# ELECTRIC VEHICLE WIRING DESIGN CHALLENGES

High-voltage wiring designs are a key element of electrified powertrains. As the performance of electromagnetic interference shields, and protective coverings influence both, safety and vehicle mass, these additional components are critical to the overall wiring performance. Federal-Mogul has developed new types of wiring coverings that reduce weight while improving safety and reliability and helping to address the current cost disadvantage of electro mobility.

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## MARKETING ASPECTS

Although full electric vehicles (EV) are gaining much-deserved publicity and consumer attention, the mass consumer acceptance level has been somewhat low due to a variety of real factors. Besides the well-documented battery and infrastructure limitations, there are additional realities of high vehicle cost, and limited driving range. Depending on the speed at which new battery technology has been adopted in some markets, the list of issues may also contain uncertain safety that has not been always addressed enough to convince the average consumer to switch to electric vehicle platforms.

These additional factors can be linked to vehicle mass, evolving regulatory requirements, and consumer education. Meanwhile, hybrid electric vehicle (HEV) powertrain technology continues to gain in popularity, and seems to be a viable bridge to a fully electric vehicle future. Since both EVs and HEVs employ similar high-voltage wiring designs, the lessons learned and applied to HEVs today are becoming the designs of the future with a prospect of growing production numbers. As such, it is very important for electrical design engineers to reduce wiring mass while improving cost, safety and reliability.

## GENERAL CHALLENGES IN HV WIRING

There are several critical components in an effective wire design, including the electrical conductor, insulation material, and connectors. Although sometimes handled as a design afterthought, wire covering components such as electromagnetic interference shields (EMI shields), bundling components, and protective coverings are equally critical. These additional components are essential to the wiring performance, and directly affect wiring cost (materials and installation cost), mass, and safety. Recent wire coverings advancements are enabling improved high-voltage wiring designs that are lighter weight, safer and less costly.

## IMPROVING WIRING SAFETY

Regulatory and industrial organisations have correctly recognised and addressed the real dangers associated with the high electrical loads carried by high-voltage wiring. In order to protect vehicle occupants, service technicians, and first responders, these wires are identified with vivid colours, and must meet stringent crash standards. For example, ISO 6469-3 and FMVSS 305 provide performance criteria that protect persons against electric shock.

The unwanted side effect of protecting the harness during vehicle crashes is typically a vehicle mass increase, since the protective solution is typically metal conduit or shielding. Drawing from the materials and construction of bulletproofing technology, new textile-based solutions have been created to address this challenge. The logic behind this technology transfer to automotive high-voltage harness protection is this: In both applications it is crucial to protect a sensitive structure against the sudden impact of a hard object that can have a high level of kinetic energy. To make matters worse, this energy can be focused on a small area. As the destructive power of kinetic energy is a product of the total mass of the impacting body and its velocity divided by the impacted surface area, the analogy between stopping a bullet and, for instance, a metal structure that hits a harness during a car crash, becomes obvious.

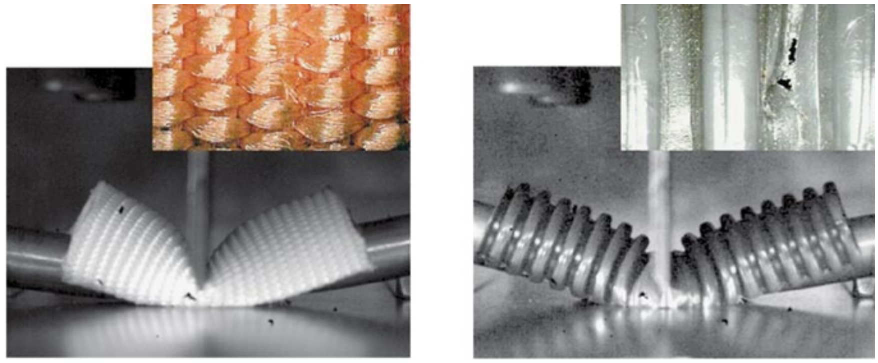
In fact, the analogy goes even deeper: While current harness protection is mostly based on rigid coverings that are designed to spread out the impact energy over a wider surface area, thus preventing cut-through damage, bulletproofing distinguishes between two types of impact absorbing mechanisms. The lighter version of the two relies on the material properties of very strong synthetic fibres. The high tenacity and E-modulus of polyester fibres in particular mean that they can endure a great deal of impact energy without tearing. This mechanism is well proven in certain applications where a bulletproof vest, e.g., has to be light enough to be comfortably worn.

One recent crash-protection covering by the name of CrushShield is a patent-pending dual-layer woven textile. It was designed to disperse the crash energy over an area, minimising the localised damaging effects of an impact, ❶. The high-tenacity polyester fibres effectively prevent cut-through from sharp edges. The lightweight textile design maintains a high degree of wire harness flexibility, which reduces assembly time and cost.

#### VALIDATING THE PERFORMANCE OF HARNESS PROTECTION

Among the many challenges facing the wiring design engineer, is the need to validate performance early in the design cycle. Certainly, a variety of test methods and specifications exist for this purpose, and are used to validate material fatigue, response to prolonged fluid exposures, and similar standard environmental concerns. However, novel solutions sometimes require special validation procedures, and one has been developed to simulate the crash protection capability on a benchtop. This comparative test uses a free falling mass having an edge similar to the damaging component. The mass and/or height of the mass is increased until the cable is sufficiently damaged, creating a baseline energy.

After protecting the cable with a covering, the test is re-run to measure how much additional energy can be absorbed before cable failure, ❷. In side-by-side crash testing, CrushShield has outperformed corrugated nylon tubing, and is able to increase the harness performance by absorbing more than three times the original crash force.

