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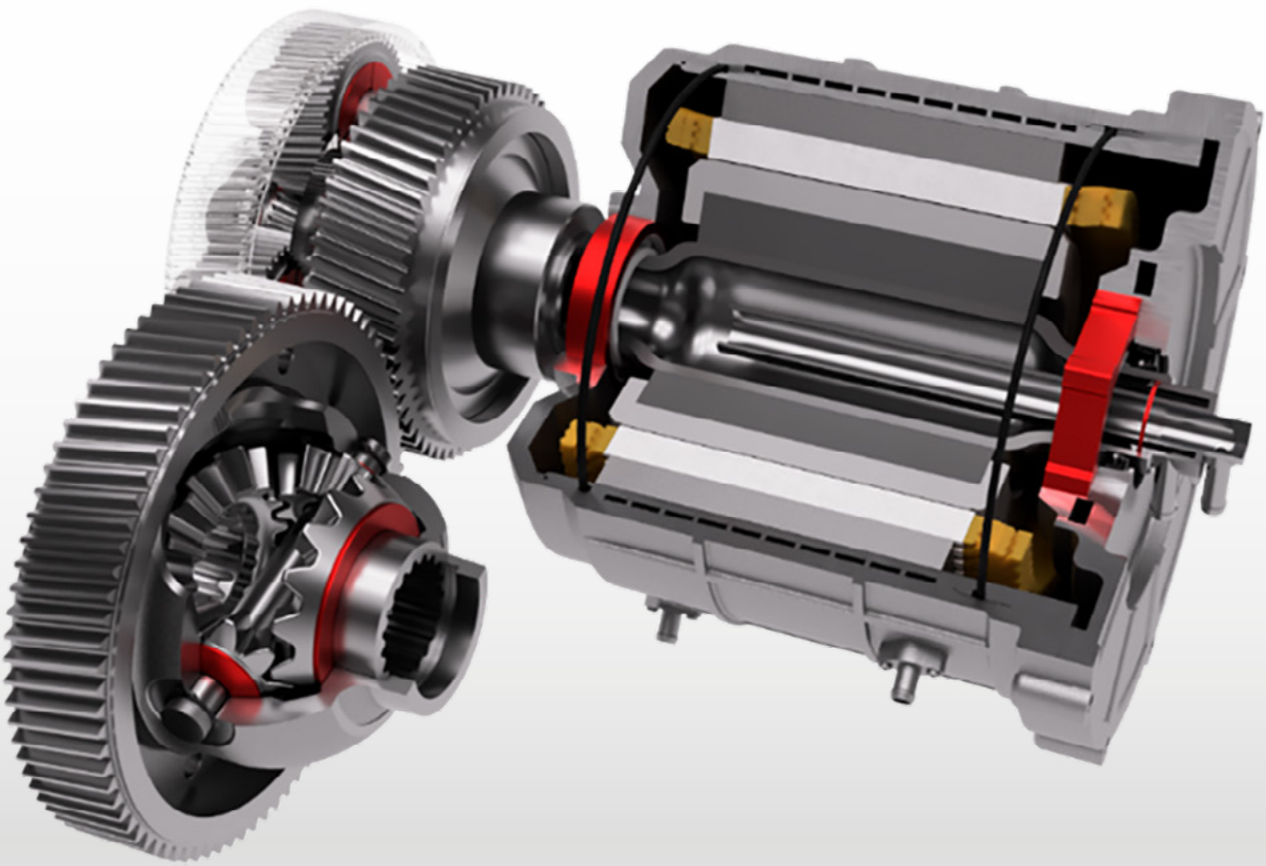
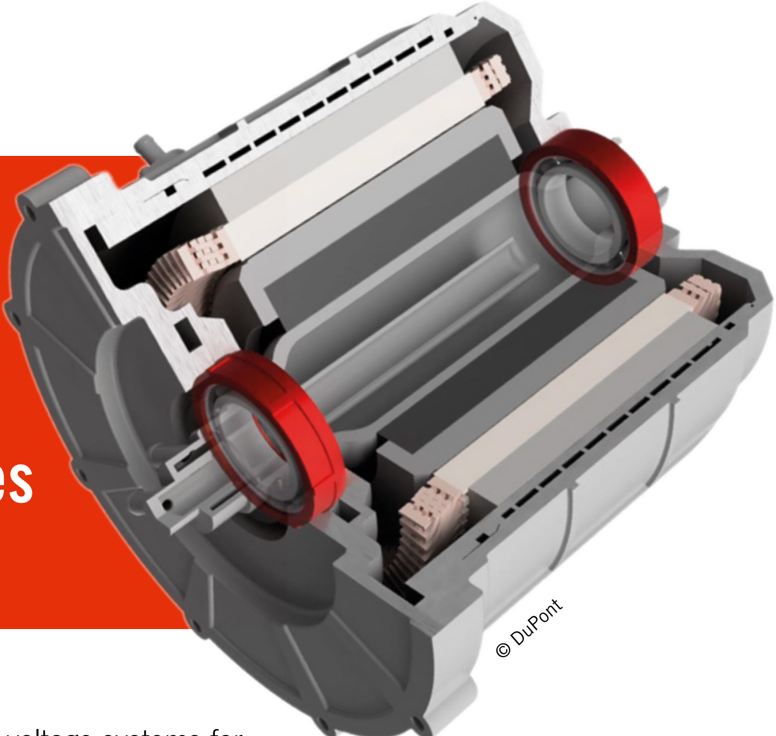


