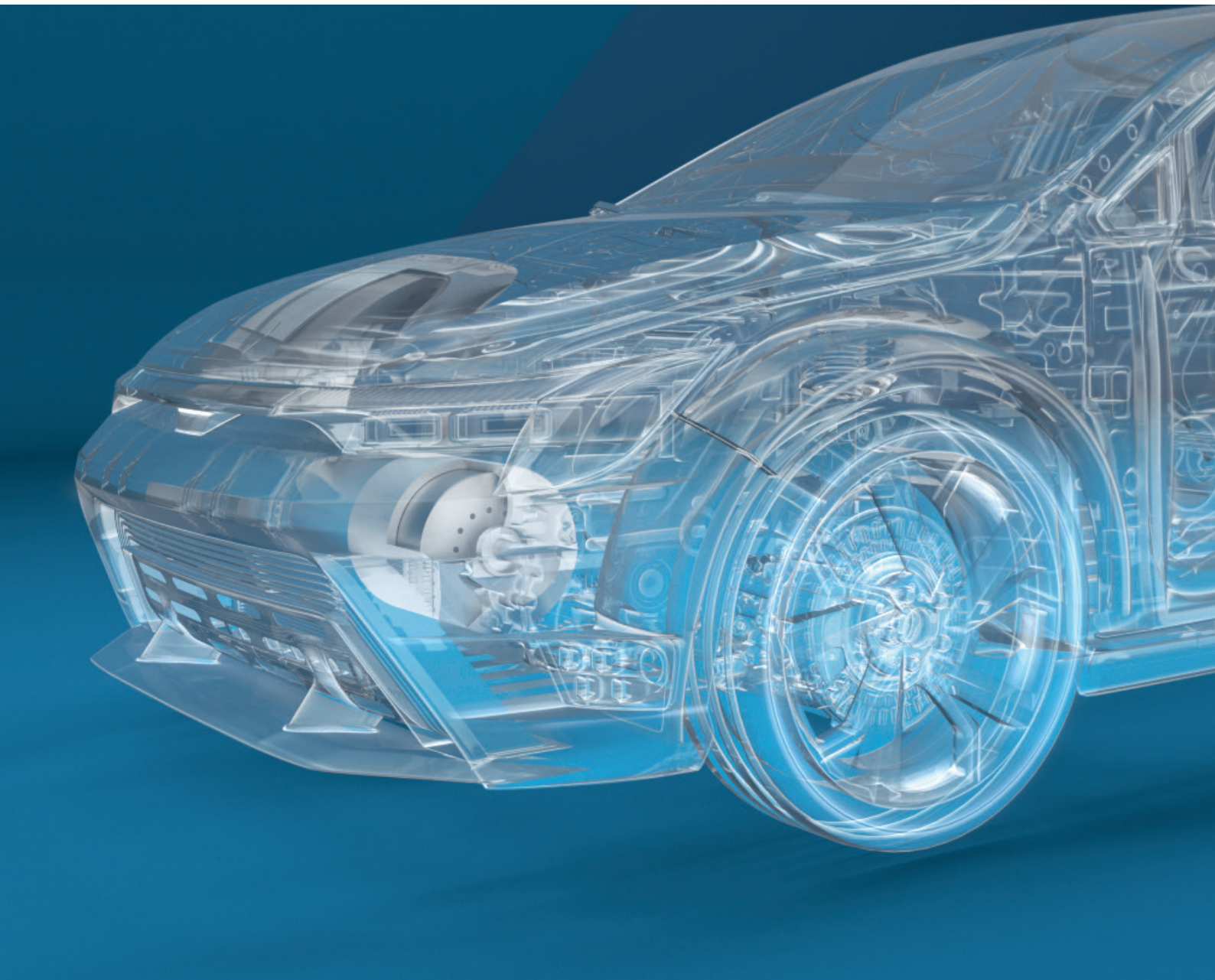
Protecting motor bearings and improving electromagnetic compatibility (EMC) in electric vehicles with AEGIS® EV Shaft Grounding Rings



Electric vehicles are the way of the future

Electric vehicles afford great potential for lowering greenhouse gas emissions. Their development has now progressed to the point where they are a technological match for conventional vehicles using combustion engines. Growing ranges and expanding charging options, combined with governmental subsidies on purchases, are driving sales of electric vehicles.

