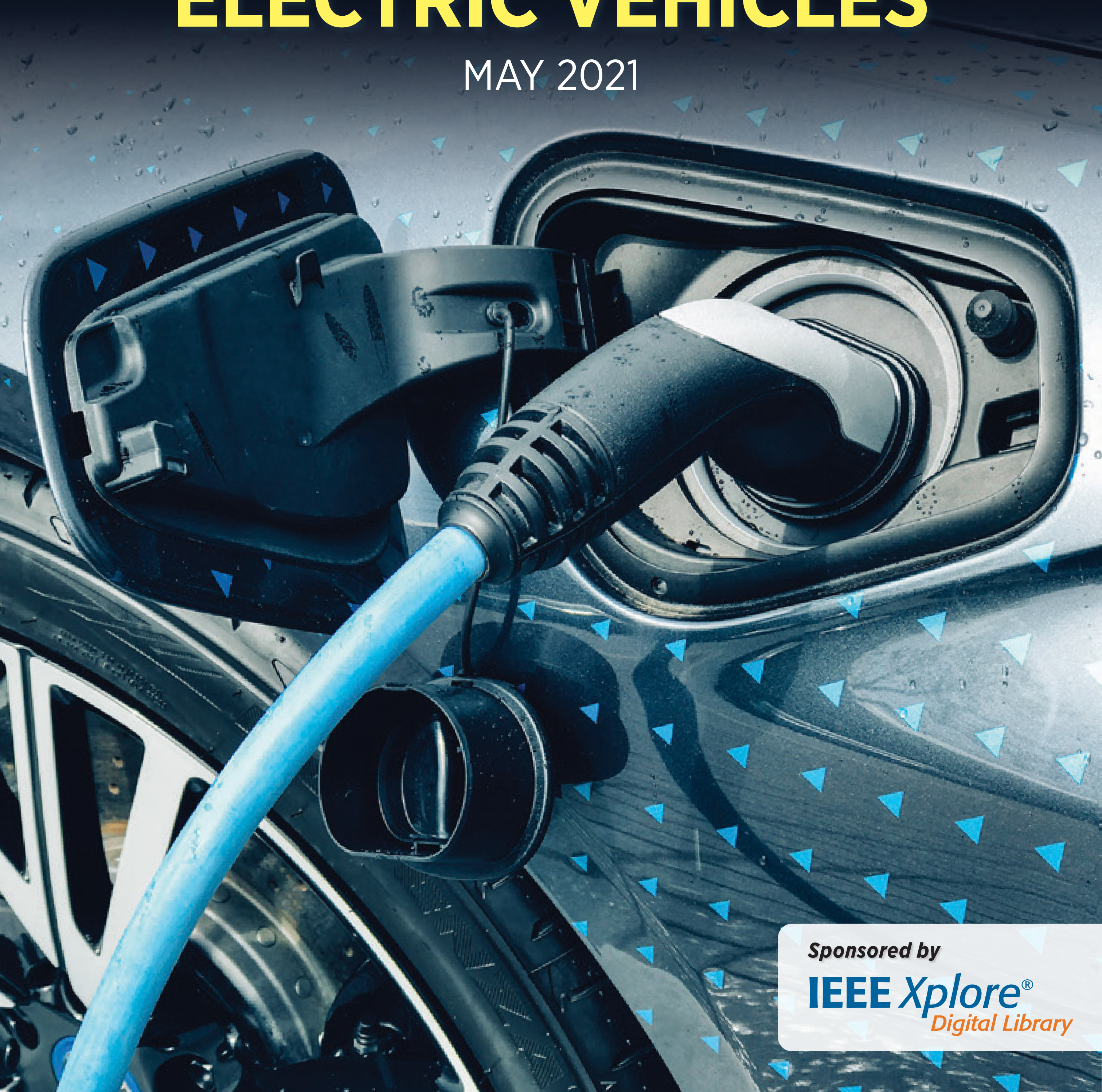
TECH BRIEFS

SAE INTERNATIONAL

SPECIAL REPORT:
POWERING NEXT-GEN ELECTRIC VEHICLES

MAY 2021



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ABSTRACT: Electric Vehicle Batteries Eye Solid-State Technology

Researchers are developing a solid-state (SS) version of lithium-ion (Li ion) batteries for electric vehicles (EVs) that promises to charge and discharge rapidly, offer longer lifecycles, provide a much higher energy density, cost less, and provide greater safety. Besides the performance improvement, safety is a major factor driving automakers toward SS technology. In SS batteries (SSBs), the flammable liquid electrolyte, which passes the charge that carries Li ions during charge and discharge cycles, is replaced by a solid electrolyte.

These ongoing improvements in battery technologies will pave the way for an installed EV base of 100 million vehicles by 2028, according to global technology market advisory firm ABI Research, Oyster Bay, New York. In fact, ABI's principal analyst James Hodgson says, "Lithium-silicon and SS are the future EV battery technologies that will improve performance, hold more energy, and last longer at a lower cost. The addition of silicon alone over the next seven years will grow the EV installed base from 8 million vehicles in 2019 to 40 million in 2025, as consumers' range anxiety slowly eases."

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Powering Next-Gen Electric Vehicles

Electric vehicles (EVs) can significantly reduce the dependency on crude oil and minimize pollutants. The U.S. Environmental Protection Agency categorizes all-electric vehicles as zero-emission vehicles because they produce no direct exhaust or tailpipe emissions.

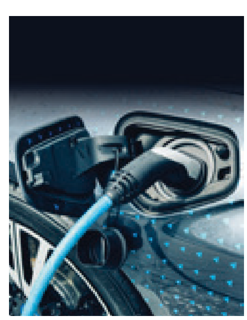
The U.S. Department of Energy found that driving an EV instead of a comparable conventional vehicle can save a driver as much as $14,500 on fuel costs over 15 years. Additionally, an all-electric vehicle is more than three times more efficient than its conventional counterpart.

One of the main challenges of EVs is addressing consumers' fears of running out of charge and getting stranded. This concern, commonly known as range anxiety, can be alleviated by a number of advanced charging systems.

This special report — sponsored by the IEEE *Xplore* digital library — highlights new technologies and methods designed to power electric vehicles into the future. ■

FEATURES

ON THE COVER



The future of mobility is electric vehicles (EVs). But as EVs grow in popularity, there is a need for new, more efficient batteries to power them. This Special Report highlights innovative EV battery technologies and methods to safely charge them.

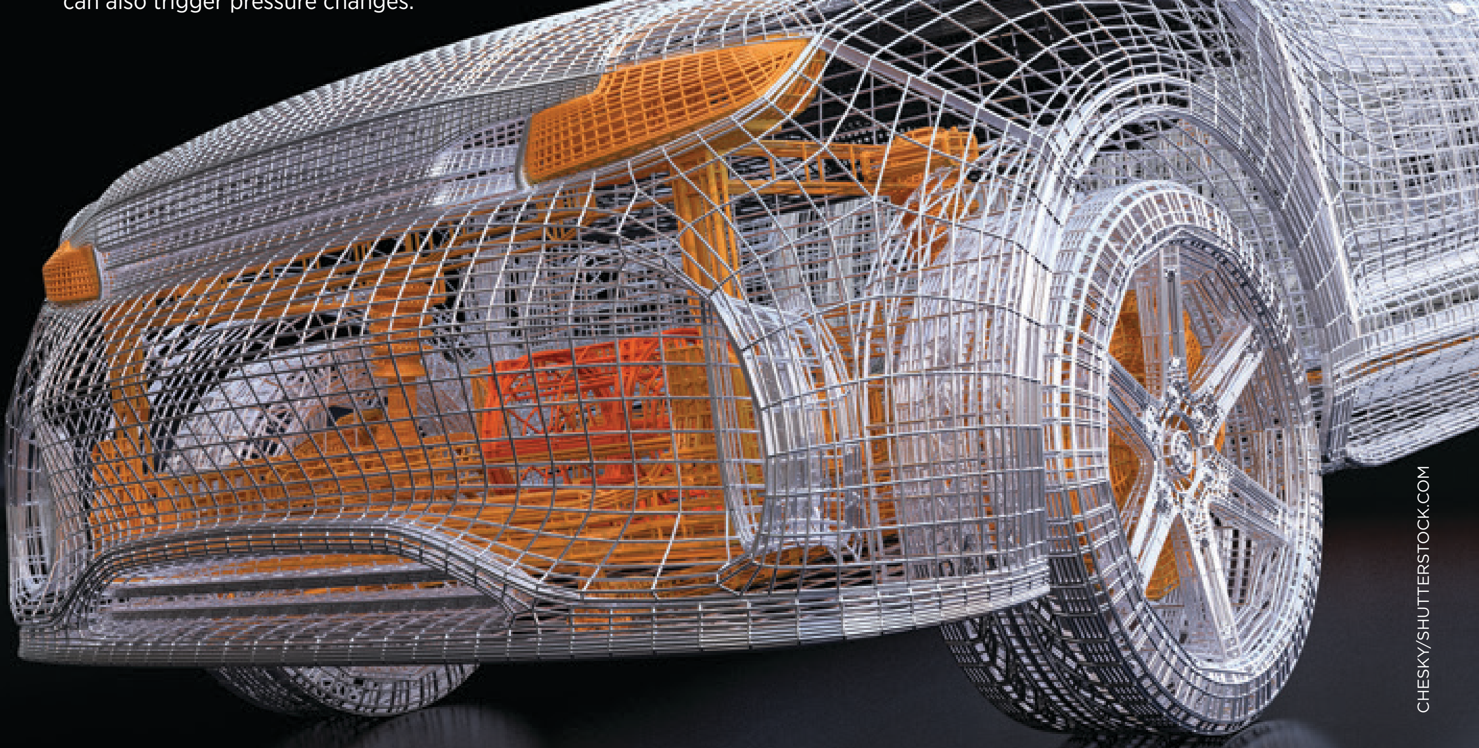
(Image by Dariush M/ Shutterstock.com)

Venting for **EV Battery Packs**

Cell chemistries, thermal dynamics, vehicle packaging, and even weather present challenges for optimizing electric vehicle battery functional safety.

Batteries for electric vehicles (EVs) need protection from harsh external conditions. Generally located on the underside of the vehicle, EV battery enclosures protect the cells from exposure to water, dust, debris, and other elements. Like other enclosures, EV battery enclosures also undergo temperature and pressure changes that can lead to problems without proper venting. But EV batteries present unique venting challenges including potentially dangerous thermal runaway conditions. Considering these challenges, integration of design, manufacturing, installation, and testing are crucial to optimal EV battery venting performance.

Numerous components in an EV require venting. Lighting, horns, electronics, powertrain, and other components all experience temperature changes resulting from weather conditions, moisture, or heat from electronic circuits. These temperature fluctuations produce pressure changes inside the components. Changes in altitude can also trigger pressure changes.



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A trek up Pike's Peak, for example, could result in pressure changes of up to 140 millibars (2 psi).

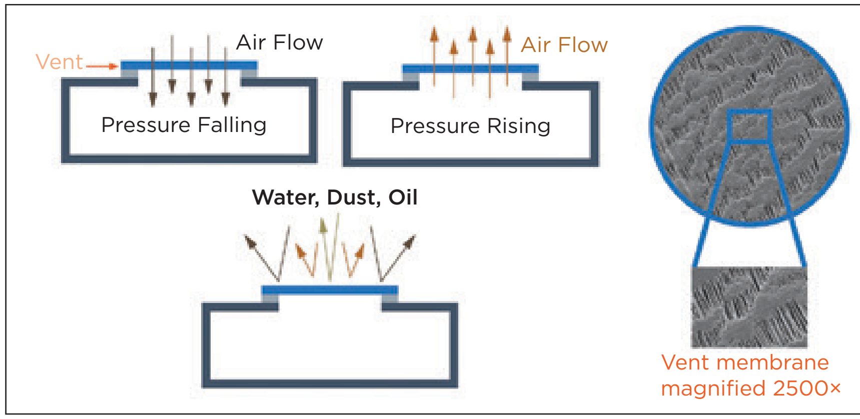
Expanded polytetrafluoroethylene (ePTFE) membranes have proven effective in venting EV enclosures and providing pressure equalization. This material allows gases to flow in and out of the enclosure but helps prevent liquid and particle contaminants from entering the enclosure.

