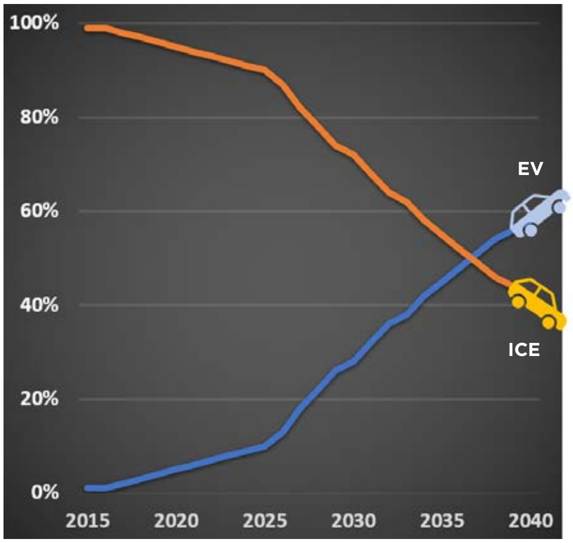
ADVANCED CRIMPING SOLUTIONS

FOR LARGE WIRE APPLICATIONS

INTRODUCTION TO ADVANCED CRIMPING TECHNIQUES FOR LARGE WIRE APPLICATIONS

The automotive landscape is poised for large changes over the next 20 years. Significant technology developments and consumer demand is driving innovations in data connectivity, electrification, and autonomous vehicles. At the same time, policymakers are working with automakers on lower carbon emissions standards which will accelerate a higher mix of electric vehicles (EVs). According to a 2020 BloombergNEF New Electric Vehicle Outlook report, EV sales in 2020 were relatively flat at 3% due largely to the COVID-19 pandemic, but are expected to grow to 7% in 2021, 10% by 2025, 28% by 2030, and by 2040 will outpace Internal Combustion Engine (ICE) sales.[1]



GLOBAL SHARE OF TOTAL ANNUAL PASSENGER VEHICLE SALES BY DRIVE TRAIN

Advanced Crimping Solutions for High Voltage

This whitepaper will look at the current challenges involved in preparing and terminating both copper and aluminum stranded high voltage cables, specifically for the Electric Vehicle (EV) market. It will address new advancements in tooling needed to prepare and crimp large diameter cable.

Current Landscape of the EV Market

The large cable markets are constantly evolving. Take the EV market as a clear example of the changing landscape:

EVs are not yet as widely purchased as ICE vehicles but the offerings are growing rapidly. 44 new EVs are expected to hit the market over the next 5 years.[2] A growing proportion of these vehicles have been designed from the ground up for an electric drive train rather than converting existing models.

The growth of the available EV landscape is creating an equally expansive ferrule and terminal offering. For harness makers, unique tooling challenges are emerging with the existence of so many styles available with larger sizes and shapes varying widely based on functionality and market.

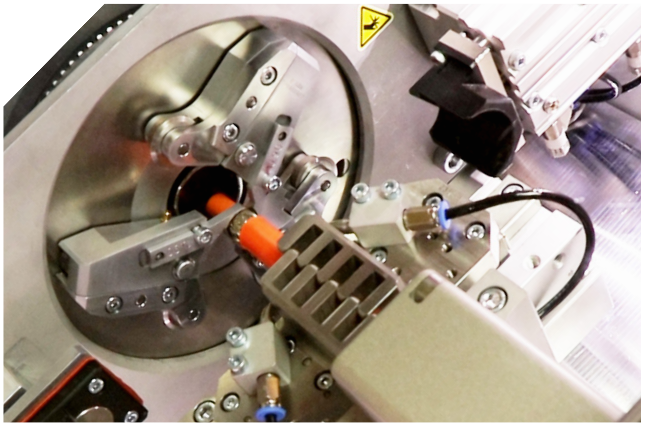
While the market share for EVs currently represents less than 3% of global sales, industry experts predict that EV sales are on the rise thanks to continual technological advancements which are closing the gap in price and functionality of EV's compared to traditional ICEs. On a single charge, highway rated EV's can now travel from 128km (80 miles) to over 482km (300 miles).

Thanks to advancements in new cell chemistries and manufacturing equipment and techniques it's expected that by 2024, battery pack prices will fall below $100/kWh on a volume-weighted average basis.[1]

1. BloombergNEF Electric Vehicle Outlook 2020

2. CarAndDriver Magazine: https://www.caranddriver.com/news/g29994375/future-electric-cars-trucks/ Feb 8, 2021

High Voltage Shielded Cable Preparation Challenges



Defining What is Considered a Large Cable

Cables can be generally classified into three sizes:

- Small wire, which is anything <= 1 mm^2 (18 AWG)
- Mid-size: 1 mm^2 (18 AWG) - 10 mm^2 (7 AWG)
- Large Cables: > 10 mm^2 (6 AWG)

Large diameter cables are used widely throughout the transportation industry in automotive, aerospace, light & heavy rail, energy storage, battery systems, and more.

