

Bearing Damage... a Lurking Problem in Electric Cars

by **Matthew Roman**
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Overview

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, drivers are likely to hold onto their money until further advances in battery technology bring about longer driving ranges and lower sticker prices.

Even if reasonably priced and with better batteries, 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 energy. 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.

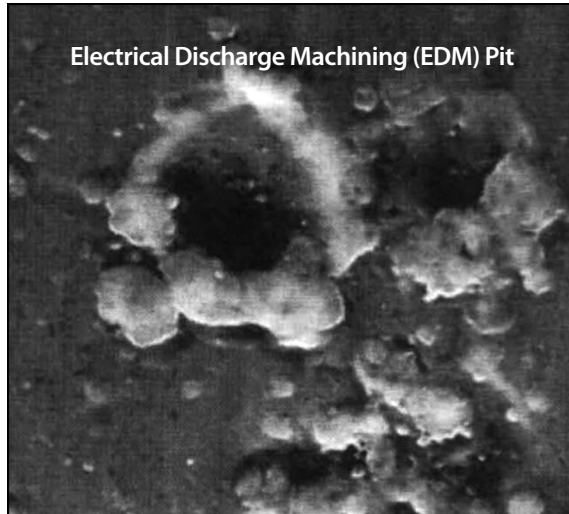
One of the most reliable and cost-effective grounding devices is a ring that fits over the motor's shaft. Engineered with specially designed conductive microfibers, the AEGIS™ SGR Bearing Protection Ring safely channels damaging currents to ground, bypassing the bearings entirely. Scalable to any NEMA 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, and construction equipment. It is now being tested by several auto manufacturers, though quietly, due to non-disclosure agreements.

Cause and Effect

For electrical damage to motor bearings, the main culprit is common-mode voltage arising from the non-sinusoidal current 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. 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.



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.



Fluted bearing race from a failed motor without shaft grounding protection

Developed by Electro Static Technology, the AEGIS™ SGR Bearing Protection Ring is superior to conventional spring-pressure grounding brushes, which corrode, become clogged with debris, and require regular maintenance. Neither metal brushes nor carbon-block (graphite) brushes work as well at high rpms, and the latter are susceptible to "hotspotting," in which an arc briefly fuses a brush to the motor shaft. In contrast, the AEGIS™ ring requires no maintenance and lasts for the life of the motor, regardless of rpm.

Non-grounding methods of mitigating electrical bearing damage tend to be expensive. Multilevel inverters and harmonic filters, for example, can cost thousands of dollars, while an AEGIS™ ring solves the problem at a low cost. Ceramic bearings are also costly, and, like bearing insulation, can pass on harmful voltage discharges to other equipment.

Proven Effective

The AEGIS™ SGR Bearing Protection Ring has already proven itself to be the most effective, reliable, and universally applicable solution to the problem of inverter-induced currents in the traction motors of electric trucks, trains, trolleys, and construction equipment as well as in industrial and commercial applications. It should be equally effective in electric cars.

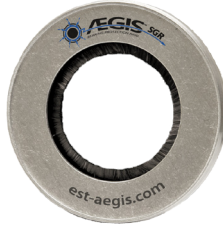


This all-electric tram in Halle (Saale), Germany, suffered bearing damage from inverter-induced voltages until the problem was solved in 2007 with the installation of an AEGIS™ SGR Bearing Protection Ring (inset) on the shaft of every traction motor in the fleet.

