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Driving Sustainable Progress

Overcoming Design Challenges: Busbar Interfaces in Liquid-Cooled Environments

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As the demand for higher performance and greater energy density in electric motors (e-motors) and battery packs intensifies, liquid cooling has become an indispensable thermal management strategy. However, designing busbar interfaces, where one side is immersed in coolant and the other requires a dry, electrically sound connection to inverters or other power electronic modules, poses a multifaceted challenge. This article considers the critical design factors that must be addressed to ensure optimal performance and long life.

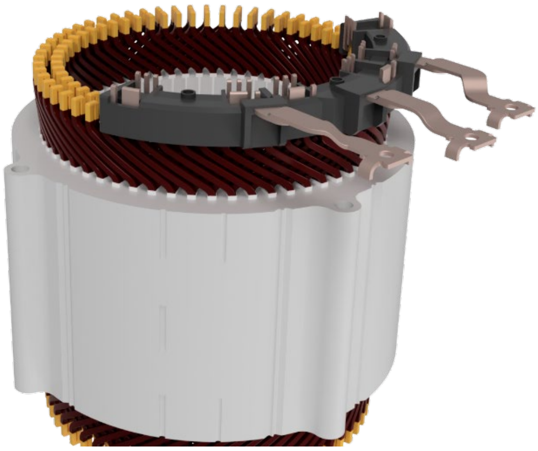

Figure 1. The importance of coolant leakage prevention between the e-motor and inverter

Leakage prevention is a fundamental concern, requiring robust sealing mechanisms that withstand wide temperature fluctuations, constant vibration, and varying pressure differentials without deteriorating over time. Alongside this, electrical isolation is crucial; the interface must exhibit high dielectric strength to prevent any unintended electrical current from flowing through the coolant. This is achieved through careful material selection and maintaining adequate creepage and clearance distances.

Material compatibility represents another significant design hurdle. The materials chosen for both the busbar and its sealing components must be corrosion-resistant in the coolant and remain robust in the surrounding electrical environment. Furthermore, designers must account for differing thermal expansion rates among materials. Disparate expansion and contraction can create undesirable gaps or stresses at interfaces, potentially leading to leakage or electrical failures.

Thermal management within the interface is equally crucial. Busbars, carrying substantial currents, generate considerable heat, which must be efficiently dissipated without compromising the integrity of the seals or the overall performance of the coolant system. Managing temperature gradients between the coolant-immersed side and the dry electrical side is also vital to prevent condensation, which could otherwise lead to moisture ingress and subsequent electrical leakage.

Beyond thermal considerations, the busbar interface must possess mechanical integrity to withstand the significant vibration and shocks inherent in HEVs and EVs, thereby preventing coolant penetration to the dry side and safeguarding electrical connections.

Finally, the increasing prevalence of higher-power-density battery architectures and the shift towards 800V and even 1200V battery architectures, coupled with faster-switching devices like Silicon Carbide (SiC) and Gallium Nitride (GaN), further compounds these challenges by increasing thermal and mechanical stresses and demanding more advanced insulation and cooling solutions.

Common Sealing Method

Traditional methods for sealing busbar interfaces often fall short in addressing these stringent requirements. Potting, a common approach, involves a secondary operation in which epoxy or silicone adhesive is dispensed into a cavity around the busbar after it has been overmolded with resin. Alternatively, using rubber O-rings or gaskets around the busbar offers some flexibility but can be prone to leakage over the assembly’s lifetime. Both conventional methods incur high costs and require additional process steps, frequently leading to long-term leakage issues that compromise reliability.

Recognising these limitations, ENNOVI has pioneered an approach that integrates seamlessly with the injection moulding process for busbar interfaces. This technology, known as ENNOVI-SealTech, effectively eliminates the need for costly and time-consuming secondary operations typical of traditional sealing methods. To cater to diverse design requirements, ENNOVI has developed two primary sealing methodologies.