High Voltage Shielded Cable

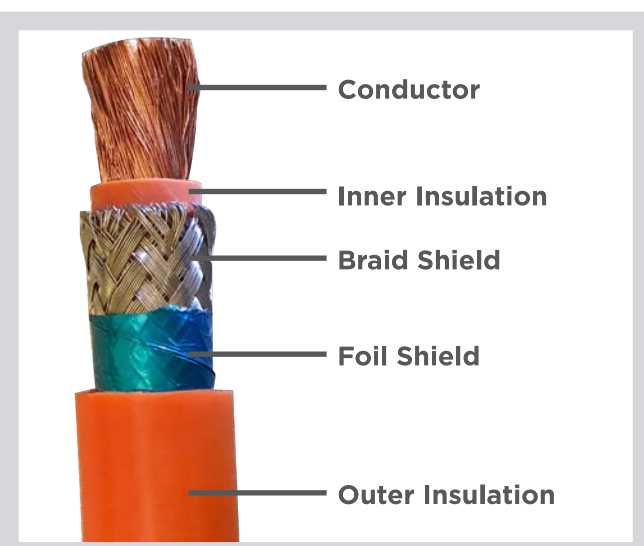


Figure 1. Components of a typical shielded high voltage cable

Challenge: "Footballing"

Hybrid electric mobility solutions (HEMS) cabling is stored and cut from large, heavy spools. As a result, deformation (footballing) of the wire end often occurs when cut. Footballing of the wire interferes with the crimping process due to difficulty in stripping cable that is not perfectly round and sliding components over the wire. For proper termination, and to prevent tooling damage, operators must confirm that the wire ends are reshaped before stripping cables and crimping terminals.

Figure 2. Example of "Footballing" in a 120 mm^2 cable

Challenge: Outer Insulation Damage

Made of a heavy silicon-based material, the outer jacket holds on to debris making it difficult to keep clean and crimp properly.

Operators must minimize the amount of insulation tearing along with balancing their cut depth to minimize damage to the underlying braiding while stripping the outer jacket.

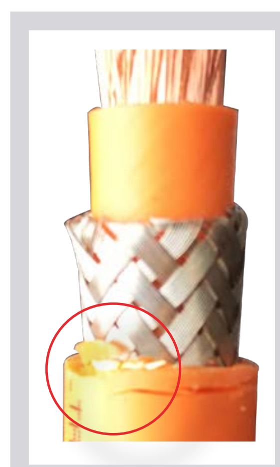


Figure 3. Example of damaged outer jacket

Challenge: Foil Shield Removal

EV's require the addition of shielding to reduce radio frequency and electromagnetic interference (RFI/EMI). In most cases the shielding is made up of a plastic backed foil that is wrapped around a tinned copper braided shield. The foil must be completely removed before terminating the braided shield so that it does not interfere with the connection to the crimped ferule.

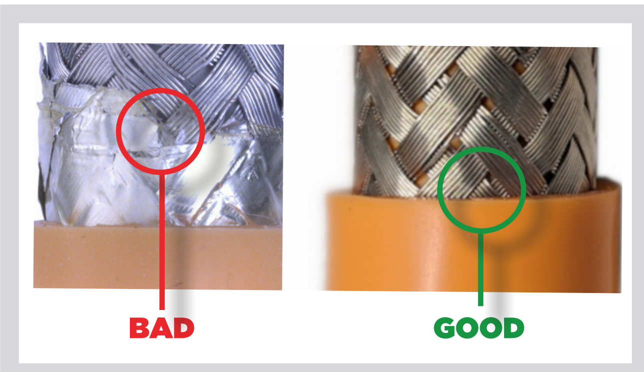


Figure 4. Example of acceptable foil shield

Modern vehicles have significantly more electric motors and wireless devices than vehicles produced only a few years earlier. Combine that extra electronic noise with the potential electro-magnetic interference (EMI) produced by high voltage battery cables and its easy to understand why proper shielding is crucial in automotive production.