BEARING INSULATION

made of Vespel polyimide for the Prevention of Damage in Electric Motors

Economic Bearing Insulation with High-performance Polyimides



The automotive industry is moving toward high-voltage systems for electric vehicles with even higher levels of efficiency. The importance of reliable and durable components has steadily increased. One component in particular, the bearings in electric motors, has emerged as a key area of concern. Electrical erosion of the bearings, caused by electrical currents passing through them, can lead to severe damage and premature failure. This is where bearing insulation provided by DuPont's Vespel polyimide parts come into play helping to solve this pressing issue.

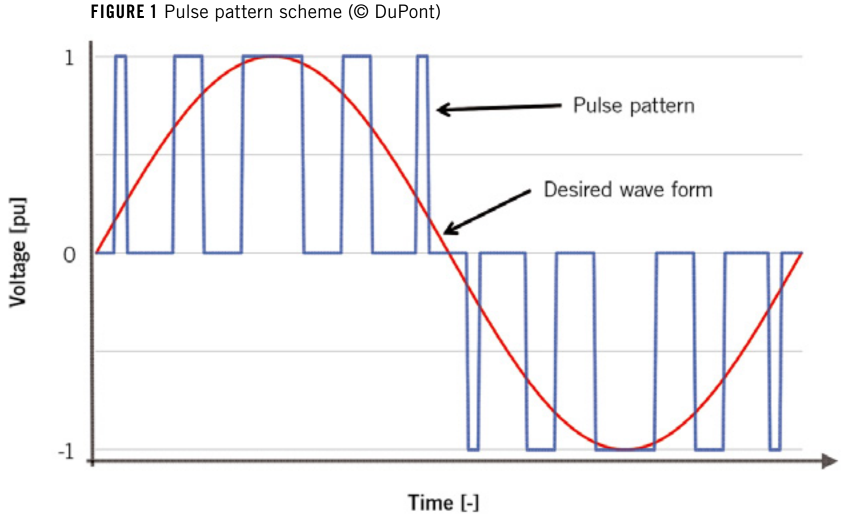
The push for worldwide electric transportation requires the development of efficient and cost-effective solutions for electric drive technology systems. The emergence of 800-V EV architecture marks a significant step toward improving vehicle performance. This technology enables higher charging capacities and faster charging times. As the battery accounts for a substantial portion of the total cost of an electric vehicle, it is important to use as much energy as possible for traction and to reduce losses to increase the vehicle's range. Improving efficiency may involve tradeoffs and careful evaluation of the performance requirements and design constraints of the system.

Traction motors in electric drives are typically powered by a Variable Frequency Drive (VFD) to enable operation at variable speed. The DC voltage from the battery is transformed into a three-phase AC voltage by the inverter. The inverter contains switches that create the desired sine wave for the motor by suitable pulse patterns, **FIGURE 1**. Modulating the pulse widths changes the wave frequency and thus the motor speed.