Challenges Unique to EV Packs

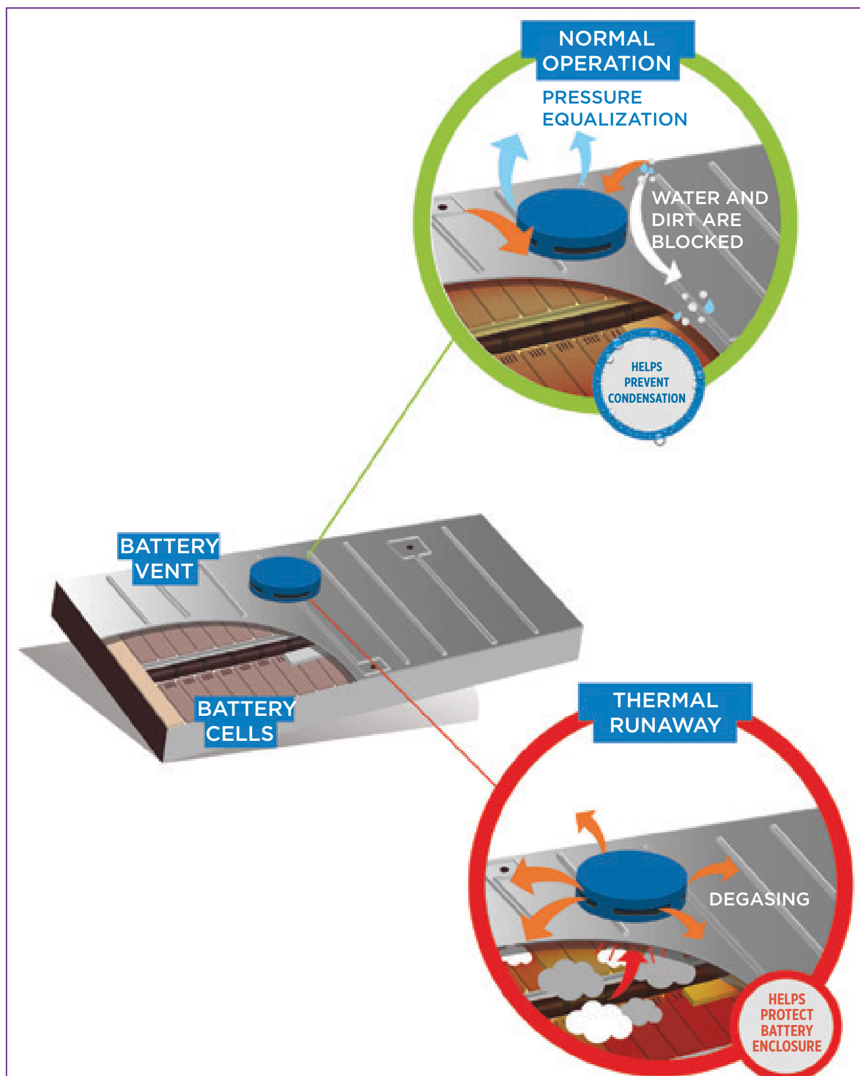
Along with exposure to the various elements experienced by other automotive components, battery packs present additional challenges due to their location, size, and chemical makeup. Packs located on the undersides of vehicles can be exposed to water fording or submersion as a vehicle traverses standing water. Roadway water may include salt and other corrosive chemicals. Car washes can expose vehicles to high-pressure sprays of varying temperature. Dust, debris, and vibration can also impact the battery pack.

The size of EV battery packs also presents challenges. Weighing up to 2,000 pounds (907 kg), the packs contain hundreds — sometimes thousands — of cells, with large air volumes that can exert forces on the enclosures as pressures increase. This creates significant venting needs to account for differential pressure due to altitude or temperature change.

Perhaps the biggest challenge with EV battery packs is the potential for thermal runaway. If lithium-ion battery cells are damaged by puncturing, overcharging, manufacturing defect, or other causes, they can release gas and heat. This can trigger other cells to decompose, leading to a thermal runaway condition where rapidly increasing temperatures and pressures released by cells exceed the venting capability of ePTFE membrane vent. At this point, the vent is unable to allow gases to escape fast enough and additional pressure relief is needed to avoid rupturing the battery pack enclosure, which is typically made of lightweight materials to conserve weight.



ePTFE membranes have proven effective in venting EV enclosures.



Dual-stage venting includes ePTFE membrane (blue) that bursts under thermal runaway conditions.

Venting for
EV Battery Packs

Dual-Stage Venting Mitigates Thermal Runaway

Dual-stage venting provides an effective solution to the unique challenges of EV battery packs. The first stage — passive venting — handles gradual changes in temperature and pressure via the ePTFE membrane. The second stage — active venting — allows the vent to rupture and gases to quickly escape in a thermal runaway situation.

As an example, an enclosure that would rupture at a pressure of 1,500 millibars (21.7 psi) could be equipped with an active venting system that opens at 300 millibars (4.3 psi), well below the rupture pressure. Without active venting, the enclosure would rupture quickly.

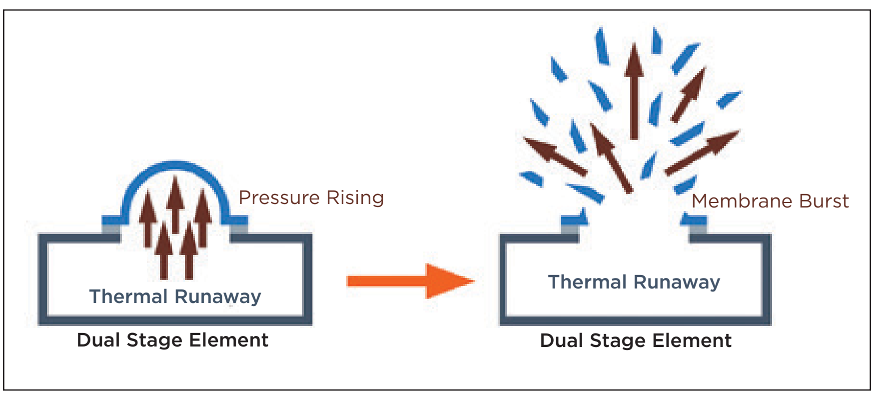
With dual-stage venting, a single assembly can help accomplish both passive and active venting functions and assist in controlling the pressure and location at which gas is released. Typically located on the top or side of the enclosure, the vents can be situated to allow for controlled gas release, which helps mitigate risk by allowing the designer to determine the location of the release.

To properly incorporate dual-stage venting, the solution should integrate design, manufacturing, and testing considerations; for example, dimensions of the vent need to be accounted for in the battery pack and vehicle design. While dual-stage vents can be manufactured with a diameter less than 50 mm (1.9") and a height of approximately 10 mm (.39"), space is often limited in areas of battery packs. Serviceability should also be considered to allow for replacement of the vent.

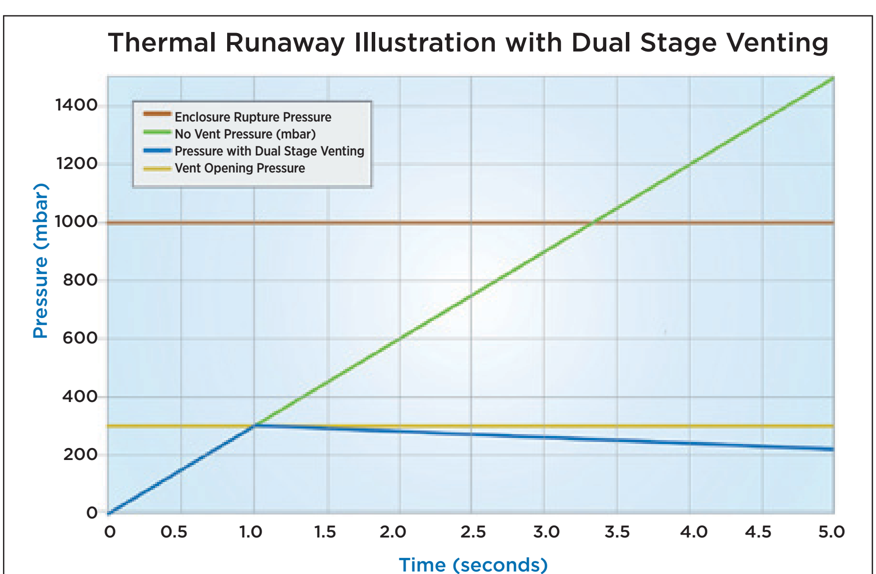
Ease of installation and efficiency in the manufacturing process are key to the overall battery pack solution, particularly if the packs will be manufactured on a high-volume basis. Different fittings are available, depending on enclosure materials. A bayonet quarter-turn fitting is most common, though threaded fittings are feasible with sufficient thickness of enclosure material. Drainage around the vent should also be provided to allow for runoff of water reaching the vent. Weight and cost also need to be considered in the solution. While vents can weigh less than 15 g (.53 ounce), they contribute to the overall weight and cost of the battery pack.

The number of vents required will vary depending on the application but common practice has been to provide at least two vents and up to 12 vents for full EVs and at least one vent for hybrid vehicles. Airflow needs will depend on free air volume and anticipated nominal operating pressures. An experienced venting partner can help analyze the battery pack and provide venting recommendations.

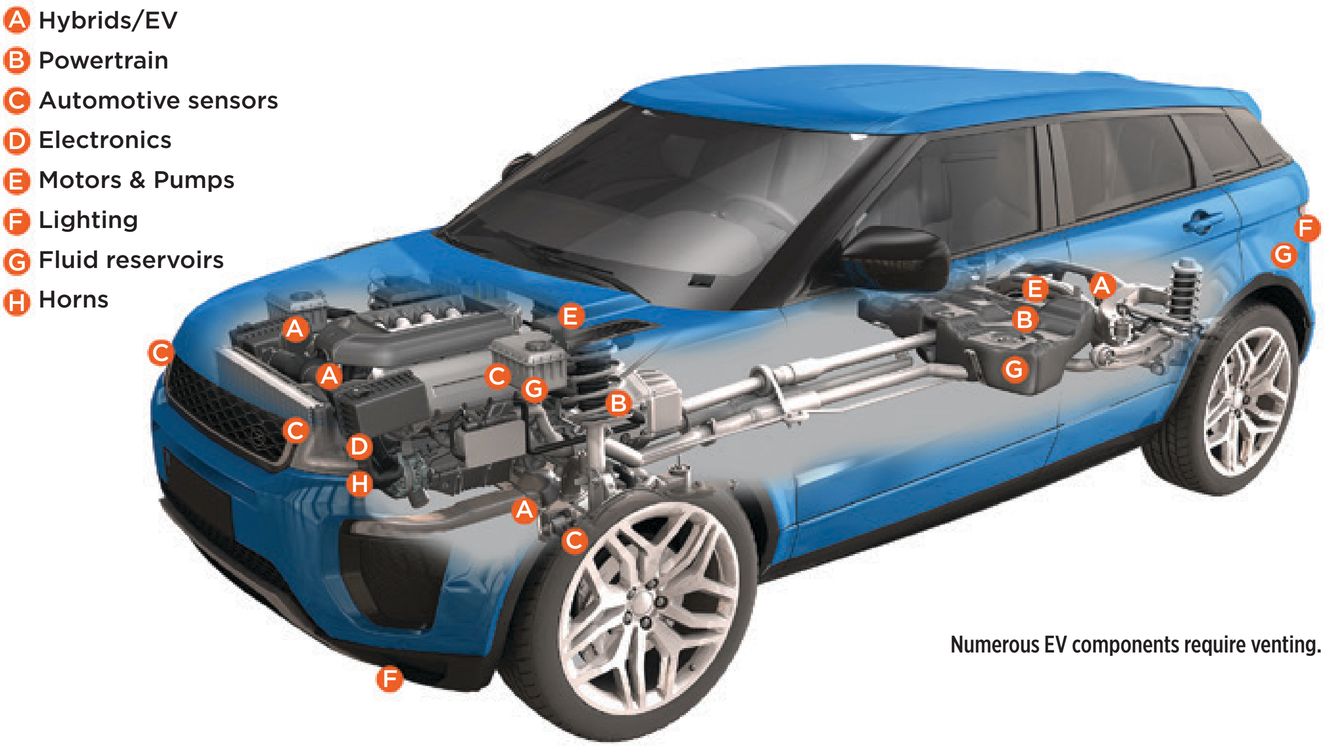
Because thermal runaway events can generate temperatures exceeding the melting temperature of the membrane, a key feature of the active vent requires designing and manufacturing the vent so it bursts before it melts, allowing hot gases to escape before peak temperatures diffuse throughout the pack. The increased pressure of a thermal runaway event will equalize throughout the pack at the speed of sound, while heat takes time to diffuse, so the vent can burst quickly and allow gases to escape.



(Left) Dual-stage venting blocks water and dirt in normal operation and allows hot gases to escape in a thermal runaway condition. (Right) Stage two (active) venting can burst in a controlled direction and help prevent rupture of the entire battery pack.



Stage two (active) venting in conjunction with passive venting can prevent enclosure rupture.



Numerous EV components require venting.