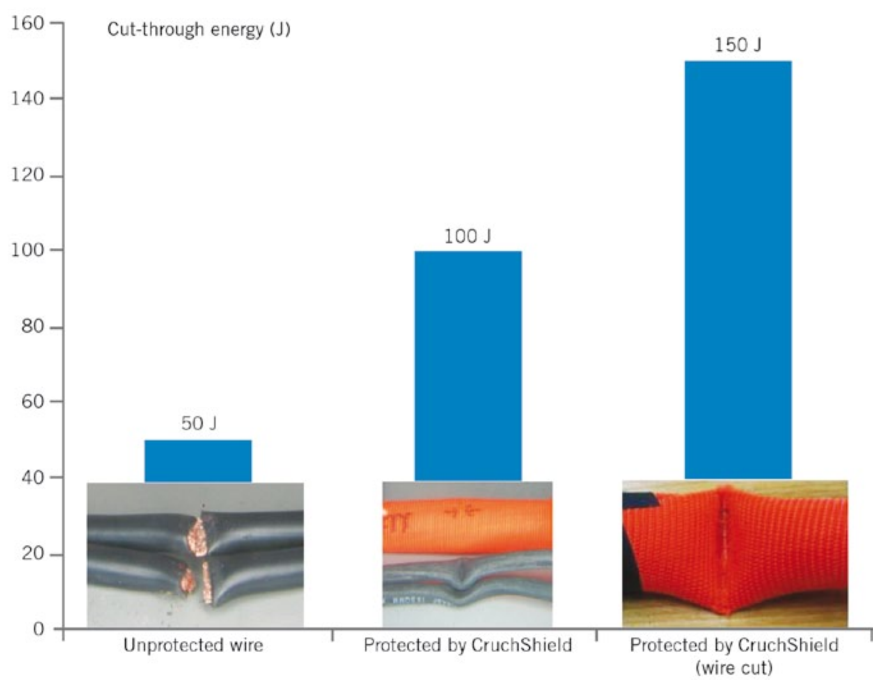


❶ Damage comparison of the CrushShield textile covering (left) versus a corrugated nylon tube (right) during and after the free-fall test

#### IMPROVING EMI RELIABILITY WITH THE COMPOSITE YARN

Safety is not the only concern for EV wiring harnesses. As vehicle electrification increases, so does the susceptibility and occurrence of radiated electromagnetic emissions, which can affect vehicle component performance. The effects of EMI range from annoying (distorted video diplays) to major loss of vehicle function. Major issues confronting the EMI market include ever-increasing frequencies, increasing cost pressures, and increased wireless technology. Although EMI interference can be a problem over a wide range of frequencies, the range from 10 kHz to 1 GHz is of greatest concern in automobiles, covering AM and FM radios, navigation systems, entertainment systems, and convenience features such as backup cameras.

A typical high-voltage wire is composed of shielded cable made from multiple layers: an inner core of conductive material




❷ Free-fall test results for the unprotected cable (left) as a baseline, and CrushShield (middle and right); on the right, the cable is damaged beneath the CrushShield, which remains intact and continuing to cover the high-voltage conductor

❸ Typical cable construction for a high voltage vehicle application

(copper or aluminium); a layer of insulation; a layer of braided metal wire; and an outer insulation material. In application, the outer layer is often covered by additional mechanical protection, ❸. Due to its metal content, the braided metal wire layer provides excellent EMI shielding at low frequencies (up to approximately 1 MHz), but the shielding performance declines with increasing frequency due to the hole size created at the interstices of the braided metal strands. Additional shielding wires may address this issue, but compromises weight and flexibility.

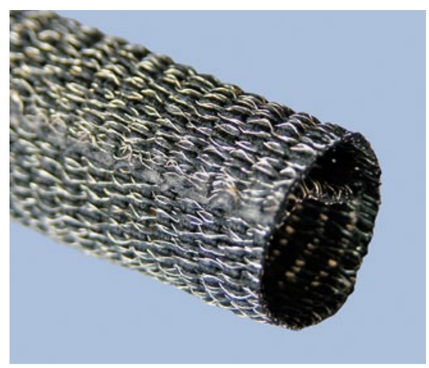
To address the issue, a new technology has been introduced by Federal-Mogul to improve shielding performance across the frequency range. This patented technology, which has been applied to TwistTube and FlexFit EMI shielding products, uses fine strands of metal wire twisted onto polymeric yarn to create a strong, thin, conductive composite yarn, ❹. When multiple yarns are precisely placed into a woven or braided textile shield, the result is an optimised EMI shield solution that is lighter weight and more flexible than the heavy metal braid.

A case study comparing the two approaches revealed that 27 % mass savings, 55 % improved flexibility, as well as a bundle diameter reduction of 38 % could be achieved. Total system cost can also be improved due to assembly improvements and reduced material content.

## SUMMARY AND CONCLUSION

Advances in wire coverings offer many benefits to high-voltage wiring design, enabling lighter weight, lower cost, user friendly options for EV and HEV electrical systems. Because they can overcome safety and performance challenges these components will continue to play an increasingly important role in the construction of EV cars. In fact, today's solutions are not only applicable to the vehicles themselves, but the technology can be employed onto charging stations as well. In addition to these technologies being used for today's HEVs, they are advancing the EV industry towards more commercially viable EV solutions.

The future of high-voltage wiring safety protection is only beginning to be developed. For example, while textile solutions enable vehicle designers to meet today's safety requirements with lightweight, cost-effective crash solutions, future designs may target additional performance goals such as thermal reduction. In these future solutions, the covering could improve the thermal behaviour of the electrical conductor, allowing its size to be optimised, creating further weight and cost savings.



❹ Hybrid conductive yarn woven into flexible TwistTube sleeving