There are various types and topologies of VFDs and inverters. They can vary in their components and mode of action. One component that has gained attention in recent years is electrically operated switches made from Silicon Carbide (SiC). Compared to inverters with common silicon technology, the SiC-based inverters are more efficient, with lower losses. SiC technology also enables higher switching frequencies, which can further increase the efficiency of the electric motor by reducing harmonic losses [1].

As efficient as they may be, SiC switches can also cause electrical problems due to the so called dV/dt phenomenon, which refers to the rate of voltage change with respect to time. High-frequency switching

FIGURE 1 Pulse pattern scheme (© DuPont)



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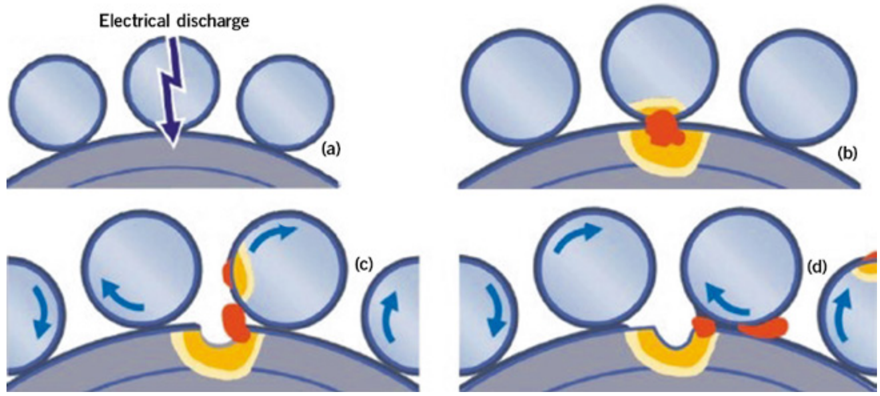

FIGURE 2 Electrical erosion [3] (© Applied Science)

can cause a rapid increase in voltage over a very short period, leading to high dV/dt values. This can create voltage spikes and Electromagnetic Interferences (EMI). These can lead to the breakdown of the motor winding insulation, disturb other devices' operation in the system, or lead to parasitic currents that can flow through the bearings and damage the raceways [2].

ELECTRIC EROSION IN BEARINGS

In traction motors, undesirable parasitic current flow can move through the roller bearings and cause damage to those components. The resulting bearing failure mechanism is called electric erosion. An electrical discharge between the rolling element and a bearing raceway causes high localized heating that can either evaporate small amounts of metal or create spot welds between the surfaces. With the ongoing rolling motion those spot welds break apart and small particles adhere to the rolling surfaces. If these particles continue to be rolled over, the deterioration will worsen, **FIGURE 2**.

This erosion can occur in bearings of various kinds of electric motors, including AC, DC, servo, and stepper motors. Typically, electrical erosion occurs in modern high-speed electric motors, in regenerative braking systems of electric vehicles, or whenever VFDs are used to control a motor. The worst-case scenario of electrical erosion in bearings is the premature failure of the electric motor, which can lead to safety hazards, machine downtime, and significant costs associated with repairs and replacement. Affected ball bearings often exhibit a pattern on the raceway surface called fluting, **FIGURE 3**.

FIGURE 3 Electric erosion on a raceway [4] (© NTN)

RISK REDUCTION METHODS

Several potential options already exist in the market to address electrical erosion in bearings, but cost-effective solutions are not yet well-established. The ideal solution would be to prevent these parasitic currents from appearing in the first place through the system design, but this is very challenging. Certain inverter technologies and associated components may be able to eliminate the risk for voltage spikes with further development. Instead of SiC-based switches, for example, Insulated-gate Bipolar Transistors (IGBTs) or switches with gallium nitride can be used, which feature different gradients and characteristics. Another alternative are so-called multi-level inverters that can divide the switching operation into multiple sub operations, reducing the risk of voltage peaks. **FIGURE 4** shows waveforms from two-, three-, and nine-level inverters.