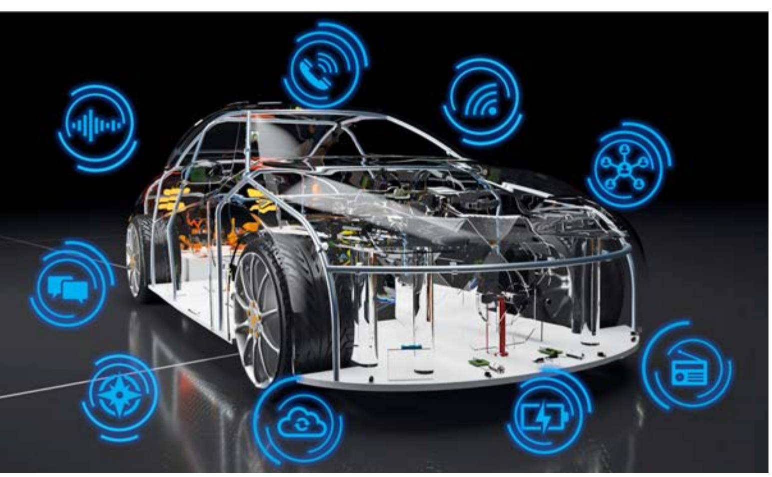


Figure 5. Example of EMI devices in a modern car

Challenge: Cutting Tinned Copper Braiding

Due to the dangerous levels of electricity in the powertrain of EV cables, high voltage cabling for EV's require a rigid protective cover to minimize damage caused by vehicle collisions. A tinned copper braiding provides this durable and difficult-to-cut protective shield. Operators must cleanly cut the braided shielding without damaging the underlying insulation. To avoid short circuits, electrical interference and other electrical hazards, special care must be made to confirm that no braiding strands come into contact with the crimped ferule or terminal.

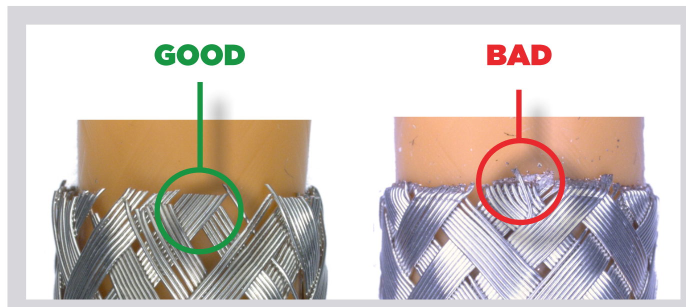


Figure 6. Example of acceptable braiding preparation

To expose the silicone-based inner insulation the braiding must be flared to allow for crimping of the ferule. Many terminals require the braiding to be unwoven. This is often a slow, manual task that requires finger protection.

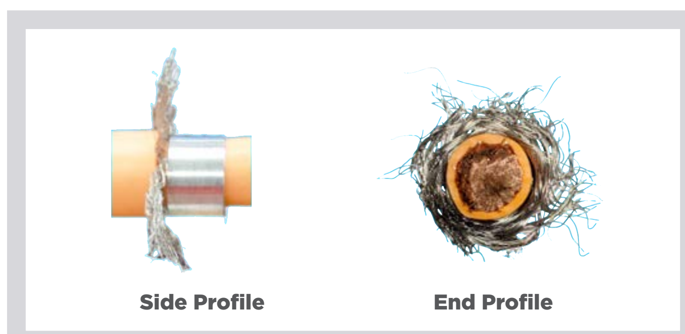


Figure 7. Example of proper braid flaring

In some cases, the foil braiding must be folded to allow for crimping of the ferule. This is ferule dependent and proper folding relies highly on proper cut length and flaring in earlier processing steps.

Crimping Challenges

The crimping process for large wire applications is similar to small and mid-sized wires, except the terminals are largely loose piece. The following are common issues associated with large wire crimping of which to be aware.

Challenge: Clocking

The clocking of the terminal on the cable is important. For very long leads you have some give in the cable, but for shorter leads and asymmetric terminals, the terminals will need to be installed in the proper orientation compared to the termination on the other end of the cable.

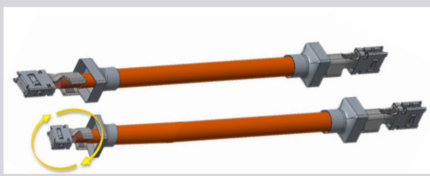


Figure 8. Example of "clocking"

Challenge: Multi-conductor Assemblies

Multiconductor assemblies are common in the automotive market, especially for battery-to-battery connections. Multiple conductors are wrapped in a single outer insulation or connected together by additional components. Due to limited break out length and bend radius, care must be taken to properly terminate these cables.