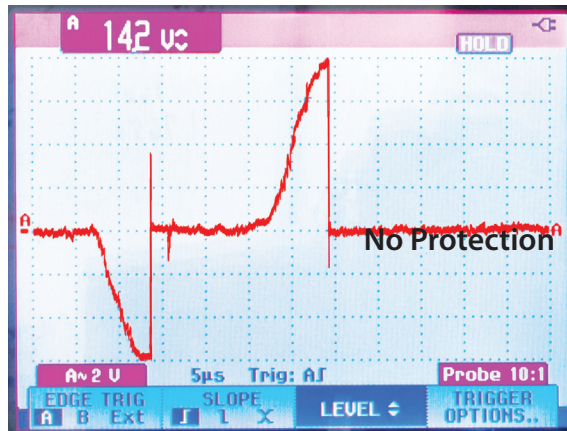


Bearing race from a motor with AEGIS™ Shaft Grounding protection

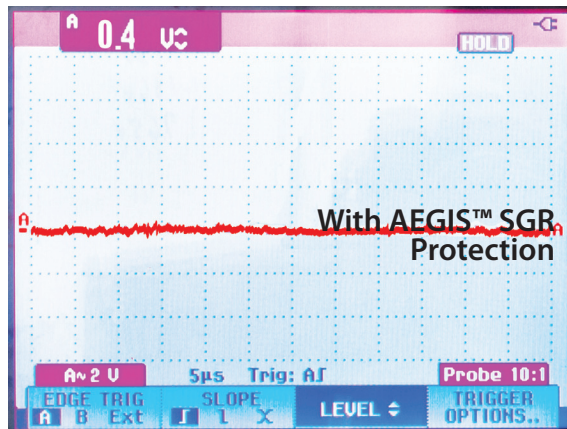
Key to the ring's success are the patented conductive microfibers arranged along the entire inner circumference of the ring that completely surround the motor shaft. Secured in the patented FiberLock™ channel, these fibers can flex without breaking. The deep channel also protects the fibers from dust, liquids, and other debris. Tests of the ring on multiple motors show surface wear of less than 0.001" per 10,000 hours of continuous operation and no fiber breakage after 2 million direction reversals.



The effectiveness of the AEGIS™ SGR can be seen on an oscilloscope. Without shaft grounding, damaging inverter-induced shaft voltages show up as peaks and valleys.



After the installation of an SGR, the nearly straight line demonstrates how the ring diverts these voltages, channeling them safely to ground.

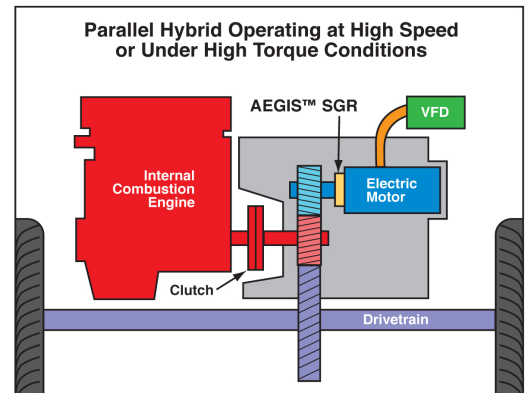
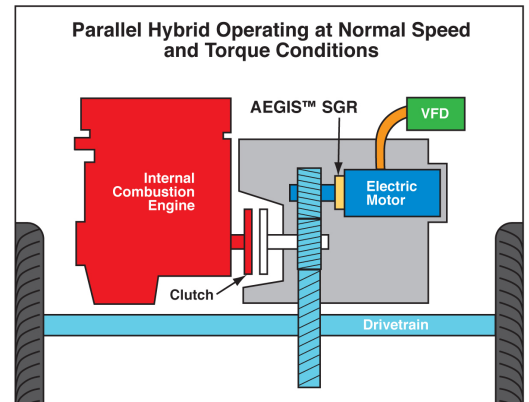


Inverters on the Road

Regardless of how the automobile market shapes up in the coming decades, many electric vehicles are already on the road. These vehicles are classified based on the extent to which they rely on electric motors to power their wheels and provide traction. Classifications include:

Hybrids: Hybrids rely on some combination of electric motor and gasoline engine to achieve vehicle propulsion. Many newer hybrids rely more on their AC electric motors than on their gasoline engines.

- A **mild hybrid** (Chevrolet Malibu hybrid, Honda Civic hybrid, etc.) combines a conventional gasoline engine with an oversized starter motor that can also be used as a generator to recharge an oversized battery. Only the combustion engine is attached to the vehicle's transmission, but at high loads the motor/generator assists the engine. As mentioned, the market seems to be moving away from mild hybrids and toward AC motor/generators that contribute more to a vehicle's traction.
- In a **parallel hybrid** (Toyota Prius, Ford Escape hybrid, Nissan Altima hybrid, Cadillac Escalade hybrid, Dodge Durango hybrid, etc.), the wheels can be driven by a gasoline engine or by a battery/motor/generator system [Figure 6]. Although these two power sources are not coupled, traction can be provided by both simultaneously.