Testing is Critical

Vents should be thoroughly tested to demonstrate performance, with quality testing included for multiple pressure and temperature cycles, thermal runaway, ingress protection, vibration, thermal shock, and salt spray. Pressure cycle testing should include a sufficient number of cycles to simulate the design life of the product. Ingress protection (IP) should be provided to at least a rating of IP67. Standard tests are available for most of these parameters, though pressure cycle and thermal testing may require custom testing based on the application.

Compatibility with leak testing is another consideration. Ideally, the vent port can also serve as a port for leak testing, service, and inspection of the pack. This can help minimize the number of holes in the pack. If the vent is to remain installed during testing, it is also important that the vent can withstand the vacuum pressures introduced by leak testing.

ENVIRONMENTAL TESTING EXAMPLES

Test	Description	Method
IP67/IP68	Protection from water ingression	ISO 20653
Pressure Cycle	Simulation of the venting operation tested at ±50 mbar pressure for 60,000 cycles	Custom
Temperature Cycle	-40°C to 80°C hold 30 min, 80°C to -40°C hold for 30 min, repeat for 500 cycles	ASTM D3045-92
Vibration	32 hours of vibration of each of the 3 axes, from 5hz to 2000hz	ISO 19453-3
Shock Test	50g for 6ms on all axes	ISO 19453-3
Thermal Runaway	Battery mounted on vehicle to test vent performance during TR	Custom
Drop	Drop part from 1.5 meters on all 3 axes	ISO 2248

A combination of standardized and custom tests is recommended to vent an EV battery.

With venting a necessity in battery pack design, dual-stage venting efficiently provides both passive and active venting in one assembly. Proper venting, however, requires careful planning and integration in the overall process and should not be treated as an afterthought. To achieve successful solutions, vehicle and battery pack manufacturers should engage an experienced venting partner with the expertise and resources needed to analyze issues and develop precise solutions. The partner should have a proven track record, with solutions approved by other OEMs.

With a strong partnership engaging the expertise of the venting and battery pack manufacturers, dual-stage venting can contribute significantly to the successful production and operation of EVs.

This article was written by Jake Sanders, Supervising Engineering for the Venting Solutions team at Donaldson Company, Inc. (Bloomington, MN). Contact Sanders at jake.sanders@donaldson.com; 952-703-4868.

For more information, visit ***http://info.hotims.com/76506-220****.* ■

New SAE Wireless Charging Standard is EV Game-Changer

SAE J2954 paves the way for electric vehicle charging without a plug and enables alignment for manual/autonomous parking.

With SAE J2954 Wireless Charging, power is transferred by creating a magnetic field between a transmitting pad on the ground and a receiving pad located under the vehicle. The equipment will be available for residential and commercial EVSE installations. (BMW)

SAE International on October 22, 2020 announced publication of the first global standard that specifies, in a single document, both the electric vehicle (EV) and EV supply equipment (EVSE) ground system requirements for wireless charging of electric vehicles. The new standard, SAE J2954, helps pave the way for charging without the need for plugging in — widely considered to be a key enabler for accelerating the adoption of EVs and autonomous vehicles.

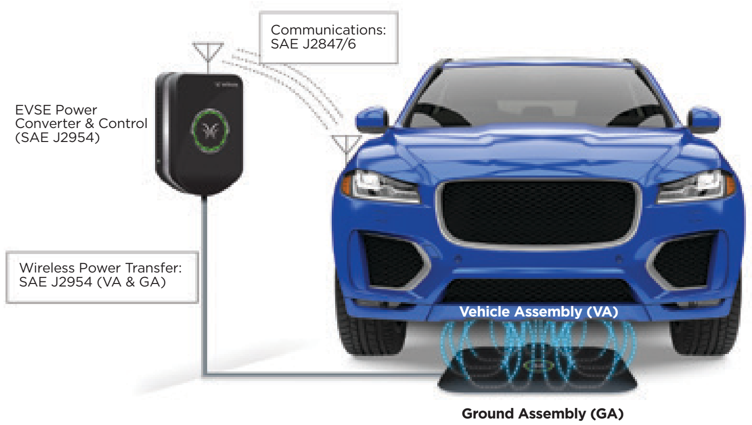
The new standard was more than a decade in the making. SAE kicked off its pioneering pre-competitive research at a time when few contemporary electric cars existed and wireless power transfer (WPT) systems for EVs were an unproven concept. The SAE J2954 Wireless Power Transfer and Alignment Taskforce worked since 2007 to thoroughly vet and test the technology in partnership with government agencies, regulatory bodies, and private-industry groups including the American Association of Medical Instrumentation (AAMI), U.S. Dept. of Energy (DOE), U.S. Food & Drug Administration (FDA), automotive OEMs, Tier 1 suppliers, and many others.

"Charging your EV should be as simple as parking and walking away — the wireless charging SAE J2954 Standard gives freedom and convenience to do exactly that, safely and automatically," stated Jesse Schneider, chair of the SAE J2954 Task Force.

WPT systems work by parking in a wireless charging spot with the vehicle positioned over an SAE J2954-compatible ground assembly pad. After a communications handshake, charging begins automatically without a physical corded connection. Power is transferred by creating a magnetic resonance field between the transmitting pad on the ground (wired to the grid) and a receiving pad fitted on the underside of the vehicle. The energy crosses an air gap (the ground clearance between the pads) and is then converted from AC into DC on the vehicle to charge the vehicle batteries.

The technology is a safe and efficient method for transferring power from the

New SAE Wireless Charging Standard is EV Game-Changer



Functional elements of a Wireless Charging System consist of three major partitions: the grid-connected converter with its attendant GA coil for power coupling, with a communication link to the vehicle system (the GA); the vehicle-mounted VA coil with rectification, filtering components, and charging control power electronics necessary for regulation/safety/shutdown when required, with a communications link to the infrastructure side (the VA); and the secondary energy storage system, battery management system components, and associated modules necessary for in-vehicle communications (CAN, LIN) required for battery SOC, charge rate, and other necessary information (the energy storage system).

AC grid supply to the electric vehicle. Tests using a 10" (250-mm) ground clearance have shown that WPT systems operate at grid-to-battery efficiencies of up to 94%. WPT with additional alignment elements in SAE J2954 also fulfills the charging requirements for autonomous EVs to charge themselves without human interaction.

"The SAE J2954 standard is a game-changer by giving a 'cookbook' specification for developing both the vehicle and charging infrastructure wireless power transfer, as one system, compatible to 11 kW," Schneider said. "The SAE J2954 alignment technology gives additional parking assistance, even allowing for vehicles to park and charge themselves autonomously."

He noted that the SAE J2954 task force coordinated its efforts with industry and other standards organizations to ensure global harmonization. "Publishing SAE J2954 is a major step forward in wireless charging commercialization for EVs," Schneider said.

11-kW Universal Ground Assembly

A critical issue addressed early in the SAE J2954 process was to classify products in terms of charging levels, vehicle ground clearance, and systems interoperability. Three power levels were established: WPT1 (3.7 kW), WPT2 (7 kW), and WPT3 (11 kW). The WPT system consists of two "sides." The Ground Assembly (GA) encompassing the charging hardware is wired into the grid. The other side includes the on-vehicle equipment known as the Vehicle Assembly (VA).

SAE J2954 establishes a universal Ground Assembly for WPT3, critical especially for public infrastructures. It is downward-compatible to charge vehicles also at WPT1 and WPT2. The goal is that the WPT-GAs will be installed in publicly available parking spaces, per the setup in today's plug-in charging infrastructure. Installation with WPT3 will allow downward compatibility. For ease of use, SAE J2954 specifies the requirements to make the GAs and VAs fully interoperable, so that any vehicle will be able to charge when it is parked in an SAE J2954 GA-equipped parking location. There is also the possibility to have specific designs for captive fleets; as described in SAE J2954 in this case, a GA would only be expected to fully operate with a specific group of vehicles.

To validate its performance targets, safety limits, and methodologies, the SAE J2954 standard includes key parameters such as minimum efficiency, EMI, and EMF (electromagnetic interference and field) limits as well as foreign object detection. There are three overlapping ranges of vehicle ground clearances from 100 to 250 mm (3.9 to 9.8") and three levels of grid input to the GA up to 11.1 kVA. Parking tolerances are ±75 mm (3.0") in the direction of travel and ±100 mm (3.9") in the lateral direction.

The SAE J2954 task force concluded that to ensure interoperability, the ability of systems to transfer power, as designed by different manufacturers, must be validated in both bench and vehicle testing. SAE J2954 standardizes a WPT GA/VA test station along with coil specifications to evaluate the requirements for safety, interoperability, and performance. This allowed OEMs and Tier 1s alike to prove their vehicles and charging subsystems were compatible with SAE J2954 requirements and guidelines.

The baseline bench testing of the WPT systems was carried out at both the DOE's Idaho National Laboratory and TDK RF Solutions, evaluating the GA side and the VA sides. For vehicle systems testing, a group of companies including Aptiv, BMW, Continental, Ford, General Motors, Hevo, Honda, Hyundai, IHI, KAIST, Lear, Qualcomm, Toyota, and WiTricity under SAE leadership created a Cooperative Research Project (CRP) with industry-committed funds for additional vehicle and emissions testing. In those tests conducted at TDK RF Solutions near Austin, TX, automakers and suppliers brought vehicles. Different suppliers brought GAs that were tested for performance, interoperability, and EMI/EMF emissions.

This article was written by Jennifer Shuttleworth, Associate Editor, Automotive Engineering. *For more information, visit* ***https://www.sae.org/standards/content/j2954_202010/*** *or contact Dante Rahdar, SAE Ground Vehicle Standards Specialist at Dante.Rahdar@sae.org.* ■

SAE J2954

Practical Design Solutions to Improve Contactless Current Sensing in Electric Vehicles

The automotive industry is moving beyond the small electric commuter car and is now offering a variety of models to meet an increasing range of needs, from family transport to sports and recreation. These vehicles are typically larger and, as a result, heavier than earlier EV models. These require larger electric motors which, in turn, consume more power. Whether the vehicle is full-electric, plug-in hybrid, or mild hybrid, the voltage and current levels involved are considerable. In most cases, the batteries must supply many hundreds of volts to achieve the driving experience necessary to take electric vehicles to the next level of performance. Because of this, closely monitoring the volume of current flowing to the motor is becoming a critically important function for automotive manufacturers.

The Challenge of Accurate Current Measurements in EV Environments

The shift away from internal combustion toward electric drivetrains raises many new challenges for engineers from multiple disciplines. For system engineers, the challenge is balancing the power-to-weight ratio, while electrical and electronic engineers need to focus on power management. More power means faster and more responsive vehicles but using too much power too quickly leads to rapidly depleted power sources and reduced range. It is therefore critical that every part of the design must be optimized.

The key to power management is accurate measurement — the current sensor is the EV equivalent to the fuel flow sensor in a conventional vehicle. Current measurement can easily be achieved using a shunt or low-value resistor. The higher the current, the larger the shunt, so measuring currents of the magnitude required for powerful electric motors would demand physically large shunts that are heavy and expensive.

Contactless current sensing provides an attractive alternative to the shunt resistor. Based on the magneto-resistive, or Hall effect, it takes advantage of the electromagnetic fields generated as current passes through a conductor. Because of their smaller size, non-intrusive nature, and inherent galvanic isolation, contactless current sensing is rapidly becoming the preferred current measurement approach for electric vehicle manufacturers.

Contactless Sensor Types for Automotive Applications

The size of the magnetic field surrounding the conductor is proportional to the current flowing but even with large currents, the field strength is still relatively small. Although Hall sensing elements can be very sensitive, this sensitivity also makes them prone to reading stray or background electromagnetic fields. Fortunately, this distortion can be reduced through shielding or applying compensating techniques.

However, compensating for all forms of stray EMI would demand a deep understanding of all the various sources of interference, which would be challenging. The simplest and arguably more robust approach is to select a contactless current sensor that offers some inherent immunity to stray fields.

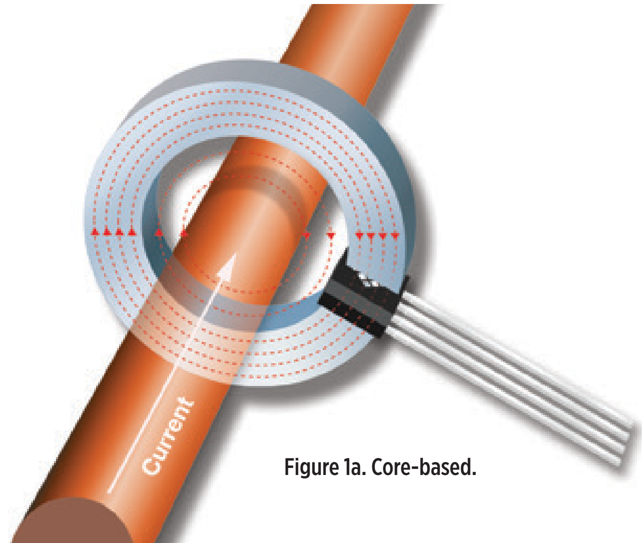


Figure 1a. Core-based.