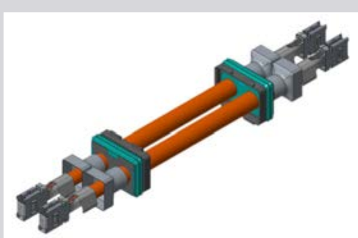


Figure 9. Example of a multi-conductor cable assembly

Challenge: Crimp Force

As cable size increases, so does the crimp force required to terminate it. For small wire sizes you are likely to see forces below 3,000 lbf. For mid-size wires, forces are generally below 10,000 lbf.

For large wire sizes, forces continue to rise with some 95 mm^2 cable terminations requiring greater than 30,000 lbf to terminate. As current requirements increase, and 120 mm^2 cable becomes more common, we will likely see forces approaching 40,000 lbf.

Challenge: Extrusion

All terminals extrude slightly during the crimping process. This varies based on material and size. A mid-sized cable of 5 mm^2 will generally extrude less than 1.5 mm during termination. Conversely, 70 mm^2 cable can extrude as much as 5mm. Die sets are designed to allow for and control extrusion, but these features are only effective when the die set is loaded as intended.

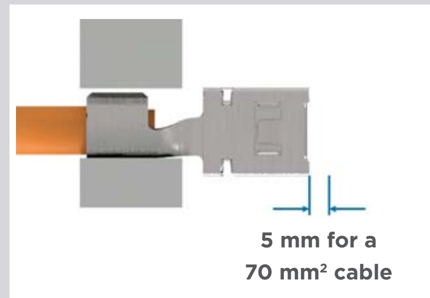


Figure 10. Example of terminal extrusion

Challenge: Cracking

Cracking of the terminal is a big concern for large cable terminations and can decrease the durability of a crimp. Cracking can occur when deviating from the terminal specification such as: over crimping, using an inappropriate cable size, and using a machine that crimps at an inappropriate speed. Cracking prevention by following the application specification is very important as it is only visible with cross sectioning of the terminal.

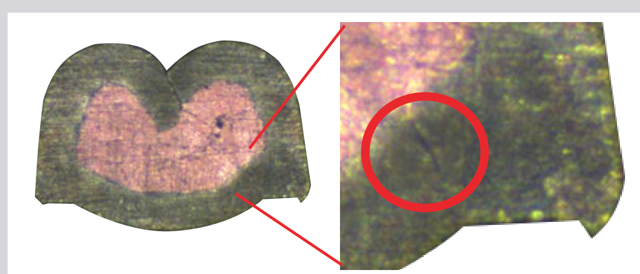


Figure 11. Example of terminal cracking

Crimping Challenge: Short Circuits

Loose strands, from the braid or conductor can become stuck to the insulation and seal. If not removed before assembly, these strands can come loose and short two or more terminals. Due to the high voltage of these systems, this can cause tripped fuses or even system failure.

Figure 12. Example of loose braiding that could cause an electrical short

Crimping Challenge: Crimp Height

Terminals are designed to balance electrical and mechanical performance within their crimp height range. Crimping at an improper crimp height setting can cause missed strands, higher temperature changes during load, shorter life, and a higher risk of failure.

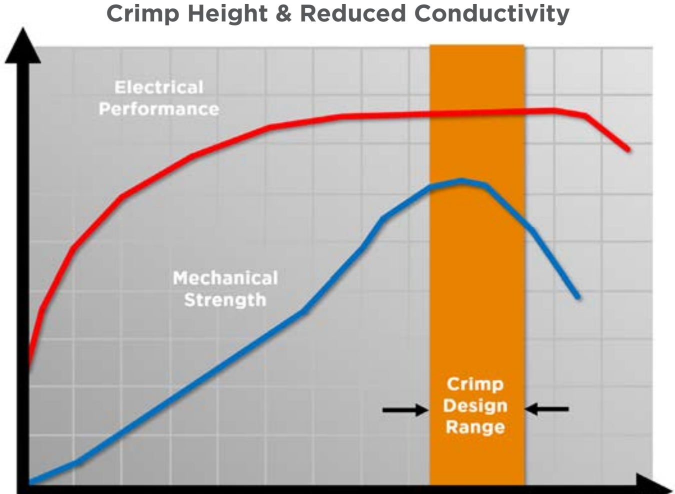


Figure 13. Example shows how peak electrical performance and mechanical strength falls within a specified crimp design range outlined in the 114 Spec

Crimping Challenge: Cross Sections

It is important to check for proper crimping throughout your production run. If not using an automated crimp quality device, it is important to confirm the crimp profile with cross sections at the interval dictated by either the industry standard or terminal manufacturer. Cross sectioning requires the terminal to be cut through the wire barrel after crimping. This process allows for the inspection of proper crimp height, compression, and more. Due to its destructive nature, it can't be used on crimps destined for assemblies.