However, undesirable electrical and electromagnetic effects can adversely impair their reliability. To solve this problem, Electro Static Technology developed the AEGIS® EV ring and well-known automotive manufacturers have tested and using them today in large volumes worldwide in their series production vehicles.

Electric vehicles are the way of the future. Every established automotive manufacturer now has a large range of models in its portfolio or is pressing ahead with developing new models to bring to market. Electric vehicles' success in the market will depend in large part on their reliability, which in turn depends on all their systems working harmoniously and as designed. When systems behave destructively or unpredictably, problems result. One source of such problems is the variable frequency drive (VFD or inverter) that controls the vehicle's traction motors.

Since batteries deliver direct current (DC), inverters are required to convert the direct current to alternating current (AC). They do this by generating series of high-frequency DC voltage pulses to approximate an AC waveform.

However, inverters come with an undesirable side-effect: They generate parasitic voltage on the motor shaft. Without effective, long-term grounding using AEGIS® EV Rings, this shaft voltage can lead to motor bearing damage and premature bearing failure. In addition, electromagnetic interference signals may adversely affect the operation of infotainment systems and electronic vehicle controls.

The special importance of bearing protection

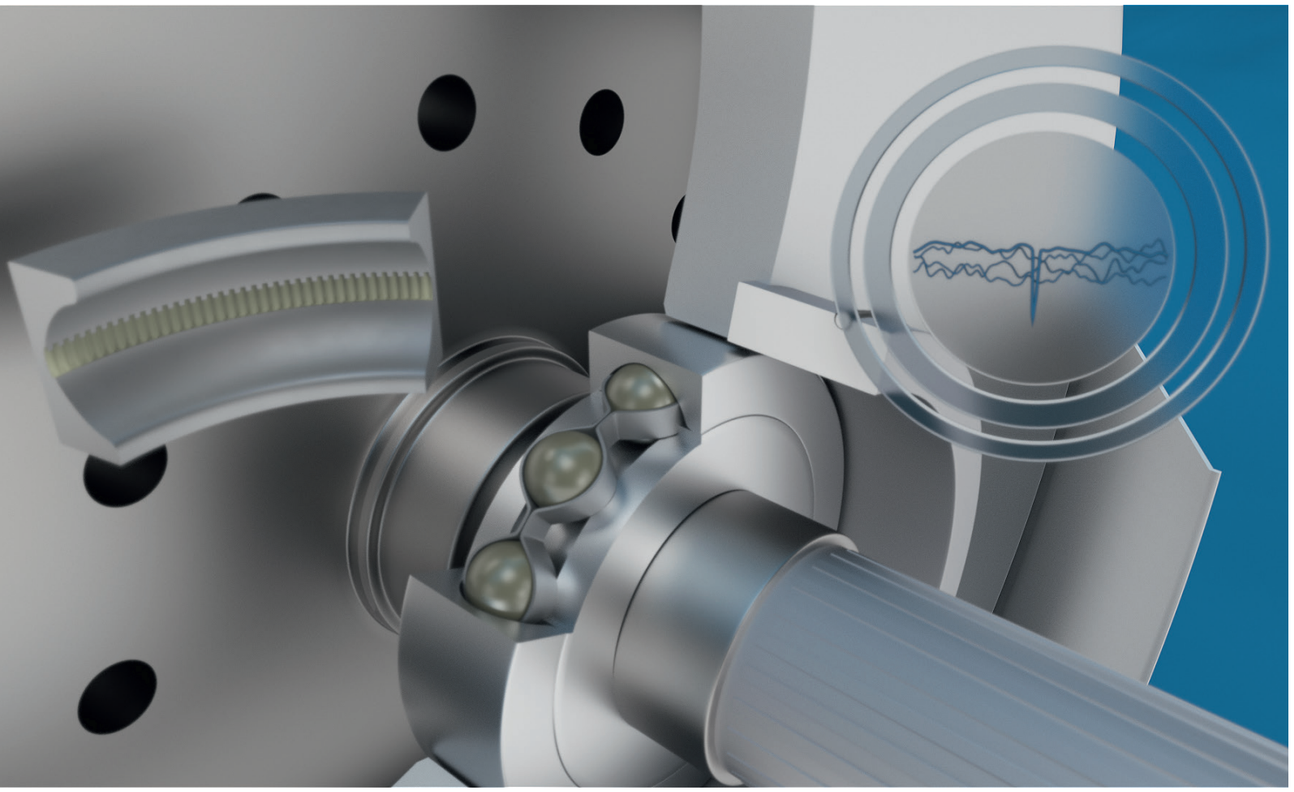
There has been growth in purchases of electric vehicles. Significantly improved battery technology and the growth in charging points have alleviated concerns over the lack of range for many vehicle-drivers. This fact, along with the increasingly affordable purchase price, argue in favor of electric vehicles, but customers can be put off if they get the impression that the vehicles are unreliable and come with high repair costs.