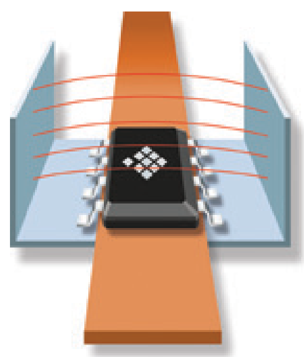


Figure 1b. U-shaped.

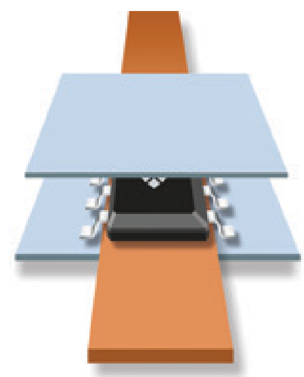


Figure 1c. Symmetrical.

Figure 1. The three main types of contactless current sensors used in automotive applications.

ALL IMAGES: TDK-MICRONAS

In general, there are three approaches to contactless current sensing, as shown in Figure 1. These include the core-based sensor, the U-shaped sensor, and the symmetrical "sandwich" shielded sensor. While comparing all three is difficult due to the number of variables presented by unique applications, it is useful to measure performance based on a typical scenario. In this instance, the sensors were evaluated using a 20-mm-wide by 2.5-mm-thick busbar with a rectangular cross-section carrying 1000 A.

Core-Based Contactless Current Sensors

In a core-based sensor, a flux concentrator is positioned around the material carrying the current to be measured. The circular shape of the concentrator is interrupted by a small air gap into which the magnetic field sensor is

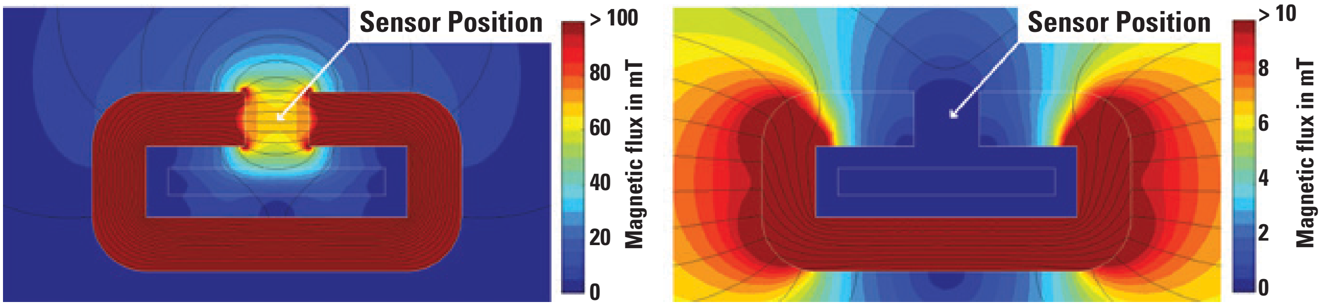


Figure 2. Simulation of a core-based current sensor.

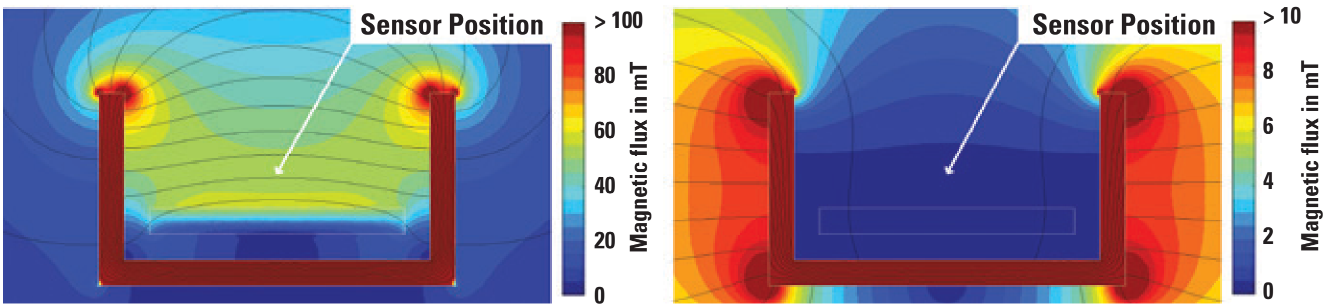


Figure 3. Simulation of a U-shaped shielded sensor configuration.

placed. The core helps focus the flux induced by the current flowing in the busbar to the sensor.

The sensitivity of the sensor to the flux generated by the current flow is dependent on several factors. The first of these is the size of the air gap, as a smaller air gap allows a higher amount of flux to reach the sensor. It follows, therefore, that a smaller sensor would allow for a smaller air gap. As shown in Figure 2, in this experiment, a current of 1000 A results in the sensor registering a flux density of 200 mT. By comparison, if no core were present, the same sensor would register a flux density of just 20 mT. Sensors suitable for this configuration include the HAL 24xy from TDK.

To measure this configuration's immunity to stray fields, a simulation was carried out assuming an external field with a flux density of 5 mT. The results can be seen in Figure 2, showing how the magnetic field is trained by the shape of the core to flow through the sensor. With the external field present, the sensor's ability to accurately detect the field generated by the current flow is reduced by a factor of 40. The conclusion here is that the core-based sensor offers a good level of shielding from other sources of EMI and with an appropriate level of signal conditioning, its effects can be further mitigated. In this case, it would be reasonable to expect an offset error of just 0.06% full scale.

However, the core-based approach has the disadvantage of being relatively difficult to mount, as the busbar needs to pass through the core, while the sensor must be located in the air gap. Furthermore, to avoid saturation from large current flows, the core also needs to be physically large. In addition to this, the amount of magnetically sensitive material used in the core itself can result in it becoming a source of hysteretic error and interference.

The U-shaped current sensor addresses many of these disadvantages.

The U-Shaped Shielded Current Sensor

As the name suggests, the U-shaped sensor features a larger air gap but still offers a degree of shielding from stray EMI. The sensor benefits from shielding on three of its sides thanks to the use of a soft magnetic material. The shape of the concentrator makes assembly easier than a core-based configuration, as the sensor itself can be positioned above the busbar, mounted on a small printed circuit board.

This style of shielded sensor will have lower sensitivity than a core-based approach, which is one of the tradeoffs engineers must consider when selecting the most appropriate design for their application. As shown in Figure 3, with 1000 A flowing through the busbar, the sensor detected a magnetic flux density of 50 mT, corresponding to a gain of 2.

The low gain has its benefits, however. It means almost any sensor can be used such as the HAL 24xy or the CUR 423x closed-loop sensor based on tunnel-magneto resistance (TMR) from TDK. Also, because there is less concentration of the magnetic field, the shielding material's thickness can be optimized for space, weight, and cost.

As Figure 3 shows, the field is once again directed around the shielding; however, in this configuration, the offset error caused by the stray field is 0.55% full scale. Adjusting the shape of the shielding and the space around the sensor can improve this offset error.

The core-based solution is symmetrical in terms of susceptibility, while the U-shaped configuration is asymmetrical. This means the U-shape is more susceptible to vertically oriented fields than to horizontal fields. This is another factor to take into account when selecting and locating a contactless current sensor. In its favor, however, this configuration has lower hysteretic error than the core-based sensor, as

Practical Design Solutions to Improve Contactless Current Sensing in Electric Vehicles

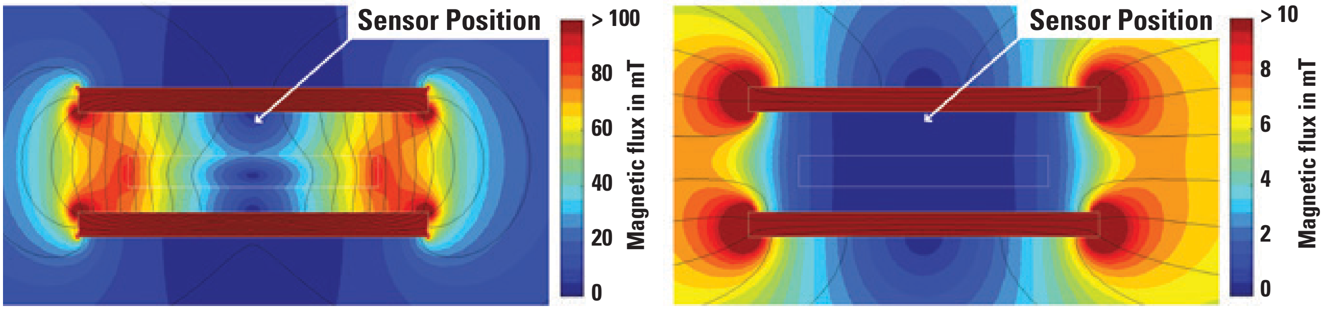


Figure 4. Simulation using the symmetrical shielding sandwich configuration.

there is less magnetic material present. Conversely, the size and shape of the sensor are still largely governed by the level of shielding needed.

The symmetrically shielded sensor provides yet another option, bringing benefits in both size and shielding ability.

Current Sensors with Symmetrical Shielding

For applications that require a higher level of shielding at the cost of sensitivity, the symmetrically shielded — sandwich — configuration may be the most appropriate. In this approach, the sensor is located centrally above the busbar, as with the U-shaped approach. However, in this configuration, the sensor is shielded using two pieces of soft magnetic material; one piece sits above the sensor while the second is placed below the busbar. In this way, fields generated by the busbar and any stray EMI are both directed across the sensor's plane of measurement.

This results in a gain of 0.3, as shown in the simulation results in Figure 4, meaning that for the same current of 1000 A, the sensor measures just 7.8 mT. This indicates attenuation of 70%. Because of this, only sensors with a high sensitivity level, such as TDK's CUR 423x TMR sensor, can be used.

The major benefit of this configuration is the relatively high levels of shielding it offers when compared to the core-based and U-shaped configurations. Also, while the signal is attenuated and combined with the stray EMI, the result is still an offset error of only 0.51% FS, which is comparable to the U-shaped approach but without the disadvantages that configuration brings.

Parameter	Core-based	U-shaped	Symmetrical
Signal field amplification, Flux density @ 1000A	10 200 mT	2 50 mT	0.3 7.8 mT
Shielding factor	40	17	124
Offset error due to EMI field (5mT)	0.06%FS	0.55%FS	0.51%FS
Hysteretic error	High	Medium	Low
Dimensions	34.0 × 7 × 16.5 mm³	28 × 15 × 15 mm³	28 × 12 × 12 mm³
Weight (core/shield)	20 g	13 g	11 g

Table 1. Comparison of the three sensor configurations.

The biggest advantage of the symmetrical shielding configuration is that the hysteretic error can be fully compensated. This is because the fields in each of the two soft magnetic materials used in the shielding have opposing field orientations. By careful design, the two shields can effectively cancel out any residual magnetic field created by the current flows.

Another major benefit of this approach is its size. The size of the complete sensor implementation is no longer dictated by the size of the flux concentrator or shielding. This means the symmetrically shielded approach can be optimized for size, weight, and cost, whatever the size of the busbar or the current being measured.

Conclusion

While all three of the solutions presented here have their relative benefits, the application will ultimately influence the choice. If high levels of immunity are needed, the core-based design is hard to surpass. If low hysteretic error and small size are driving factors, then the symmetrically shielded sensor configuration is likely to be favored. The results presented in Table 1 provide a good snapshot of the discussion.

The demand for robust, cost-effective, and reliable contactless current sensing in electric vehicles is increasing. As more manufacturers extend their product offerings in this area, consumers can enjoy the benefits that fully or partially electric drivetrains provide.

This article was written by Lukas Klar, application engineer, TDK Micronas (Freiburgim Breisgau, Germany). For more information, contact Mr. Klar at Lukas.Klar@micronas.com or visit ***http://info.hotims.com/79411-164***. ■

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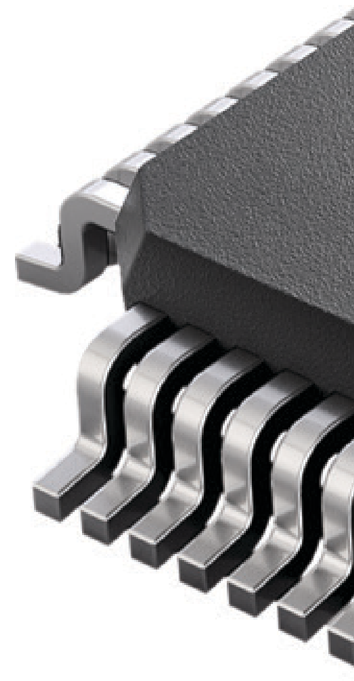
21-EA-324a 03/2021

Nano Diamond Battery Provides Universal Applicability



Modern life is heavily reliable on mobile battery-powered devices affecting daily aspects of our lives, ranging from telecommunication devices to transport vehicles. There is an increasing demand for efficient and cost-effective batteries. Conventional batteries have been riddled with numerous concerns and in the age of increasing consciousness about global warming and waste accumulation, production must be in line with sustainable development principles and processes.