- A **series hybrid** (Fisker Karma, Chevrolet Volt in primary operating modes) draws on two energy sources — gasoline and batteries — but its wheels are driven only by its electric motor/generator. The gasoline engine is coupled to another generator to charge the batteries. All energy used for traction goes through an inverter to the AC motor/generator. This makes it as vulnerable as a BEV to bearing damage.

Battery Electric Vehicles (BEVs): BEVs (Nissan Leaf, Tesla Roadster, Audi E-Tron, Think City, Citroen C-Zero, etc.) rely solely on electric motors. Having no gasoline engine, they are plugged in for recharging.

Regardless of their type or classification, all these electric vehicles use inverters in their power trains. This means the need to mitigate damaging inverter-induced currents is already upon us, and this need will become more pressing if the BEV market takes off.

Many Cars, Many Paths

The news lately has been teeming with forthcoming hybrids and BEVs. Two cars that have been getting a lot of hype since they were introduced to the American market (in preliminary production runs) are the Chevrolet Volt and the Nissan Leaf. Several other models with smaller advertising budgets are reportedly on the way from other manufacturers.

A plug-in hybrid, the Chevrolet Volt has a manufacturer's suggested retail price (or sticker price) of \$40,280. For the 2011 model year, production is limited to 10,000 cars to be sold in only six states. The Volt's propulsion system [Figure 7] includes a gasoline engine that increases the car's battery driving range of 20-50 miles by another 300 miles or so (on a full tank of gas). Although the battery pack is designed to be recharged with 120-volt household current for 10-12 hours (or just 4 hours if the customer buys a special 240-volt charging station), braking or coasting replenishes it somewhat.



The Chevrolet Volt has a gasoline engine (left) as well as an electric motor/generator (right).

A plug-in BEV that can go about 100 miles on a full charge, the Nissan Leaf has a sticker price of \$32,780. Its battery takes about 20 hours to charge at 120 volts, about 7 hours at 240 volts (from a special charging dock), and, maybe someday, about 30 minutes (for an 80% charge) at one of the 480-volt quick-charge stations Nissan hopes to build. This vehicle, too, is being released in a dribble; Nissan has capped U.S. reservations at 20,000 until next year.

Other models (rumored or real) in our future include:

- A Canadian two-seater hybrid from Kor Product Design that reportedly will have an electric motor/generator that can be charged by solar panels on a buyer's garage and a backup internal combustion engine powered by pure ethanol.

- Toyota plans to launch the Prius PHV, a plug-in hybrid, in 2012. The company promises a maximum battery driving range of about 13 miles, full recharging from a standard 110-volt outlet in 3 hours (1.5 hours with a 220-volt outlet), and 50 miles per gallon of gas.
- The Inizio, a two-seater BEV sports car with an onboard charger and a driving range of 250 miles that, according to its North Carolina designer, will do 0 to 60 mph in 3.4 seconds.
- The Model S BEV from Tesla Motors. Tesla plans to finish testing this new sedan in late 2011 and bring it to market in 2012. The company says the high-end version (price tag \$75,000+) will do 0 to 60 mph in 5.6 seconds and will go 300 miles between charges.
- Designed and built for auto shows, Rolls-Royce's new concept car — the 102EX — does not need to be plugged in to be recharged. Instead, it can simply be parked over a special pad where an innovative system charges the vehicle by means of a magnetic field.

Conclusion

With the recent surge in sales of hybrids and BEVs, the United States seems to be embracing electric vehicle technology. Yet, as the transition from gasoline-powered to all-electric cars gathers momentum, the potential for bearing failure in these vehicles grows. The AEGIS™ SGR Bearing Protection Ring offers automobile designers a way to improve the reliability of hybrids and BEVs now and in the future. Not only will it protect electric motor/generators from bearing damage and thus extend their lives, but it will also protect other components from the same inverter-induced voltages. In short, it offers the promise of high reliability that buyers want before they invest in an electric vehicle.

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About the Author

Matthew D. Roman is the Engineering Manager for Electro Static Technologies responsible for New Product Development. He holds a B.S. and M.S. in Mechanical Engineering from Rochester Institute of Technology and has spent the last seven years working in Product Development positions.



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