Damage to the motor bearings on electric vehicles due to the passage of electrical current presents automotive engineers with several fresh challenges. As the VFD-induced shaft voltage follows the path of least resistance, partial remedial measures such as insulated motor bearings can displace the damage to the transmission bearings, gearwheels or wheel bearings. Even the combustion engine in a hybrid vehicle is not protected against such damage if the vehicle is being operated in electric mode.

To solve the problem of electrical bearing damage, it is worth looking at other sectors confronted with the same problem of bearing damage caused by VFD controlled motors. Such motors have been used for decades in manufacturing and processing industries, in HVAC, and in conveyor technology to save energy costs by regulating the speed of AC motors. In these industries it was repeatedly found that savings on energy costs can rapidly be wiped out without an effective method for safe discharge of the shaft voltage induced by the VFD, since high repair costs are incurred when replacing damaged motor bearings.

Making a VFD-controlled system reliable requires an effective, long-term method for grounding the motor shafts. Investigations have shown that a shaft grounding device fitted to the motor can discharge harmful voltage before it can cause damage to the motor bearings.

A ring developed by the American company Electro Static Technology and fitted on the motor shaft has proven to be one of the most reliable and most cost-effective methods of shaft grounding. The AEGIS® EV Ring is equipped with high-conductive microfibers, specially developed for the purpose of bearing current mitigation, which safely discharges the harmful shaft voltage to ground, bypassing the bearings entirely. This shaft grounding ring is manufactured to fit the size of the shaft and has been successfully fitted in industrial motors to drive pumps, fans, turbines, conveyors, etc. in millions of installations worldwide. AEGIS® EV Rings have also proven their worth in traction motors on electrically powered trucks, trains, running gears and construction machines, which are regulated using variable frequency drives. When it comes to the use of AEGIS® EV Rings in electric vehicles, they are being applied by many electric vehicle manufacturers or are being tested intensively for series use on next generation electric vehicle drivetrains.



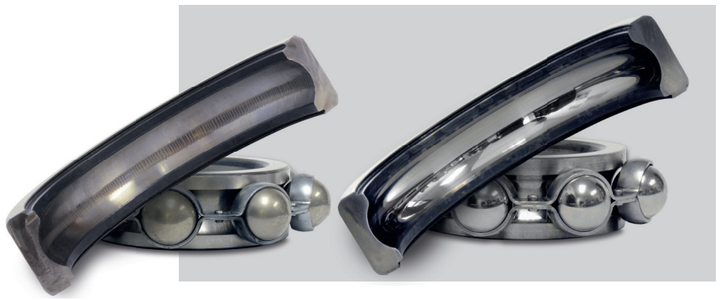


Fig. 3
The "fluted" bearing race (left) on a of an electrically damaged bearing, caused by VFD-induced bearing currents.
The bearing protected by an AEGIS® EV Ring, (right) is undamaged.

Preventing electrical bearing damage

The primary cause of electrical damage to motor bearings is the imbalanced common mode voltage in the power supply via the inverter. Today's inverters typically use IGBTs (insulated gate bipolar transistors), as such the associated extremely short voltage rise times (i.e., large dv/dt) cause capacitively coupled voltage on the shaft. Without mitigation, this voltage discharges through the bearings. The consequence of this is electrical bearing damage ((Electrical Discharge Machining, EDM) that causes micro-pitting on the rolling elements and the bearing race, thus leading to early failure of the bearings and motor. Such a failure leads to a very expensive repair cost as it requires replacing the bearings in the motor.