The Nano Diamond Battery (NDB) is a high-power, diamond-based alpha, beta, and neutron voltaic battery that can provide lifelong and green energy for numerous applications and overcome limitations of existing chemical batteries. The NDB acts like a tiny nuclear generator. The power source for the NDB is intermediate- and high-level radio isotopes that are shielded for safety by multiple levels of synthetic diamond. The energy is absorbed in the diamond through a process called inelastic scattering, which is used to generate electricity. The self-charging process will provide a charge for the full lifetime of any device or machine, with up to 28,000 years of battery life.

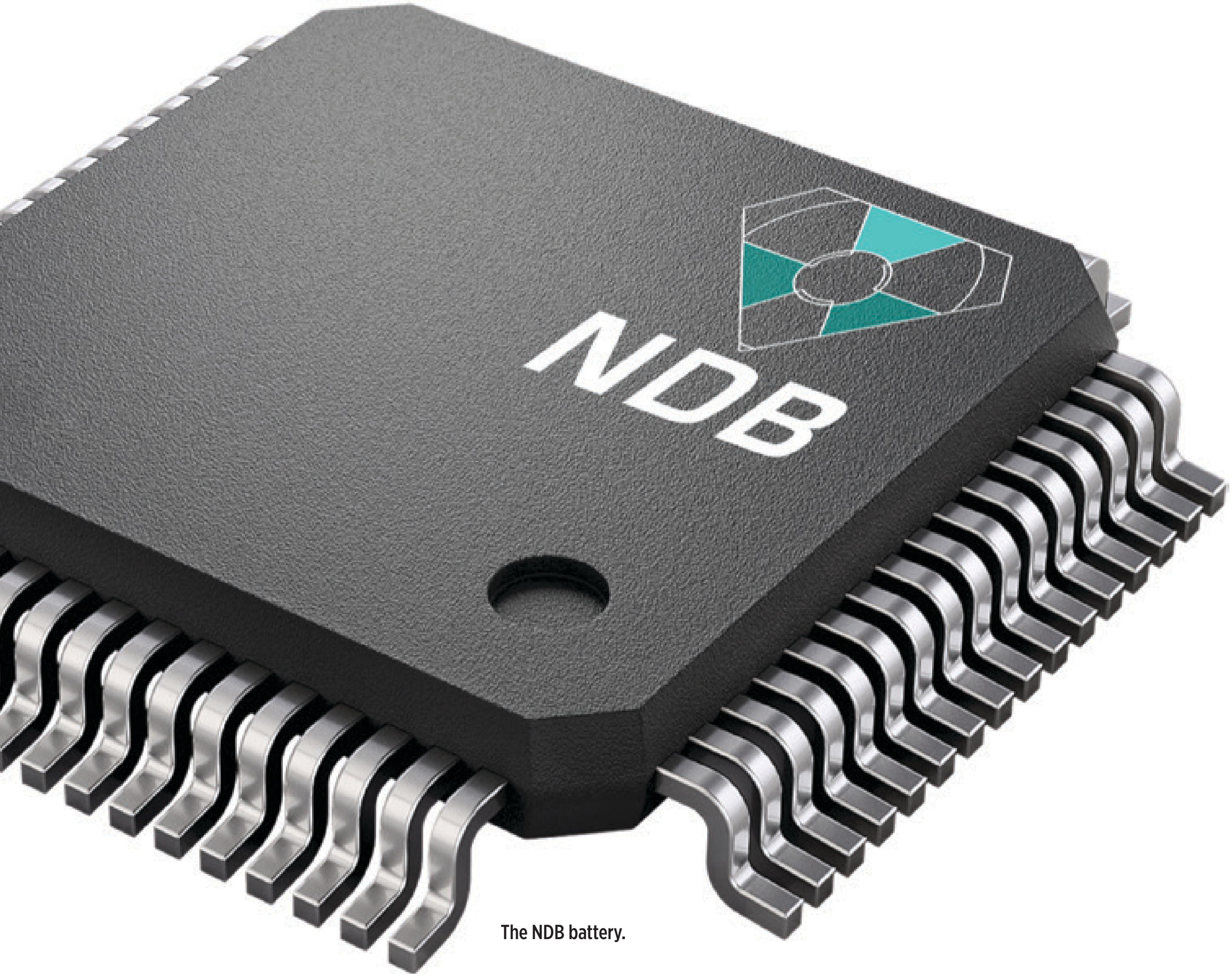
Since the battery is self-charging and requires only exposure to natural air, any excess charge can be stored in capacitors, supercapacitors, and secondary cells to extend battery life for cellphones, aircraft, rockets, electric vehicles, sensors, and other devices and machinery.

System Technologies

Diamond Nuclear Voltaic (DNV) technology — As a device, DNV is a combination of a semiconductor, metal, and ceramic that has two contact surfaces to facilitate charge collection. Several single units are connected together via conductive channels that are fabricated by deposition of Ni on the side of the DNV to create a +ve and -ve contact of the battery system, which is called DNV stacks. In between these are radioisotopes that, upon decay, will release either an alpha, beta, or neutron radiation. This is then inelastically scattered in the single crystalline diamond (SCD) to generate charges that are collected by the charge collectors.

Every layer of the DNV stack consists of a high-energy output source. This kind of arrangement improves the overall efficiency of the system and provides a multilayer safety shield for the product.

NDB



The NDB battery.

Rapid conversion from radiation to electricity — All radioisotopes are known to produce high amounts of heat. The strategic placement of the source between the DNV units facilitates inelastic scattering originated due to the presence of SCD in the DNV unit. This design prevents self-absorption of heat by the radioisotope and enables rapid conversion to usable electricity.

Thin film structure — The thin-film profile exhibited by NDB allows radiation absorption in the SCD with minimal self-adsorption. Due to its flexible design structure, this technology can take any shape and form in accordance with the application. NDB can be made as big as the application requires, where the minimum size limit is 40 µm.

Nuclear recycle process — Radioactive waste is reprocessed and recycled to enable sustainability and promote a clean energy source in a safe and secure environment.

Safety Features

Key innovations of NDB are sophisticated safety features covering thermal, mechanical, and radiation safety.

Diamond encapsulator — Radiation safety is achieved through the encapsulation of the DNV using a diamond encapsulator that contains the radiation within the device. The DNV stacks, along with the source, are coated with a layer of polycrystalline diamond, which is known for being the most thermally conductive material and has the ability to contain the radiation within the device. It is also 12 times tougher than stainless steel, making the battery tough and tamperproof.

The nanolayers are made of chromium and lead in a "hole and cap" structure that captures radiation from the DNV. The hole acts as a thermal conduction channel that conducts heat to the outer portion of the encapsulator. While the cap captures the radiation that comes out of the hole built into the diamond encapsulator component of NDB, it can absorb and contain secondary radiation as well as the primary radiation close to background radiation levels.

Built-in thermal vents — The high energy source present in the battery system produces heat during operation. This leads to thermal conduction in the system. Thermal vents in the system help conduct this process with respect to the outer surface of the diamond to keep the interiors at an optimum level.

Boron-doped SCD — To utilize every aspect in the system, NDB — in addition to alpha and beta — also incorporates

Nano Diamond Battery
Provides Universal Applicability

Rather than using conventional EV batteries, NDB could be used during the day to power the car; at night when the car is parked, the NDB-powered EV could be plugged into a house where the generated charge could then power the house and any excess could be sold to the grid.

The aircraft black box sends out a signal periodically to broadcast its location; however, the availability of the signal is based on the battery that powers it. Currently, limitation in the battery charge of the black box restricts the search time since the location signal will become unavailable once the battery charge runs out. NDB will be able to increase the battery life of the black box, allowing the search party a greater chance of salvage.

the use of neutron radiation with boron-10 doping. Doping helps to convert the extra neutron into alpha ray.

Lock-in system — Using a nuclear power source for a battery system brings up the question of nuclear proliferation due to production of fissionable isotopes such as Pu-238 and U-232. To tackle this issue, NDB uses an ion implantation mechanism, called a “lock-in system,” that prevents usage other than power generation. This increases usability by meeting consumer safety requirements.

Applications

Automotive — Electric vehicles have been heavily promoted by various governments and as such, it is one of the fastest-growing fields in recent years. Naturally, its key component — the battery that propels the vehicle — has also been heavily developed. As a battery solution, NDB powers the traditional aspects of the car as well as the motors. What is perhaps the most interesting is that innovations such as heads-up displays, augmented reality, self-driving, and onboard AI could also be supported using the NDB.

NDB could be used during the day to power the car; at night when the car is parked, the NDB-powered EV could be plugged into a house where the generated charge could then power the house and any excess could be sold to the grid. This effectively means that the national grid is crowd-sourcing electricity, alleviating the increased electricity demand that comes with the increased adoption rate of EVs.

Aerospace — The aviation market is vast and many of the technological advancements come from the digital revolution. Some examples of NDB’s use include securing essential power to areas such as the cockpit to improve airline safety and powering of the black box to aid in salvage of missing aircraft. The black box sends out a signal periodically to broadcast its location; however, the availability of the signal is based on the battery that powers it. Currently, limitation in the battery charge of the black box restricts the search time since the location signal will become unavailable once the battery charge runs out. NDB will be able to increase the battery life of the black box, allowing the search party a greater chance of salvage.

Recent advances in space technology and the rise of electric aircraft have led to increasing demand on their battery systems, hindered by concerns regarding longevity and safety. Satellites and space vehicles rely heavily on solar power, which can be disrupted by harsh space environments. NDB can be utilized to power drones, electric aircraft, satellites, space rovers, spacesuits, and stations while allowing for longer activity.

Medical Technology — In-situ medical devices and implantables such as hearing aids and pacemakers can benefit from long battery life in a smaller package with the added benefit of safety. With NDB, patients no longer have to worry about recharging a pacemaker due to its long half-life. Since NDB has a layer of native radiation absorber integrated into its structure, it prevents radiation leak from implantable devices.

Industrial — NDB's safety, power output, and universality provide power to many routine applications and to those that are difficult to implement. Data centers, remote locations, and hostile environment applications of NDB make it an outstanding promise for productivity and futuristic applications.

One shortfall of the Internet of Things (IoT) is in the physical devices themselves. Since each function (such as lighting) will need sensors and Wi-Fi connectivity receivers, they inevitably will need electricity. Traditionally, this has been satisfied by the use of batteries and direct electrical wiring but in either case, there are limitations — batteries will run flat and wires require an electrician to set up, which could be inconvenient. If an NDB was used, the IoT devices would be fully wireless and could be placed anywhere without the need to worry about the battery depleting.

Conclusion

NDB is green as it has no emission, it is inert to the environment, and does not require cobalt mining. NDB is a more energy-dense, longer-lasting, weather-independent alternative to traditional energy sources. The added values are lack of harmful byproducts and recycling of nuclear waste.

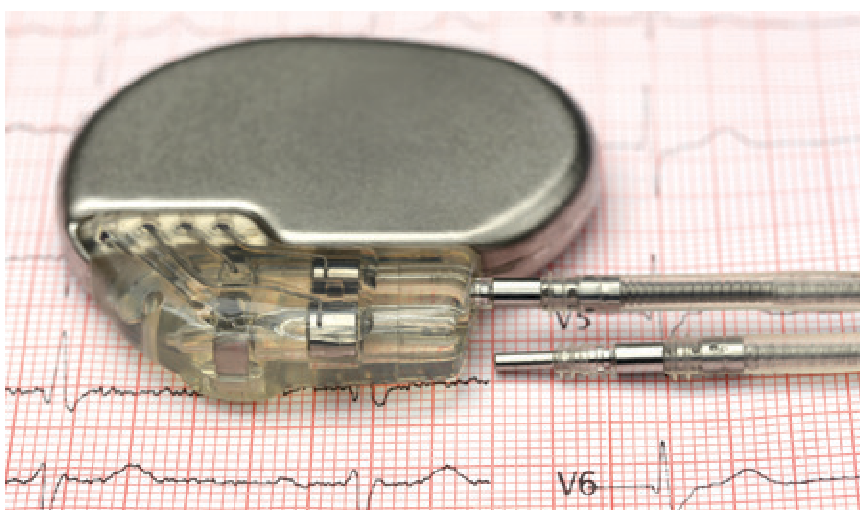
The technology has the potential to replace other energy sources such as gasoline and lithium-ion batteries, reducing their negative environmental impacts caused by emission and toxic metal waste products.

