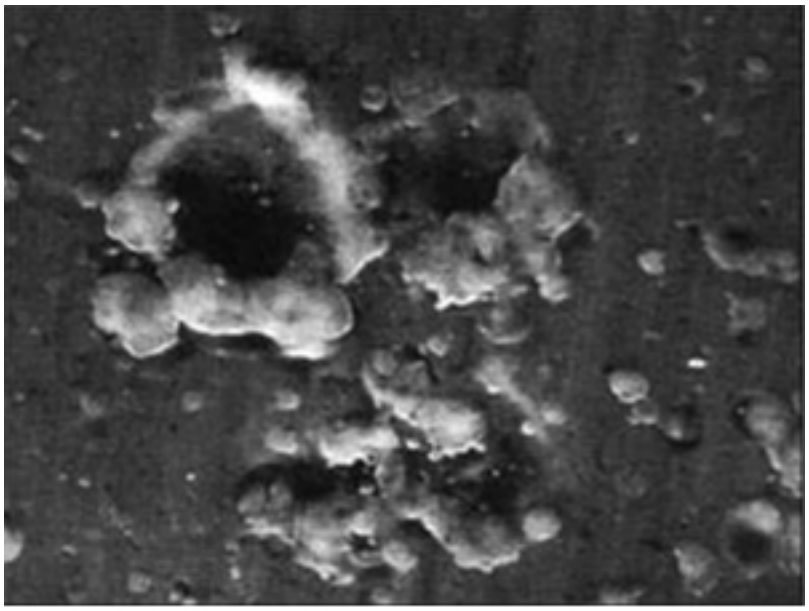

Figure 2. EDM pitting of a bearing race wall (magnified) — the result of inverter-induced electrical discharges from the motor shaft.

Cause and effect

For electrical damage to motor bearings, the main culprit is common-mode voltage arising from the non-sinusoidal waveforms produced by an inverter's power-

switching circuitry. The extremely fast voltage rise times (dV/dt) associated with the insulated gate bipolar transistors (IGBTs) typically found in today's pulse-width-modulated inverters can cause charges to build up on the motor shaft. Without mitigation, these voltages discharge through bearings, causing unwanted electrical discharge machining (EDM) that erodes ball bearings and race walls and leads to premature bearing/motor failure.

Electric motors in vehicles operate in a range from 1,000 to over 16,000 rpm, and at such speeds the very thin grease layer between the rolling elements and race in a bearing can break down due to voltage discharges of 5 to 40 volts. Every time the grease dielectric is overcome, an electrical arc through the bearing burns the grease and blasts a tiny pit (fusion crater) in the steel surface [Figure 2]. At inverter carrier frequencies of over 12 kHz, many millions of pits can be created in a very short time. This process also generates steel and carbon particles that contaminate the grease, further reducing its lubrication properties and giving it a black "burnt" color [Figure 3].

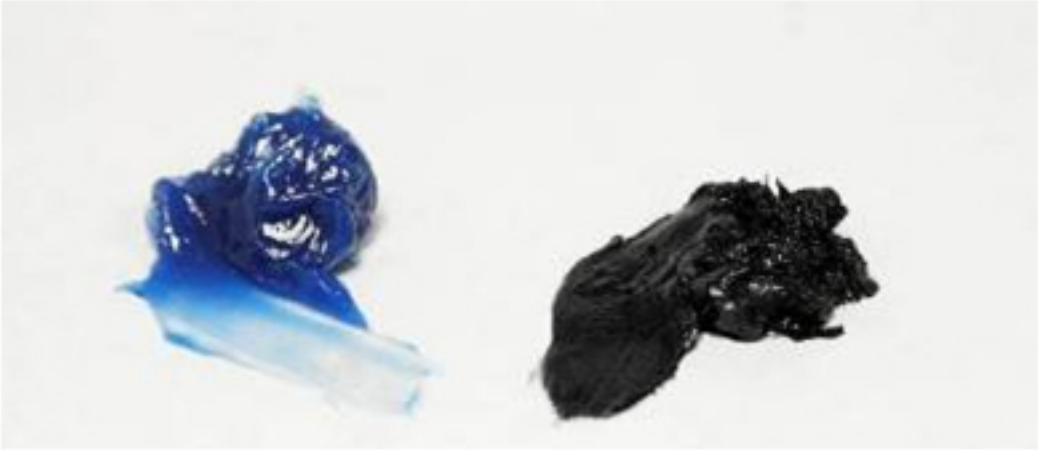

Figure 3. New (left) and used (right) bearing grease. Burned and contaminated with particles of steel from EDM pitting, the used grease provides less lubrication and thus further shortens bearing life.

Before long, frequent discharges can leave the entire bearing race riddled with pits known as frosting. In a phenomenon called fluting, the operational frequency of the inverter causes concentrated pitting at regular intervals along the bearing race wall, forming washboard-like ridges that result in noise and vibration [Figure 4].

Figure 4. Taken from a failed motor, the "fluted" bearing race wall (left) resulted from VFD-induced bearing currents.

Conclusion
All hybrids and BEVs use inverters. This means the need to mitigate damaging inverter-induced voltages is already upon us. The AEGIS SGR Bearing Protection Ring offers automobile designers a way to improve the reliability of electric motor/generators now and in the future, by protecting bearings and other components. In short, it offers the promise of high reliability that buyers want before they invest in an electric vehicle.

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