Motors in electric vehicles may be operated at speeds of 20,000 rpm or above. The shaft voltage may range from 5 to 80 volts. These voltage levels are sufficient to overcome the dielectric of the thin grease layer between the rolling elements and the bearing shell, producing small pits in the bearing race [Fig. 1]. At inverter carrier frequencies of over 12 kHz, millions of EDM pits can be created in a very short time. As this happens, the grease also becomes contaminated with particles of metal and carbon, its lubrication properties deteriorate, and a black, "burnt-looking" color arises [Fig. 2].

Within a short time, the entire bearing race can be covered with EDM pits due to frequent discharges - something known as frosting. The vibrations generated as the rolling element travels over these EDM pits cause the phenomenon known as fluting. This is when grooves comparable to a washboard are formed, leading to more significant development of noise and further vibrations [Fig. 3].

The AEGIS® EV Ring from Electro Static Technology functions better than conventional grounding systems such as carbon brushes, which can become fouled by oil and grease. Carbon brushes also require regular maintenance and replacement. Neither metal-doped carbon brushes nor pure graphite brushes dissipate shaft voltage as effectively at high speed as do AEGIS® EV Rings. Additionally, graphite brushes are also susceptible to "hot-spotting", a phenomenon where a brush is briefly melted together with the motor shaft due to arcing. Conversely, AEGIS® EV Rings are running practically wear- and friction-free, require no maintenance, and last beyond the lifetime of the bearing, regardless of the speed at which it operates.

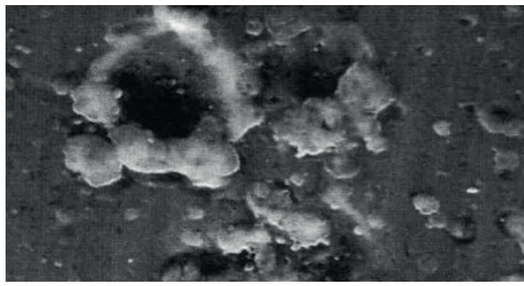
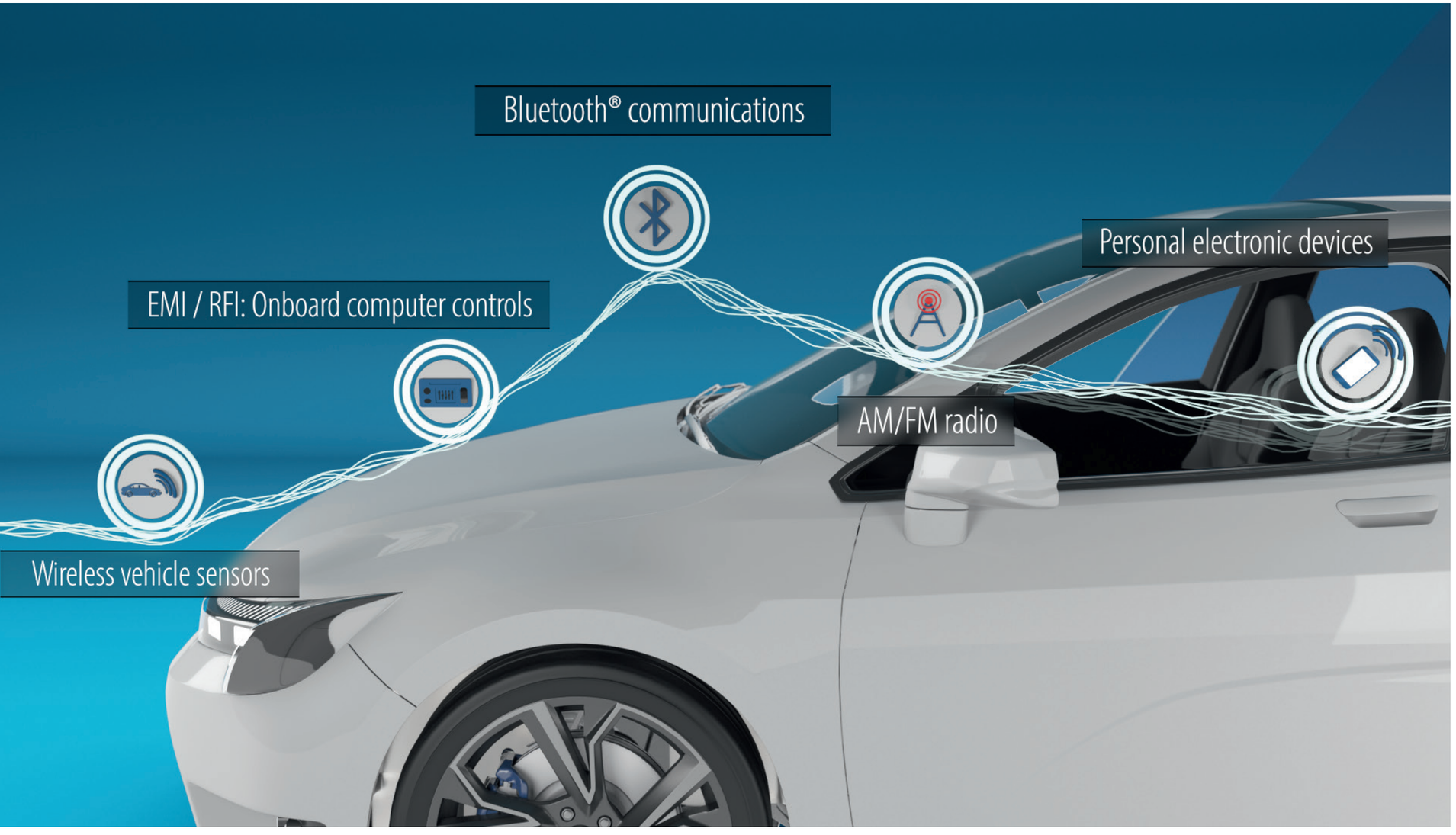