Another trend is the shortage of cobalt, a crucial component of Li-ion batteries. Since the NDB does not contain cobalt, it is a solution that is not affected by the supply shortage of its raw material.

Finally, one of the most important recent trends is the sudden increase in demand for electric vehicles. Governments around the world are working towards shifting the fossil fuel-powered vehicle to electric vehicles — a market that is a natural fit for NDBs.

This article was contributed by Dr. Nima Golsharifi, Chief Executive Officer of NDB (San Francisco, CA). For more information, visit ***http://info.hotims.com/79410-222****.* ■

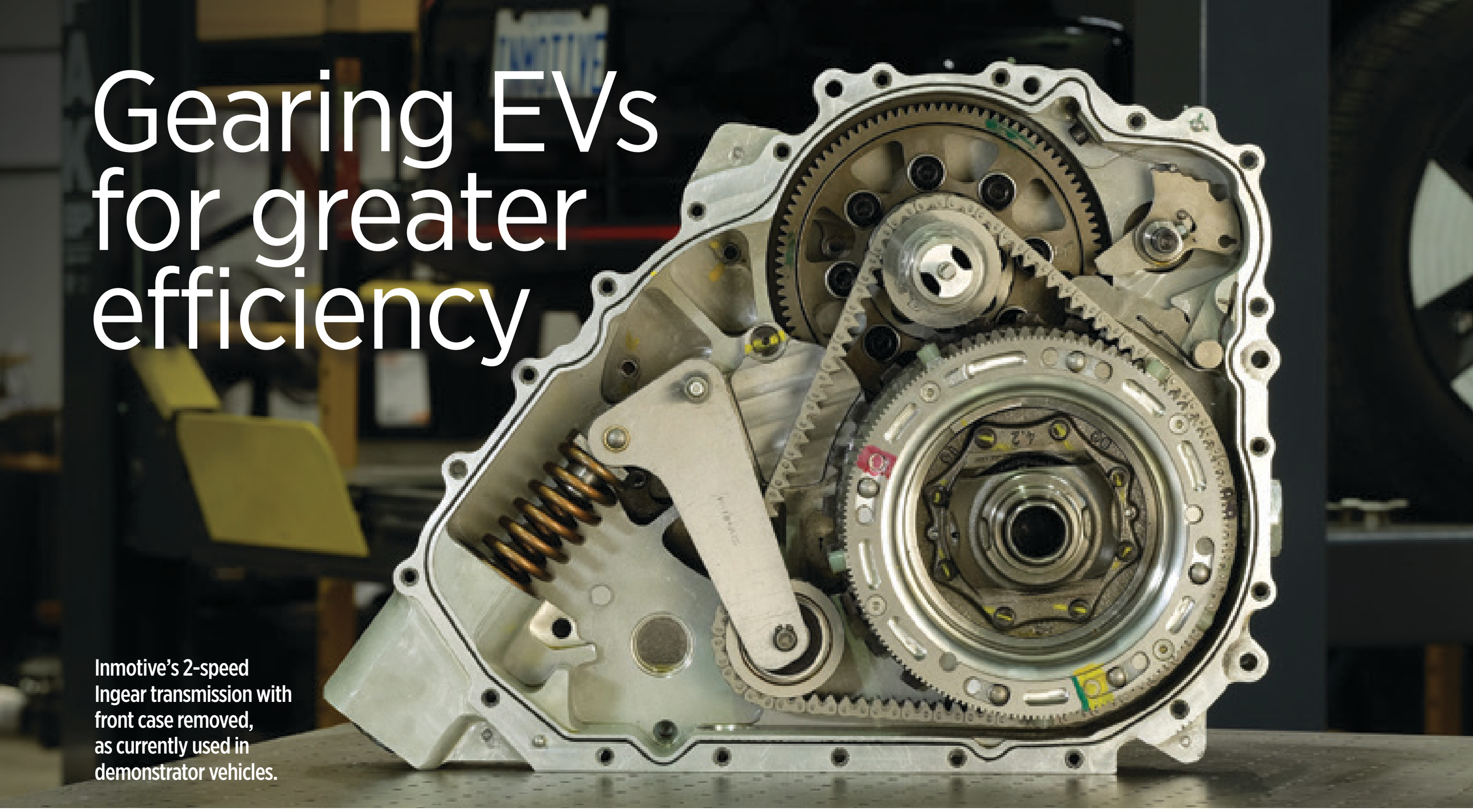
The International Space Station and astronauts' spacesuits could both be powered by NDB.



Implantables, such as pacemakers, can benefit from long battery life in a smaller package with the added benefit of safety. With NDB, patients no longer have to worry about recharging a pacemaker due to its long half-life. Since NDB has a layer of native radiation absorber integrated into its structure, it prevents radiation leak from implantable devices.

TOP: NASA

Gearing EVs for greater efficiency



Inmotive's 2-speed Ingear transmission with front case removed, as currently used in demonstrator vehicles.

Ingear, an innovative 2-speed transmission born in Canada, aims to unlock electric-vehicle performance and efficiency.

by Lindsay Brooke

A long-touted benefit of electric vehicles (EVs) has been the utter simplicity of their drivetrains. With just a pair of reduction gears between the traction motor and final drive, single-speed gearing helps to minimize the bill of material (BoM) and driveline-system cost while delivering acceptable performance.

But the more demanding duty cycles of commercial EVs, off-road equipment, and high-performance passenger EVs are prompting development of multi-speed solutions. Tesla got there first, albeit unsuccessfully, in 2007. While still a start-up staffed mainly by electronics engineers, Tesla developed its own 2-speed gearset for use in its Roadster sports car. Perhaps not surprisingly, catastrophic failures of early production units led Elon Musk to reluctantly commission a clean-sheet, single-speed unit engineered by BorgWarner.

Since then, 2-speed EVs have trickled into low-volume production at Porsche and exoticar maker Rimac. BMW used a 2-speed transmission on its hybrid I8 and ZF has prototyped a compact 2-speed unit. Enter Inmotive, a Toronto, Canada-based supplier founded in 2010 with a novel twist to the 2-speed (and potentially 3-speed) solution.

"We've been hearing from OEMs around the globe, with growing demand for a 2-speed EV solution that provides enhanced range, improved performance characteristics, and the opportunity to reduce cost by downsizing the batteries and motors," said Paul Bottero, Inmotive's CEO. His company's product, known as Ingear, currently is under evaluation by passenger- and commercial-vehicle makers. Conceptually influenced by the classic derailleur-type bicycle drivetrain, Ingear uses off-the-shelf automotive technology and standard materials and processes to keep per-unit costs less than $150. Features include a BorgWarner Morse inverted-tooth Hy-Vo silent chain, powder-metal components and splash lubrication rather than a pressurized pump.

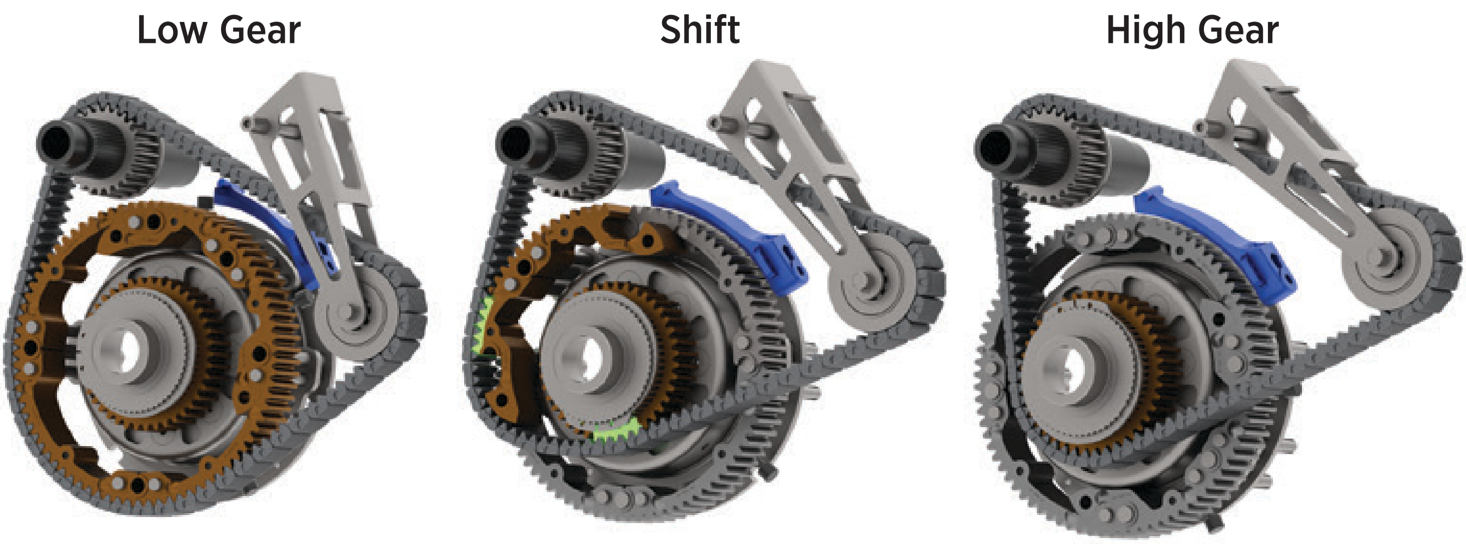
CAE analyses and prototype testing have shown the Ingear 2-speed gearbox, in combination with some electric-motor optimization, is capable of system efficiency gains of 7% to 12% compared to single-speed types. Acceleration, gradeability, and towing are improved by up to 15%, according to Inmotive CTO Tony Wong. Inmotive has retrofitted a Kia Soul EV with Ingear for industry demonstrations.

Right-Sizing the E-Machine

The idea for Ingear came to Wong, an avid cyclist, during a commute ten years ago. "I was thinking about the torque-transfer inefficiencies of a bike transmission — the derailleur shoving the chain side to side, often with a slight misalignment of the chain," he explained. "So, I thought, what if instead of moving the chain, we instead moved the sprocket underneath it? There is empty space between the sprockets; what if we cut the sprockets into 'pie slices' and devised a method of maintaining chain engagement with the sprocket teeth throughout the shift?"

Wong presented his invention to Bottero, a tech-industry veteran, and the two began a patent search. Among Ingear's "special sauces" are what they call the "key segments" — the sprocket component (now patented) that controls chain-to-sprocket alignment.

ALL IMAGES: INMOTIVE



The Ingear low-to-high gear shift process showing 'key segments' sliding out from large sprocket ring, Morse Hy-Vo silent chain, and idler mechanism.

"Obviously, a bike derailleur would never work in a car; it would grind itself to pieces very quickly," Wong noted. "It's the key segments that enable us to maintain, as the chain folks say, the 'synchronicity' of the chain with the sprocket teeth even during a gearshift. These components are really what make the Ingear practical at automotive speeds under automotive torque loads." Also patented was a concept called the 'sequencer,' which ensures the key segments always move first during a gearchange.

To commercialize the Ingear technology, Bottero, Wong, and another colleague founded Inmotive in 2010. "We spent the first five years working on industrial applications — equipment like crushers, conveyors, and HVAC fans for buildings," Bottero noted. "These applications proved our core concepts and technology work. The 2-speed gearing comes into place under peak loads and allows you to right-size the electric motors."

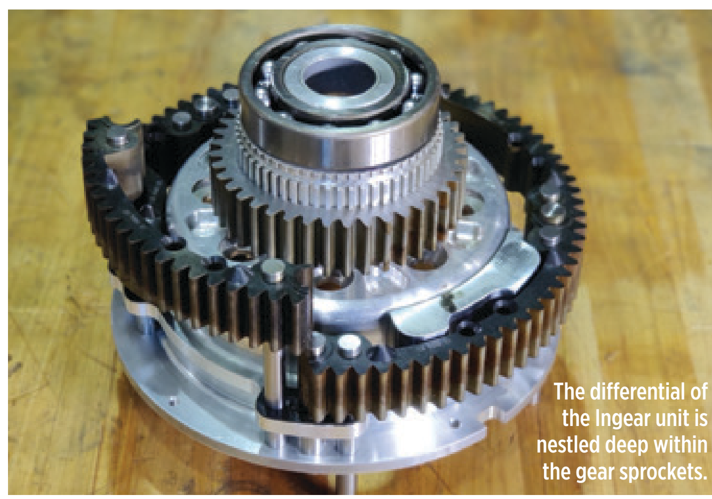
The next steps, in 2015, aimed at making Ingear more robust and durable for automotive. Transitioning from toothed-belt drive in early iterations to the Hy-Vo chain — used in the Chevrolet Volt and countless 4wd transfer cases — enabled much higher torque density "with supreme durability and efficiency," Wong said.

Added Bottero: "The market was ready for us; we always thought the best fit for us was EVs."