Figure 14. Examples of terminal cross-sections

Crimping Challenge: Excessive Electromagnetic Interference

Improper care with the braiding may lead to interference from the high voltage drivetrain, such as radio interference, and unexpected operation of equipment. As cars contain more sensing equipment as well, much of which is safety equipment, preventing interference transitions from a cosmetic issue to one of safety.

Crimping Challenge: Water Egress

Improper treatment of the seals may reduce seal integrity, shortening the life of the termination and overall assembly. Seals can be damaged by chemicals, an improper storage environment (temperature, humidity, light), and mishandling.

Automation Difficulties

Unlike small and mid-size wire applications that can be processed by the hundreds or thousands per hour on semi-automatic and fully-automatic lead makers, EV cables are too heavy and complex to be run on existing high-volume machines.

Automation Challenge: High Mix/Low Volume

As new EV's rapidly enter the market, new and frequent product developments from OEM's enter the mix. New terminals, ferrules and wire shielding developments are widening the existing high voltage landscape, constantly evolving wire prep and crimping requirements. The wide mix of terminal shapes, sizes, and crimping requirements (terminals and ferrules) make it more difficult to offset equipment and setup costs with automated equipment.

Automation Challenge: Additional Assemblies

Ferrules, connectors, housings, and seals often need to be placed onto the wire before crimping. In some cases, they need to be put on before stripping the wire to prevent damage to the conductor strands.

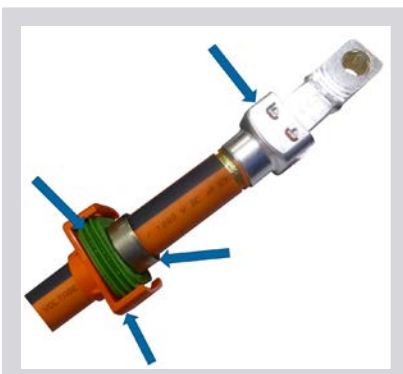


Figure 15. Example of multiple assemblies on a typical cable

Automation Challenge: Lead Length & Weight

The weight of large wires makes it unsafe to create large bundles of leads as they could quickly become unmanageable for workers. For example, 2m of 50mm cable can weigh on average, 1.3 kg. In some cases, leads may be as long as a bus or train carriage and the limited bend radius of these cables dictates a large storage area.

Automation Challenge: Time & Cost

It's not only the cables that are getting larger. Many small wire terminals can be bought for less than $0.50/piece (USD), and in large quantities, only a few cents. Large wire terminations can run from a few dollars to greater than $90 depending on capacity and quantity. The cable itself is also expensive, running at more than $30/meter. Large wires can double or triple the crimp time due to wire management. All of these costs together can make setup many times more expensive, so care must be taken to design and use processes that reduce the amount of scrap and non value-added steps.

Automation Challenge: Traceability

Traceability is an important part of any quality system. With the modularity required for automation, a robust traceability system allows for the tracking of a product through the assembly line.

Figure 16. Example of barcode printing for traceability requirements

After completion, it allows for quality control to confirm the appropriate equipment was used, such as the die set, and also that important metrics were maintained, such as crimp height and crimp speed.

To achieve this, proper labeling of each assembly is key. Using a wire marking system provides an easy to automate method to identify each piece produced. In the event of a quality issue, this information narrows down the other assemblies which may have been affected reducing costs and effort required to resolve the matter.

Aluminum Vs. Copper Conductors

Beyond automation, there are other ways that the industry is trying to reduce costs while improving products. Moving to aluminum cables is one such strategy. One of the major ways to reduce both emissions and consumption is to reduce weight. Aluminum is lighter and less costly than copper leading it to be the next viable choice for manufacturers.

Did You Know?

Comparatively, aluminum is 40% percent less conductive than copper, but is also only 30% its weight. That means a bare wire of aluminum weighs half as much as a bare wire of copper that has the same electrical resistance.

These weight savings can be applied to both ICE and BEV vehicles alike, although the increased large gauge cabling in BEVs will likely lead to higher weight savings. While aluminum is already used in some markets, it comes with unique challenges for automotive applications.

Challenge: Ultrasonic Welding

Many current applications also use ultrasonic welding, which is slow, has a high capital cost, is sensitive to wire surface quality, requires greater amounts of energy for large cables, has a post sealing requirement to prevent corrosion, and may also need secondary strain relief.