Fig. 1
EDM pitting on a bearing race (enlarged) - the result of electrical discharges in the bearing.

Fig. 2
New (left) and old (right) bearing grease. Old grease, which is burned and contaminated with metal particles due to EDM, provides lower lubrication and thus shorter bearing lifetimes.



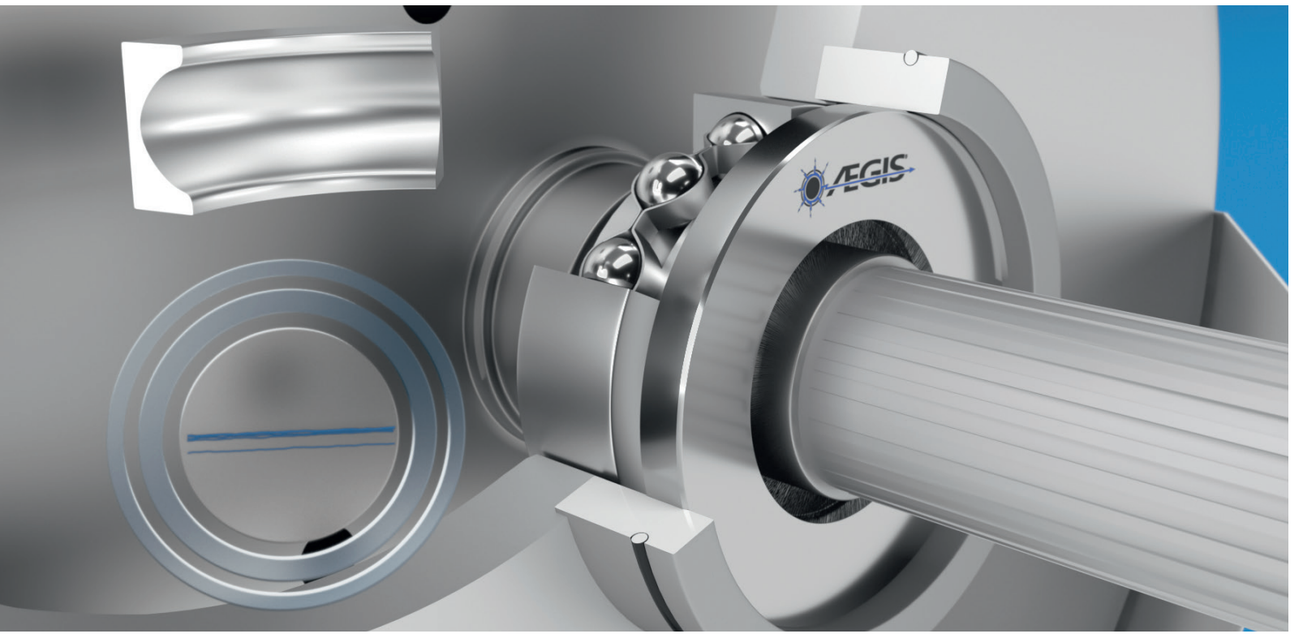
Electromagnetic Compatibility (EMC)