Sprocket Dynamics

On a typical EV with two helical-cut reduction gears, the electric machine's output shaft turns about nine times for each revolution of the wheels. The Ingear replaces the second reduction gear with the Hy-Vo chain drive and a "morphing" sprocket.

To execute a Low-High or High-Low shift, an actuator directs the five interlocking sprocket segments into place during one revolution of the wheels (about 30 milliseconds). This changes the size of the sprocket, effectively increasing or decreasing the gear ratio. The segments slide on hardened-steel pins similar to those used in injection molding equipment, Wong said. When the segments are rigidly locked, they operate exactly like a conventional one-piece sprocket. The system's patented geometry keeps motor and wheel speeds in sync.

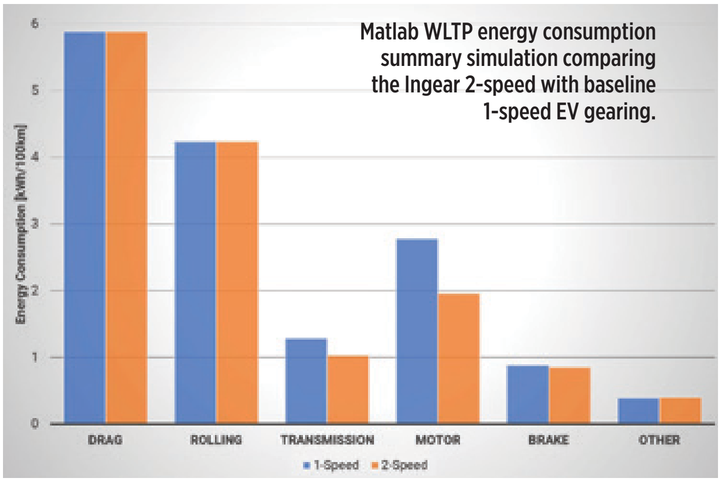


The differential of the Ingear unit is nestled deep within the gear sprockets.

A moving idler (similar in function to a derailleur idler) is used to take up chain slack as the high- and low-gear sprockets meld. "We set the geometries so that the 'wrap angles' of the chain are appropriate in both low and high gear," Wong said. "It took some time to work out the chain path but we've got it down pat." He said Ingear can transmit continuous torque during the low-to-high gearshift.

"The motor speed comes down very quickly, resulting in a smooth shift that the passenger doesn't feel," Bottero explained. Wong's team has developed torque-fill algorithms to further minimize any perception of gearchange to the vehicle occupants. In the process, less energy wasted equals more EV range per battery charge. Braking regeneration can be continuous even while downshifting, Inmotive claims. Enabling the electric

Gearing EVs for greater efficiency



Matlab WLTP energy consumption summary simulation comparing the Ingear 2-speed with baseline 1-speed EV gearing.


Inmotive CTO Tony Wong's conception of the Ingear transmission was based on the classic bicycle derailleur.


Inmotive CEO Paul Bottero notes growing demand from EV makers for 2-speed gearing solutions.

motor to operate more efficiently allows more of the battery's power to move the car rather than be wasted as heat.

"OEMs making delivery trucks are talking to us about 2-speed transmissions," Bottero said. "Such vehicles have to be very efficient; they can't have an oversized motor that will cost them range. With a 1-speed transmission, loaded, they'll have difficulty getting up the largest hills. These vehicles also are built to a price point — the return on investment for the end customer is substantial. We can help make a vehicle that will handle a measurably higher grade; the analyses we've done with truck and bus manufacturers show that with 2-speeds and optimized motors, we can definitely improve gradeability. Get up that 17-percent grade at a reasonable speed by having that low-gear ratio."

New transmissions prompt questions about ratio spread. Porsche's planetary 2-speed in the Taycan EV uses a short 15.5:1 low gear to provide maximum acceleration and a long-ratio 8.05:1 high gear for top speed and highway efficiency. Bottero and Wong said the Ingear architecture is scalable to cover broad applications.

"We've found that an approximately 2:1 ratio really opens up the capabilities of an electric motor," Wong said. "For larger trucks and off-highway vehicles, really large spreads are going to be necessary — and probably more speeds overall. We can accommodate that. But for passenger cars and sports cars, a 2:1 ratio means that when you're running on the highway, your motor can spin at half speed. That's a huge improvement. We're finding that OEMs are happy with that proposal."

Three Speeds the Charm?

As SAE's *Automotive Engineering* has reported, the trend in e-motors is to higher shaft speeds — beyond 20,000 rpm in some new designs. According to Wong, such high-speed machines will actually perform more efficiently at lower speeds, in conjunction with the Ingear 2-speed.

"All the OEMs we talk with seem quite aware of the challenges their motor designers face with the higher rpms," he noted. "The centripetal forces at 16,000 rpm and above are significant. You start compromising air gaps. You need really good bearings. Even the rotor structure will have to be magnetically compromised, so it can be mechanically strong enough to withstand the huge centripetal forces. Field weakening only partly reduces the eddy current losses, which create drag and a lot of heat in motors at high speeds," Wong said. "We can get a lot more out of motors by not having to spin them to such high speeds."

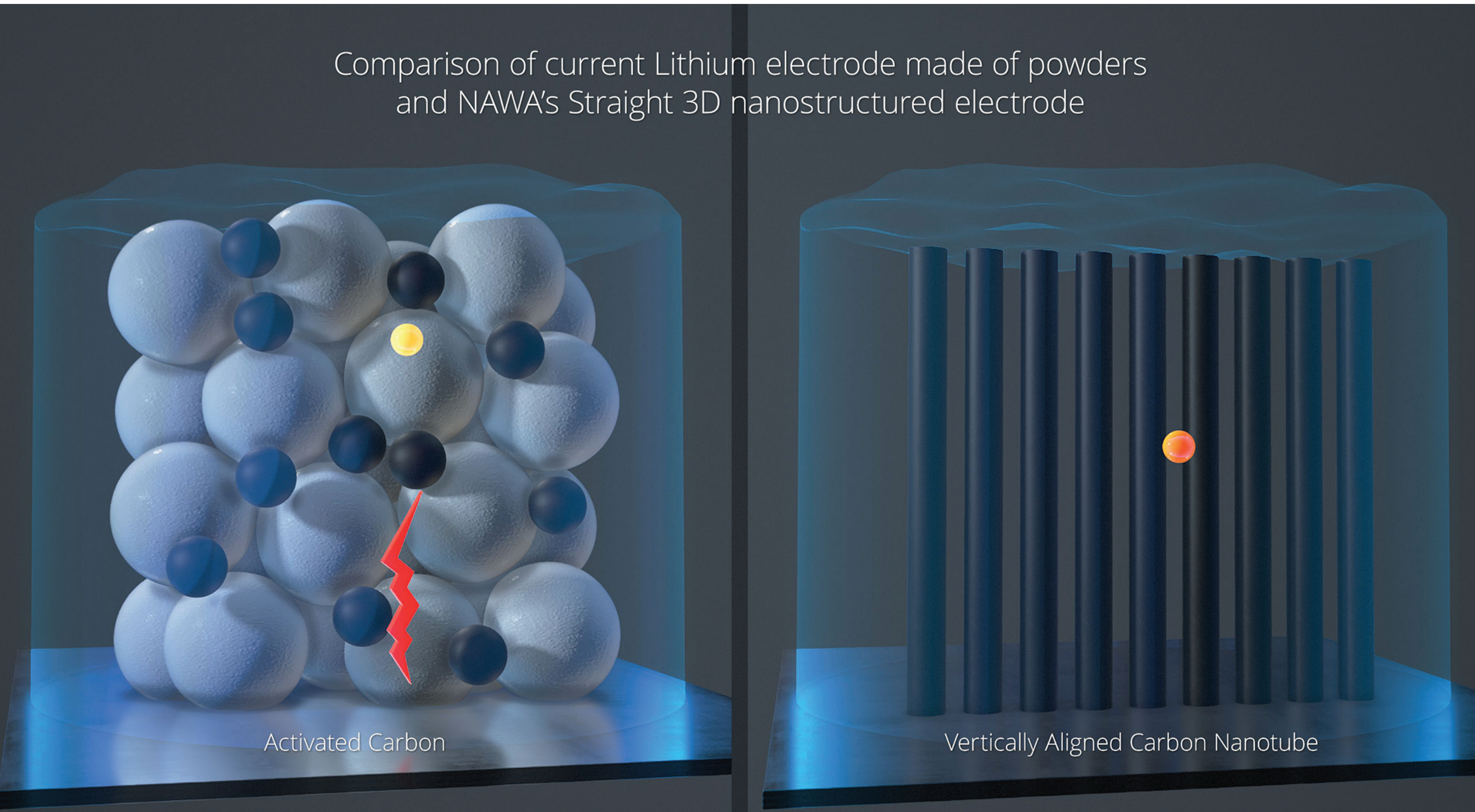
Using the 2-speed gearing helps keep the electric machine in or as close to its optimum-efficiency "island" at all times.

"The motor has to be sized to dissipate the heat created in its low-rpm, thermally dangerous operating range,and get it up into its high-efficiency 'sweet spot,' where we can shift and keep it in that zone. The 2-speed gets the motor off the line and spinning faster, which prevents overheating," Wong explained.

If two speeds are good for EVs, can three be better? Inmotive's analyses show that three ratios in light vehicles may provide "another percent" efficiency, according to Wong. And with a fourth ratio, "the return on investment is negligible. That's why two speeds really offer a lot of bang for the buck." Regarding that "bang," Bottero claims that for Ingear's $150-per-vehicle cost, at high volume, OEMs can save more than $1,500 per passenger vehicle by right-sizing batteries, motors, and inverters. He is optimistic for Ingear to enter production by late 2023. ■

ALL IMAGES: INMOTIVE

NAWA aims for 5-minute EV charge



NAWA regards its nanostructured electrode as heralding an EV battery step change.

NAWA

A new nano-based carbon electrode is key to reducing electric-vehicle charging time.

by Stuart Birch

A French nanomaterials company has developed a technology that it claims can significantly increase the storage efficiency of electric vehicle batteries. NAWA Technologies' Ultra-Fast Carbon Electrode (UFCE) is a key to bringing EV battery charging time into parity with gasoline refueling time, while improving battery lifecycle performance by a factor of up to five, according to company founder and CTO, Pascal Boulanger.

In an interview with SAE's *Automotive Engineering*, Pascal Boulanger said the UFCE technology can help deliver 1,000-km (620-mi) operating range for mass-market EVs, with a time of five minutes for an 80% charge. "The uniqueness of the technology is its 3D structure and use of vertically aligned carbon nanotubes [VACNT]," he noted. Each nanotube is formed from a graphene sheet that is rolled in a cylindrical shape. The tubes have "the same aspect ratio [between diameter and length] as a kilometer-long piece of spaghetti, with the electrode being made of a hundred trillion of these tubes!" The UFCE technology is compatible with any advanced battery cell chemistry, he said.

"Highest" Ionic Conductivity

A major limitation of incumbent lithium-based battery performance is the design and material used for the electrode, Boulanger explained. Existing powder electrodes have low electrical and thermal conductivity, along with poor mechanical behavior when discharged and recharged and can suffer from safety and lifecycle issues. He said the microstructures in today's electrode material make it difficult for ions to move around, resulting in low ionic conductivity. The UFCE's patented VACNT design, he claims, combines the "highest" ionic conductivity, thanks to its 3D fully accessible nanostructure, with continuous conductors (the nanotubes) that exhibit optimum electrical and thermal conductivity. These characteristics eliminate thermal runaway issues, Boulanger said.

Mechanically, the VACNT serves as a cage, reducing volume expansion of the electrode and allowing it to operate under less "stress" than powder electrodes. "Put simply, this means the distance an ion needs to move is just a few nanometers through the cell material, instead of micrometers with a plain electrode." This "radically" boosts the battery's ability to deliver fast charge and discharge rates, he said. NAWA previously demonstrated this in its next-generation ultracapacitors (known as the


NAWA Technologies' founder Pascal Boulanger is confident that the company's advances will bring cost-effective solutions to significantly boost EV practicality.

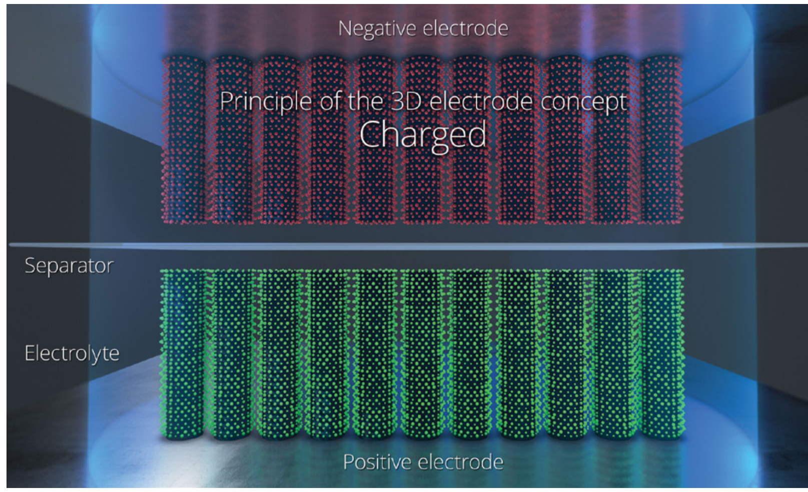


Diagram of the 3D vertical technology for EV batteries.