Potential solutions like these, however, are either lacking in efficiency or not yet on a desired price level for high volumes. In addition, their effectiveness against electrical erosion can only be guaranteed if the entire system is designed and built by a single supplier. As soon as subsystems are merged, the system's response is difficult to predict.

A common mechanical option to prevent electrical erosion is the use of hybrid ball bearings with ceramic balls. They function as insulation between rotor and housing, which means there is no path for the discharge that causes the electrical erosion. It is important to note that hybrid ceramic ball bearings are up to five times more expensive compared to standard bearings [6]. In the case of roller bearings or bearings with higher load capacity and therefore bigger diameter rolling elements, they are even more expensive or not available.

A more cost attractive option is to insulate standard metal bearings. A thin layer of ceramic or polymeric material is applied on the surface of the bearing. This layer provides insulating properties and interrupts potential electrical current passing through the bearing. However, such coatings can also negatively impact the effectiveness and durability of the bearings. Ceramic coatings are typically thin and are not only sensitive to mechanical impacts, but they can also act as a capacitor at high frequency currents. A capacitor is a passive electronic component that stores electrical energy in an electric field between two conductive plates, which are separated by a dielectric material. Once the applied field strength is high enough, an electric discharge can occur, again causing electrical erosion of the bearing.

The existing polymer solutions often contain glass fibers for mechanical strength, but this can cause abrasive wear in the aluminum housing easily.

To tackle the above-mentioned problems and limitations, a Vespel polyimide-based insulation solution with unique features was developed.

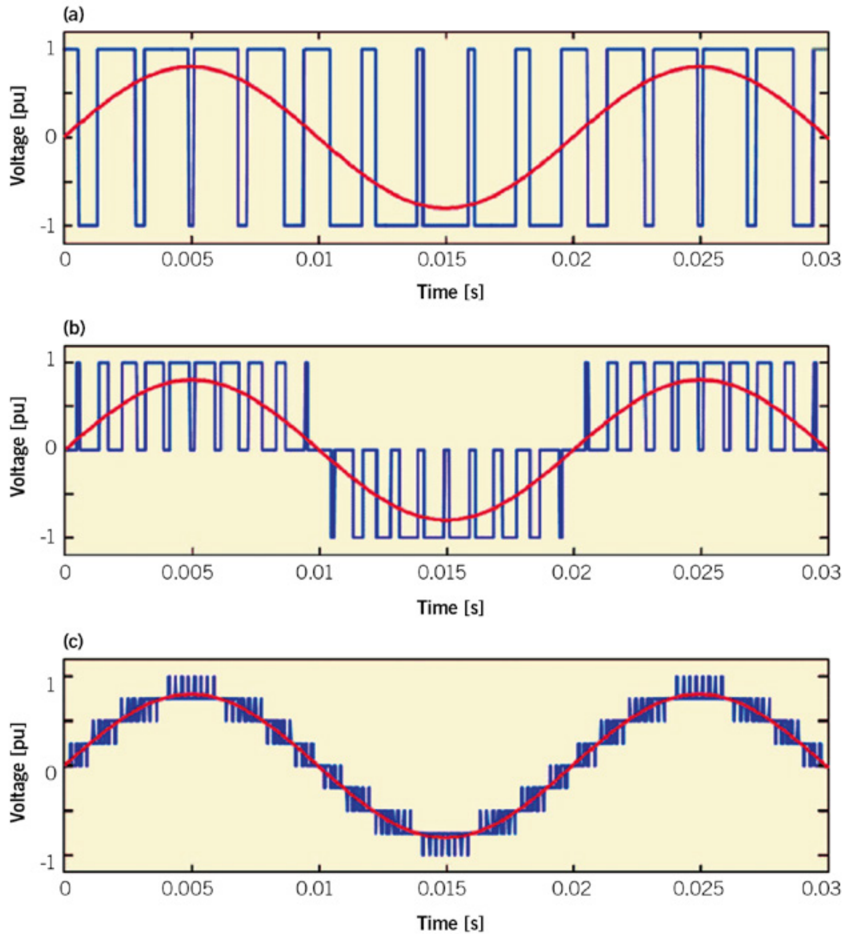

FIGURE 4 Two-, three-, and nine-level inverter pulse patterns [5] (© IEEE)

POLYIMIDE-BASED INSULATION

Vespel polyimide parts are utilized for demanding applications that require durable and long-lasting performance. Vespel S is a sintered polyimide which has no observable glass transition temperature or melting point below a decomposition temperature that is more than 400 °C. This unique property is key for applications where high loads and elevated temperatures can occur, as may be the case in traction motors in critical drive modes or in the case of malfunction.