Electric vehicles need to run reliably. They also need to have user-friendly electronics. Like many new vehicles, electric vehicles feature many electronic functions and accessories, including satellite navigation systems, Bluetooth® communications functions for telephones, tablets, and other personal electronic devices, AM/FM and satellite radios, stereo sound and entertainment systems, integrated computer controllers, wireless sensors, emergency call communications systems, etc. In the not too far-off future, this list will be supplemented with many sensors and communications interfaces for new autonomous driving systems.

But shaft voltage can also cause electromagnetic interference (EMI) and radio frequency interference (RFI). Installing an AEGIS® EV Ring can drastically reduce EMI/RFI, especially when using it together with a silver coated layer on the shaft. In this way, the residual signal remaining on the shaft can be pushed into the mV range and no longer disturb the entire system.

The special performance requirements for electric vehicle motors merit particular attention. A shaft grounding device for an EV motor needs to be able to function under the following, very demanding conditions:

- **Very high speed – sometimes over 20,000 rpm**
- **Forward and backward running at very high speeds**
- **Rapid acceleration and braking**
- **Operation at variable speeds and continuous (high) speed**



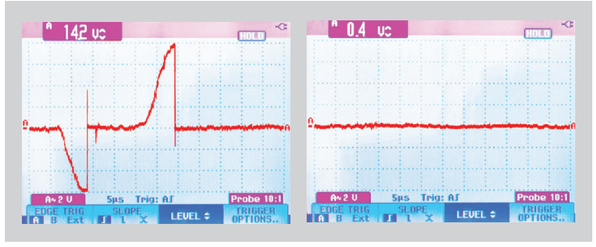


Fig. 5
Voltage discharges on the motor shaft before (left) and after (right) fitting the AEGIS® Shaf

Electric vehicle motors present particular challenges

In numerous applications, the AEGIS® EV Ring has proven to be the most effective, most reliable, and universally usable solution for the problem of inverter-induced bearing currents, as found intraction motors on electric-powered trucks, trains, running gears and construction machines, and in industrial and commercial applications. Its effectiveness and reliability also come to the fore in electric vehicles. One illustration of this is the Bolloré Bluecar designed by Pininfarina - a small, four-seater electric car launched as a series production car in 2011. It was fitted with a 30 kWh lithium metal polymer battery, coupled to a supercapacitor. This gives the Bolloré Bluecar a range of 250 km (urban) and a top speed of 130 km/h. Since September 2015, over 4,500 Bluecars have been registered in France. From only a short time after its market launch, every one of them was fitted with an AEGIS® Shaft Grounding Ring installed in the electric motor, in order to prevent damage to the motor bearings and to improve EMC. These small electric cars can today be found operating reliably in many European cities.

A key element in the AEGIS® EV Rings are the patented high-conductivity microfibers, arranged along the full internal diameter of the ring, which surrounds the motor shaft 360°. The fibers are so flexible that they do not break, even when the direction of rotation changes. The FiberLockTM channel also protects the fibers against fluids, dust and other particles. Tests of the rings on several motors show surface wear of under 0,025 mm after 10.000 hours of continuous operation, and no fiber breaks after two million changes in direction of rotation.