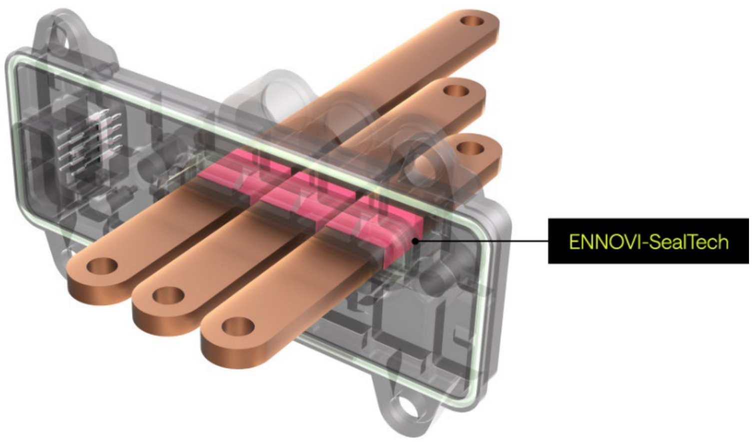

Figure 2. ENNOVI-SealTech: Integrated busbar sealing with injection moulding, eliminating secondary operations

The double-walled shrink tubing method has an inner glue layer that melts during the shrinking process, establishing a firm adhesion to the metal busbar. Concurrently, the outer layer integrates into the moulded plastic parts during injection moulding, forming a robust and durable seal. This shrink tubing solution is incorporated directly into the assembly line before injection moulding, substantially reducing processing time, costs, and labour by removing the need for any post-processing.

As an alternative approach, for more challenging applications where shrink tubing may not be optimal, is to use adhesive tape. The tape can be applied efficiently with automated equipment and exhibits excellent adhesion to both metal and plastic. Crucially, it retains its elasticity and temperature resistance throughout the injection moulding process, compressing under pressure and rebounding to form a strong, resilient seal once the pressure is released. Like the shrink-tubing method, this approach also eliminates the need for additional post-processing steps.

Validation Testing
ENNOVI's two sealing approaches have undergone rigorous testing to validate performance under extreme conditions. Testing protocols include thermal aging at 150°C for 1,000 hours in dry and oil conditions, thermal shock cycling from -40°C to +150°C in vibration test according to V1standard, blasting test, and High-Low Temperature Storage Test from 50C/+150C.

High-temperature and humidity endurance tests with voltage bias and thermal shock testing involving oil or dry conditions, performed to simulate long-term environmental conditions, confirm optimum sealing integrity. The technology's versatility allows it to adapt to a wide range of busbar shapes and form factors, and it is compatible with copper (Cu) and aluminum (Al), as well as a variety of plastics such as PA66, PBT, and PC.

For compact, lightweight designs, Al busbars offer an attractive solution for battery packs, as they are approximately 50% lighter than Cu busbars. However, for high-conductivity powertrain systems such as inverters, copper remains the preferred choice due to its superior electrical and thermal conductivity, though it requires a smaller cross-section for equivalent performance.

Ultimately, the new sealing technology offers significant benefits, including design freedom, cost advantages compared to traditional potting, space savings in compact designs, a simplified process that eliminates unnecessary steps, and demonstrably good sealing performance. It is ideal for applications requiring liquid coolant or lubricant on one side and dry electrical connections on the other, making it suitable for e-motors, inverters, battery packs, and oil pump interfaces.

Conclusions
The ongoing transformation of the automotive industry towards electrification, with a growing emphasis on liquid-cooled systems, presents formidable design challenges for busbar interfaces. Solutions like ENNOVI-SealTech represent a significant advancement, addressing the critical issue of coolant leakage. By proactively developing targeted solutions, ENNOVI plays a pivotal role in driving the efficiency, reliability, and longevity that are essential to the future success of EV and HEV.

About the Author

Dominik Pawlik is the Product Portfolio Director at ENNOVI (formerly known as Interplex), a provider of interconnect solutions. With over 25 years of experience in the automotive sector, he is recognized expert in power busbar distribution. Dominik holds an MSc in Electrical Engineering and has a proven track record of driving innovation and excellence in power interconnect solutions.
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