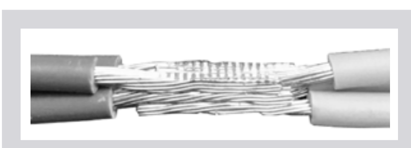


Figure 17. Example of ultrasonically welded cables

Challenge: Reduced Conductivity

Aluminum is not a direct drop-in replacement for copper. Aluminum is 40% less conductive than copper, so to have the same conductivity, you must go one wire size larger. This reduces your weight savings from 70% to 49%. In the case of existing designs, care needs to be taken to confirm there is enough room for the larger wire.

Challenge: Lower Strength

Aluminum has a tensile strength that's 38% less than copper. It can be alloyed but that reduces conductivity, and the one-size-up rule does not resolve the reduced strength. This lower strength can lead to strand fatigue, such as necking and breaks.

Figure 18. Example of additional aluminum strands needed to match conductivity of copper

It can also cause stripping difficulties as the individual strands are more fragile and prone to damage.

To prevent metal fatigue, extra strain relief and supports must be used for this type of cable.

Challenge: Oxide Film

Aluminum reacts spontaneously with water and/or air to form aluminum oxide. Aluminum oxide (Al_2O_3), forms a stable passive layer that protects aluminum from corrosion or further oxidation. This layer is about 4 nm thick and will provide corrosion protection as long as the oxide layer is stable, however the drawback is that an oxide film is non-conductive. Increasing the number of strands in an EV application requires more oxide to break up. If not, middle strands contribute little to conductivity. Low twist wires maximize flexibility but minimize differential surface scrubbing between strands, increasing the difficulty of removing the oxide layer.

Challenge: Galvanic Corrosion

Galvanic corrosion is the electrochemical process in which one metal corrodes preferentially when it is in electrical contact with another, in the presence of an electrolyte.

Figure 19. Example of galvanic corrosion on an aluminum wire strand

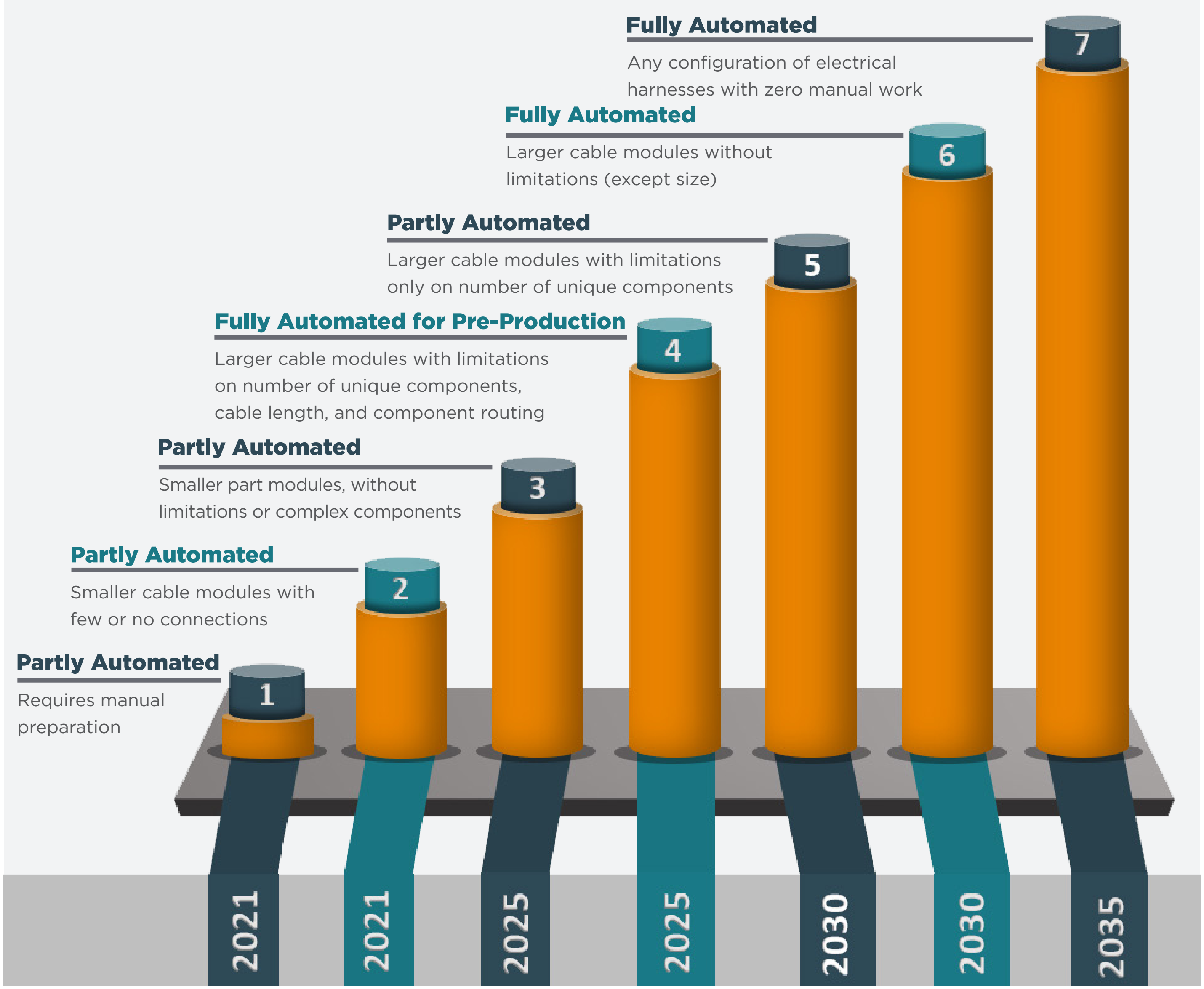
Aluminum is highly prone to galvanic corrosion, meaning additional steps are needed to maintain a closed design to prevent water egress into the wire harness.