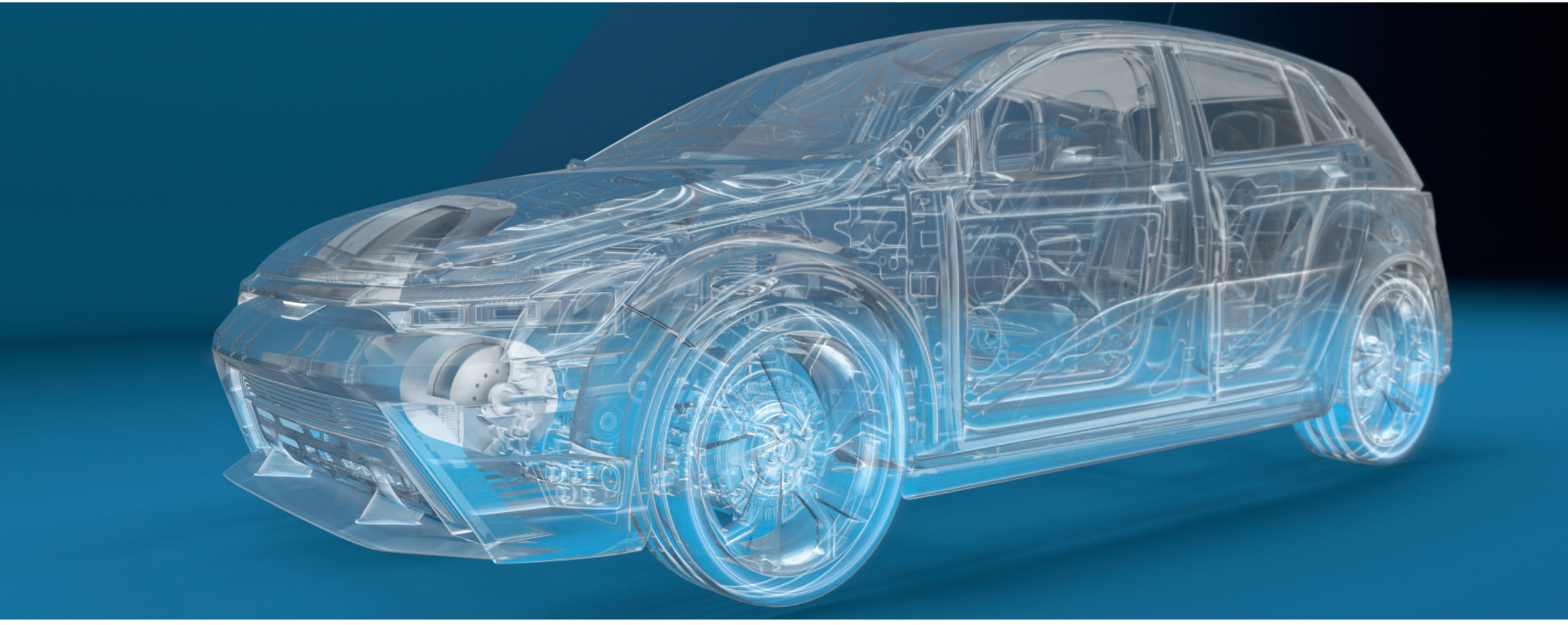
Measurements of shaft voltage using an oscilloscope demonstrate the effectiveness of the AEGIS® EV Ring [Fig. 5]. Without shaft grounding, the harmful shaft voltage induced by VFDs is high peak voltage. The practically flat line after fitting an AEGIS® EV Ring shows that it safely discharges the voltage.

Already today, large numbers of electric vehicles are on our roads. They are categorized as follows, based on their degree of dependence on electric motors:

- Electric vehicles run exclusively on electric motors. As they have no combustion engine, they are connected to the power grid for charging.
- Hybrid vehicles employ a combination of electric motor and combustion engine to power the vehicle. They are available in a range of options:
  - o Power-split hybrids can be run under normal driving conditions solely by using the current supplied from a battery, while under more challenging conditions the current is supplied by a combination of the petrol engine and the battery.
  - o On parallel hybrids, the electric motor and combustion engine can operate simultaneously on the drivetrain, adding together the torques from the individual drives.
  - o Serial hybrids use two sources of energy: Combustion engines and electric motors. In this case, the wheels are driven only by the electric motor. The combustion engine is coupled to another generator, to charge the batteries.

In all the drive concepts mentioned, the electric motors are regulated using an inverter. This means that harmful shaft voltage always needs to be taken into account, and even during the design phase attention must be paid to the safe discharge of shaft voltage.

Summary



The rise in sales of hybrid and electric vehicles demonstrates the growing acceptance of electric vehicles worldwide. With the progressive shift from vehicles with combustion engines to electric vehicles, however, the risk of bearing damage in these vehicles is also growing. The AEGIS® EV Ring offers automotive engineers an opportunity to improve the reliability of hybrid and electric vehicles. Not only does it guard against bearing damage and extend bearing lifetimes, but it also protects other components against VFD-induced shaft voltage and improves EMC, thereby offering the high reliability that buyers of electric vehicles expect.

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An ITW Company

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