The unique properties of polyimide materials are primarily due to their chemical structure, which is very resistant to chemical attacks, including components of modern e-axle fluids and automatic transmission fluids (ATFs).

Vespel S parts can be characterized as thermoset materials. In contrast, thermoplastic polymers are less mechanically stable, especially at elevated temperatures, and cannot handle high contact pressures due to their chemical nature.

Vespel on the other hand is the ideal candidate for bearing insulation. It can withstand high bearing loads without exhibiting creep – even at temperatures exceeding 150 °C, where high-performance thermoplastic materials, e.g., PEEK, already demonstrate the onset of permanent deformation. Unfilled Vespel polyimide, such as SP-1, has more than sufficient dielectric strength of 30 kV/mm, and there

FIGURE 5 Vespel bearing insulation sleeves (© DuPont)

are two ways in which the desired insulation feature can be achieved with Vespel: as a bearing sleeve, or as an aluminum die-casting insert.

VESPEL INSULATING BEARING SLEEVES

Vespel insulating bearing sleeves, **FIGURE 5**, are a versatile solution that can be deployed at various locations in e-motor bearings to achieve the desired insulating feature. They are put in place at the final assembly by pressing them either onto the rotor shaft, or onto one of the bearing rings. In all cases, a standard roller bearing can be used without costly ceramic rolling elements.

A Vespel PI insulating layer of 1 to 2 mm provides sufficient electrical insulation without increasing the risk of inadvertently creating a capacitor. This layer increases the damping impedance, diminishes the transmission of high-frequency currents through the bearing, and thus minimizes the risk of electrical erosion. Although a capacitance of zero is ideal, it would require thicker insulating layers that are not economical. Furthermore, the thicker the insulating layer, the greater the risk for the onset of plastic deformation, which would result in imbalances of the rotor.

The thermal expansion coefficient of 50 µm/mK for unfilled Vespel polyimide is higher in comparison to metal, allowing it to act like a gap filler at elevated temperatures. This can reduce the bearing outer ring movement in the housing. Furthermore, Vespel provides mechanical damping characteristics, potentially reducing NVH vibration – helping to reduce the overall noise emission from the system.

ALUMINUM DIE-CASTING INSERT

A second solution with a unique approach was recently developed. The high temperature resistance of Vespel polyimide makes it suitable as an insert for an aluminum die-casting process. As it does not have a melting point, it can withstand the high processing temperatures of up to 650 °C for the brief period in the casting process. By placing a Vespel insert into the mold prior to die-casting, an electric insulating barrier between the e-motor housing and the bearing is generated. The tight bearing seat tolerances are obtained by machining afterwards – a process that is required anyway. Together with the aluminum die caster Aluwag AG from Switzerland the feasibility of the concept was successfully demonstrated. Aluminum housings with 90-mm ring shaped Vespel inserts have been produced. The crosscut in **FIGURE 6** shows the very smooth interface between Vespel PI and aluminum.

FIGURE 6 Cross section of bearing seat with Vespel insert (© DuPont)

Multiple temperature cycles from -40 to 150 °C did not result in any structural or dimensional changes to the interface, which underlines its suitability for long-term use in demanding application environments. This is not only interesting for bearing insulation but can also be applied for plain bearings and other integration concepts. Various Vespel grades are available to meet application requirements, such as additional wear and friction reduction, enhanced damping features and lightweight requirements.

SUMMARY

DuPont Vespel polyimide provides solutions that are an innovative and cost-efficient way to tackle the issue of electrical erosion of bearings used in electric motors. With the trend onward higher voltage systems in electrified drivetrains, reliable and long-lasting components are crucial. Vespel parts offer unique features for use as a bearing sleeve or for integration into the aluminum motor housing demonstrates its flexibility and adaptability for various applications.

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