Future Trends for High Voltage Cable Assembly

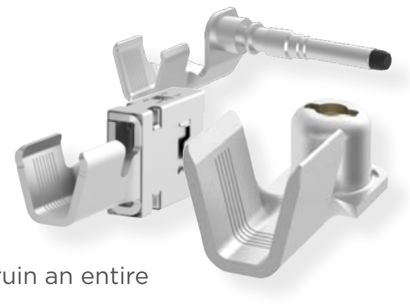
Rising consumer demand for battery-powered transportation is pushing the industry to produce faster, safer solutions. To meet production demands, cable houses will require higher levels of automation and interconnectivity with MES solutions. A push in the industry indicates that high voltage cable assembly will be fully automated within the next 15 years. With that shift to higher levels of automation, advancements in tooling will require machines with greater capacity in the number of components they can process, fewer limitations on the size or length of the cable, automatic routing between processing modules, and an advanced monitoring system to ensure each processing step is completed correctly.

The chart below shows a representation of the seven phases of automation planned for high voltage cable processing and crimping over the next 15 years.

7 Phases of Automation for High Voltage Cable Processing



The Role of Artificial Intelligence (AI) in Wire Harness Production



Unlike terminals used in common electronic applications, high voltage terminals tend to be far larger and can be much more complex, thereby increasing their price to over $5 USD each.

High voltage wire harnesses are designed to exactly fit applications with as little extra cabling as possible to help reduce weight. Thusly, cutting off a bad crimp can ruin an entire harness assembly, costing a company thousands of dollars in product and production hours.

Many common failures in high voltage cable processing can be eliminated through proper validation of tooling components and recognizing alignment issues before crimping high voltage connectors.

In order to achieve higher levels of automation, manufacturers are looking towards advanced AI systems to validate processing steps, track product through multi-step assembly lines and communicate with Machine Execution Systems (MES) to improve efficiency. While a visual inspection can catch many errors in terminal, die or wire placement, AI systems are far more accurate at eliminating potential errors before they happen. To improve accuracy and repeatability an AI system with sufficient cameras and sensors added to a high force press electronically validates accuracy and improves traceability. The next step in the process, as discussed in this whitepaper is the movement into fully automated assembly lines that will require advanced AI to maintain product accuracy as cables travel from process to process and machine to machine. With the modularity required within automation, a robust traceability system allows for product tracking throughout the assembly process. After completion, it allows for quality control to confirm the appropriate equipment was used, such as the die set, and also that important metrics were maintained, such as wire alignment, crimp height and termination speed. In the next section of this whitepaper we will explore the advanced checks capable in an AI driven intelligent validation system.

AI in High Voltage Cable Processing: A Closer Look

Using a multi-camera approach with an integrated AI system, the TE system:

- Scans the crimper, anvil, wire and terminal to confirm compatibility
- Analyzes multiple parameters pre-loaded into the software and uses that data to determine the correct crimp profile
- Measures placement and angles of the terminal and cable to confirm that everything is set and in proper alignment

Figure 20. Example of advanced vision system validating a crimp

Advanced Checks: Wire Validation

Improper wire position is a common issue in wire harness production. As discussed earlier, clocking is an especially challenging issue with rigid, high voltage cable assemblies. Validating not only wire direction, but also the angle of the wire entering the terminal needs careful inspection.