Ultra-Fast Carbon Battery), claimed to have "the lowest electrical serial resistance on the market."

Applying NAWA's technologies to lithium-based cells would improve battery power by a factor of 10 and energy storage by a factor of up to three, Boulanger stated, with battery lifecycle enhanced by up to five — and charging time reduced to minutes instead of hours.

"Normally, for a given technology — and that's the case for batteries using powders — you have to find a compromise," he noted. "And if you increase energy, you will decrease power; if you accelerate [the vehicle], you will consume more. But there is something else in a battery that is absolutely underestimated."

EV owners have learned that the more you drive, the faster you discharge the battery. Unlike a tank of gasoline, EV energy consumption is not linear. "This will also be the case for our technology; however, at a higher level of both power and energy, meaning that you will have more margin and the 'over consumption' will be lower, whatever the state of charge," Boulanger said. Initial results with NAWA's development partners, including battery giant SAFT, show that an advanced lithium-ion battery with a UFCE minimally doubles the kW-h stored. "EVs could draw on more power to go faster but farther at the same time," he said.

Carbon Nanomaterial Synergies

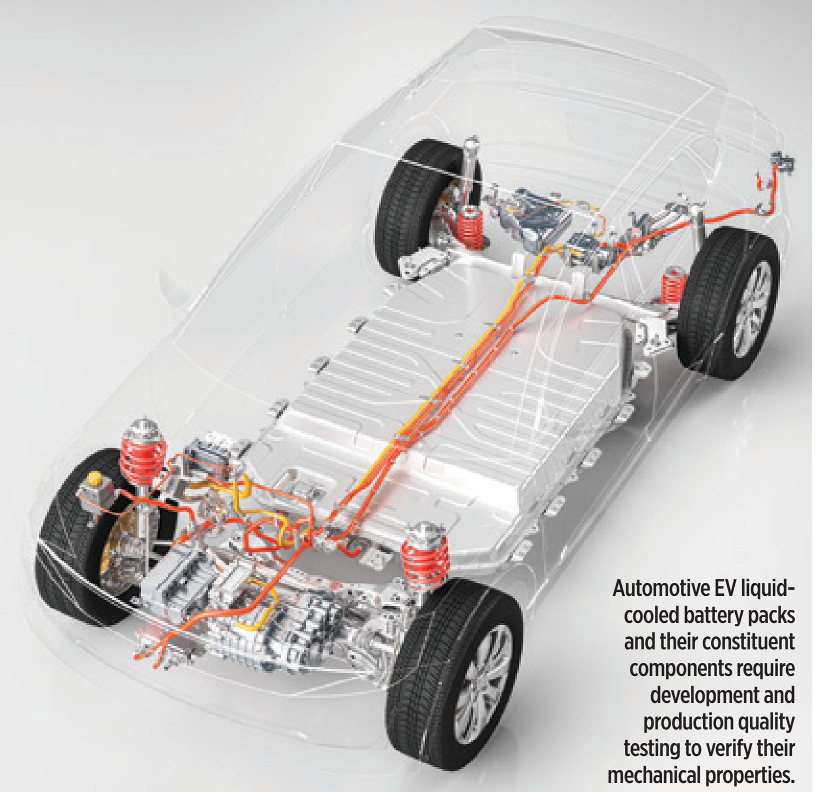
The 3D electrode is designed for manufacturability, he said. The VACNT manufacturing process is "very similar" to the production of photovoltaics or industrial glass treatment. Boulanger claimed that nanotubes are "not expensive" to produce: the equipment is proven and processes are greatly improving both in throughput and yield, keeping costs low. "We envision it can be similar in terms of dollars-per-square-meter to a coating but with a lower bill-of-materials coming from the natural and sustainable carbon sources. We will have more energy per square meter; the cost of that energy will be lower in terms of dollars-per-watt-hour, too," Boulanger said.

In moving toward commercialization, Boulanger is aware of the hurdles. "There are various ways of introducing our concept of 3D electrode to the market," he said. The easiest way is to grow a very thin layer of VACNT on a copper substrate to compete with existing carbon-coated copper substrates already in use in the battery industry. This method will yield electrical performance and anchoring of the electrode material that is superior to the incumbents and can be ready in small volume production in 2021, he said. Longer term, a real 3D and thicker UFCE "could be on the market in low volumes by early 2023 in 3D electrode form, reaching mass production in 2025."

Potential applications of NAWA's UFCE technology extend into hydrogen fuel cell systems. One uses NAWACap ultracapacitors to harvest energy that would otherwise be lost. The UFCE also can serve as an electrode for the fuel cell membrane "because VACNT are known to be able to reduce the loading of platinum," thus saving cost, Boulanger said. And materials developments by another NAWA Group unit can reduce the weight and improve the strength of the hydrogen carbon-composite storage tank. NAWA America, based in Dayton, Ohio, focuses on the commercialization of multifunctional, ultrastrong composites. Its NAWAStitch concept comprises a thin film containing the same trillions of VACNT arranged perpendicularly to carbon fiber layers. Acting as "nano-Velcro," this reinforces the weakest part of a composite — the interface between the layers — designed to greatly improve resistance to shear and shock loading, stated Boulanger.

The 3D-UFCE and NAWAStitch are complementary to another innovation: NAWAShell. A structural hybrid battery incorporating VACNT, it provides both enhanced mechanical strength and electrical energy storage within the core of the composite structure. In the future, Boulanger sees "enormous potential in combining NAWAStitch and NAWAShell to create ultrastrong, multifunctional, lightweight materials that can also store energy; for example, a solar roof panel in a car that could generate energy stored within the roof, with almost no additional mass to the vehicle structure." ■

BOTH IMAGES: NAWA



Automotive EV liquid-cooled battery packs and their constituent components require development and production quality testing to verify their mechanical properties.

STATIC TESTING of EV Components

Firing nails into your latest Li-ion battery pack is but one of many regimens in the comprehensive testing of new electric vehicles.

by Dan Caesar

The market for electric vehicles (EVs) continues to grow. To offset the immense weight of their batteries, a heightened focus has been put on lightweighting, which has brought many new materials and components into the global automotive supply chain. These components and assemblies, including polymer films used for Li-ion battery cell separators and the packs they ultimately form, require development and production quality testing to verify their mechanical properties.

One of the methodologies — static mechanical testing — is commonly performed by universal testing machines operated within manufacturing and research labs. Put simply, universal testing machines are designed to hold a test specimen and subject it to tensile (pull) or compression (push) forces by moving the machine's crosshead up or down. Transducers, such as a load cell, capture valuable data that allows labs to analyze the physical properties of the test specimen for quality checks or exploratory work.

EV-Specific Lightweighting

Within the automotive supply chain, raw material providers have long been under pressure to reduce the weight of their products while maintaining acceptable strength-to-formability properties. The substantial mass of liquid-cooled Li-ion battery packs reinforces the need to lightweight EVs to achieve an acceptable driving range for consumers.

Additional safety considerations are at play when hundreds of pounds of batteries are fastened to a vehicle. Accidents have the potential to damage the battery pack, triggering a hazardous thermal runaway. To mitigate these dangerous events, OEMs must ensure the structural integrity surrounding battery modules while minimizing weight. This has created a demand for stronger metals while maintaining formability. Plastic strain ratio (r-value) and the strain hardening exponent (n-value) are critical mechanical properties that define the formability of these products.

During a static tensile test, these formability properties can be determined if the test system is equipped with the appropriate transducers. For compliance and data integrity, labs adhere to the test procedures outlined in ASTM E517 (r-value) and E646 (n-value) or other standard bodies' equivalent test standards. To determine n-value, axial strain needs to be measured after yield and determined at or between strain values. To determine r-value, the material's transverse strain must also be measured. To accurately measure axial and transverse strain, a device referred to as an extensometer is used. Traditionally, two extensometers would be required, one for axial strain and the other for transverse. However, new technology has been developed by test system manufacturers that allow for simultaneous, dual-axis strain measurement.

Separator Film Testing

The membrane between a battery's anode and cathode is referred to as the separator. These films must be capable of withstanding harsh conditions all the way from manufacturing processes to extreme climates. A critical part of Li-ion or other liquid electrolyte batteries, separators are films typically made of polymers. They must be mechanically strong enough to withstand the winding operation during the battery's assembly. The critical mechanical properties that suppliers must control are tensile strength, elongation, and puncture resistance.

ASTM D882 outlines the tensile testing of thin plastic film, which is suitable for polymer separators. Film sheeting is prepared into 1-inch-wide strips and pulled in tension to failure with a static universal test frame. Tensile strength and elongation results can be evaluated to ensure necessary specifications are met. Regarding puncture tests, ASTM F1306 outlines the puncture testing of flexible barrier films to characterize the material response when a probe 3.2 mm (0.126 in.) in diameter is driven into a clamped specimen.

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STATIC TESTING of EV Components

Accurate measurement of axial and transverse strain requires either two extensometers or a single, dual-axis extensometer (shown).

Testing Nail Penetration

A nail penetration test of an assembled, charged battery cell, module, or pack is another form of puncture testing that battery and automotive manufacturers regularly perform to assess EV battery safety. High-energy thermal runaway is a danger of an internal short circuit of Li-ion batteries. Puncture events are a known cause of internal shorts and therefore must be evaluated for consumer safety. As nail penetration tests are not well defined in international standards, identifying the equipment and procedure necessary can be a challenge.

SAE International has provided guidance to the industry with its J2464 standard, Electric and Hybrid *Electric Vehicle Rechargeable Energy Storage System (RESS) Safety and Abuse Testing*[1]. SAE J2464 has a section that defines a battery penetration test and fundamental parameters such as rod (nail) diameter, rate of penetration, and depth of penetration. Another well-established standard is GB/T 31467.3 (Chinese national standard), *Lithium-ion traction battery pack and system for electric vehicles—Part 3: Safety requirements and test methods*[2].

Various laboratory equipment providers have developed single-purpose systems to perform nail penetration and crush testing of batteries. Fully enclosed, fire-resistant, and ventilated for safe operation, the systems are configured with temperature and voltage sensors. Similar systems have been developed by universal test machine manufacturers but given the extreme hazards, the integration of a third-party test chamber has filled this competency gap.

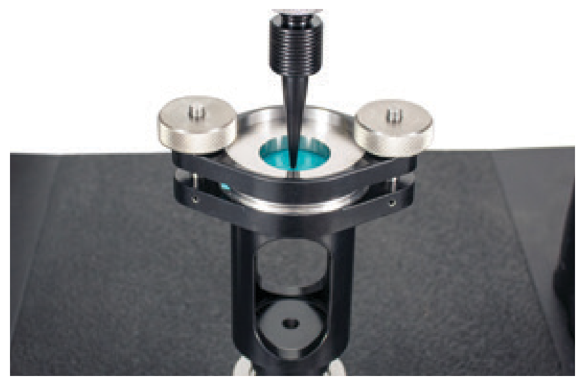
Component Testing and Cost

EVs introduce new components into the automotive industry that require mechanical testing for both development and quality-control environments. Battery packs consist of thousands of interconnected battery cells, resulting in thousands of potential failure locations. Each assembly's quality is a critical concern for OEMs. Testing components can be challenging to fixture into a universal test machine and depending on the number of components, it can be a frustratingly inefficient process.

Static universal testers offer automated and semi-automated testing solutions to improve throughput by removing the operator and the need to repeatedly reposition and fix specimens to jigs. Freed up from constant specimen preparation, operators can focus on more value-added activities.

Vehicle OEMs are challenged to generate sustainable profitability with EVs, given their still-significant cost (mainly from the battery) deltas versus combustion-engine vehicles. Testing is one area that offers meaningful cost-reduction opportunities. Quality labs and R&D centers are now implementing more efficient processes toward that goal, with the help of automated universal test machines. ■

An example of a static universal testing machine is the Instron 68SC-1 shown.



ASTM F1306 outlines the puncture testing of flexible barrier films to characterize the material response when a 3.2-mm-diameter (0.126-in.) probe is driven into a clamped specimen (shown in blue).

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[1] https://www.sae.org/standards/content/j2464_200911/

[2] https://www.codeofchina.com/standard/GBT31467.3-2015XG1-2017.html

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