Figure 21. Example of an improperly bent wire

Advanced Checks: Terminal and Ferrule Validation

Terminal validation doesn't just include making sure that you are using the correct terminal for the installed die set. It also requires making sure that it is properly placed on the wire and that it is properly seated in the lower die nest.

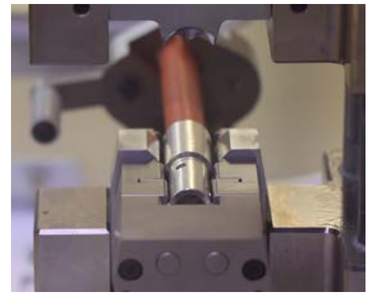


Figure 22. Example of a properly seated terminal

Examples of Cable Checks that Should Be Performed:

- Cable Outer Diameter
- Cable Centerline (angle)
- Protrusion
- Insulation in Terminal
- Strip Length

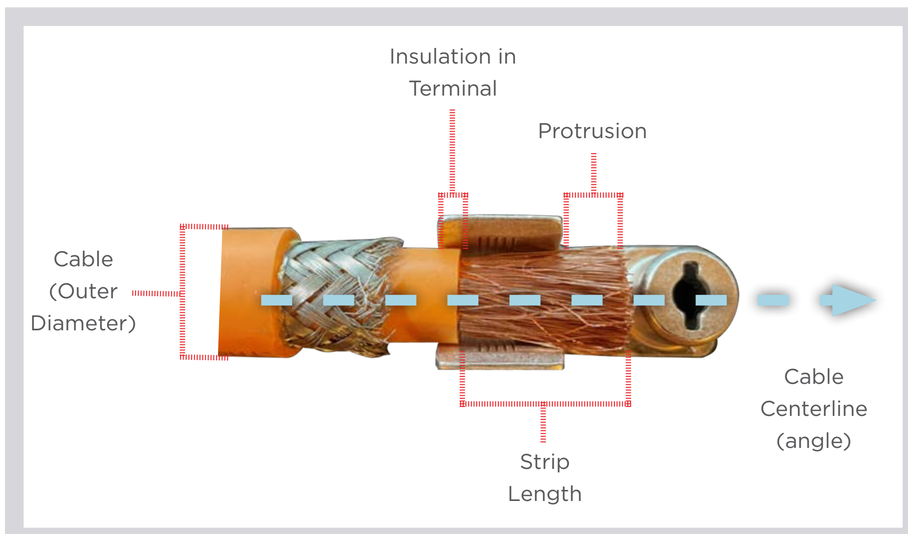


Figure 23. Depiction of various cable check parameters

Potential Failures: Tooling Validation

High voltage crimping machines include the press, upper crimp dies (commonly referred to as the anvil), lower crimp dies (commonly referred to as the crimp nest), and a die holder. Incorrect alignment of the tooling or using mis-matched die sets is a common error that can occur but is a simple detail to catch with a proper validation process.

SUMMARY

TE Connectivity works diligently to maximize the quality of its tooling so wire harness manufacturers can produce the best crimps. Here are five keys to creating high quality large wire crimps.

1. Use Only High Quality Tooling

High quality tooling includes the applicator, terminator, crimper, and anvil. The applicator must be easy to set up and must maintain consistent quality. Users should select a crimper and anvil designed and manufactured for initial quality as well as longevity.

2. Set Up the Applicator Properly

Users must properly load the terminal into the die set and the crimp height must be setup correctly to match the terminal specifications.

3. Understand Proper Cable Prep

High voltage cables require a much more involved process to confirm proper termination. Understanding the makeup of your cable assembly is critical to success.

4. Multi-part Assembly Process

High voltage cable assemblies have many parts that need to be completed in order. Proper preparation and the right tooling will speed up production, allowing you to stay efficient and profitable.

5. Process is the Key to Quality

Creating a standardized process will maximize your efficiency.

Reliability Beyond the Tool

The best electrical components and matching equipment are only as good as the skill of the operator. Our global field service team can handle equipment set-up and training to help your workforce meet the same high caliber as your tooling. Whether it's time or scrap, in manufacturing everyone knows that waste costs money. With our on-site certification and preventative maintenance services, we can help customers reduce downtime scrap, maintain crimp quality and improve manufacturing efficiency.

Trusted Everywhere You Need Us

As a leader in application tooling for electronic components, customers trust TE to be available for support wherever they need us. On-site troubleshooting and repair will get your equipment back to production quickly.

However, sometimes meeting face-to-face with a customer isn't feasible. With the help of live-streaming capabilities our field service team is ready to provide remote support for customers around the globe.

We can also maintain the quality of your portable tools and applicators with factory repair and certification.

Remote Capabilities

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- Troubleshooting
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