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Cable connector comparison study: continuous shear vs. crimp compression

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Abstract

This research paper aims to identify the solution that offers the highest reliability for cable connections. To answer the question, we compared continuous shear and crimp compression technologies, using current cycle tests. Our results showed that although there are many benefits to the widely adopted crimp compression technologies, continuous shear technologies offer improved installation and long-term superior performance, resulting in a more reliable connection. The results of this study can be used to help improve reliability and performance in utilities.

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Introduction

Continuous shear vs. crimp compression – which one is the more reliable technology for cable connections?

This study sets out to uncover that answer by breaking down the science behind continuous shear and crimp compression technologies. Our research will be laid out in three different sections of this paper:

Part 1 asks:

How well do we really understand the CSA hex die system and its benefits or is there more to this story than meets the eye?

What is a best practice for a utility to qualify the CSA hex die system and what is the best way to implement the CSA hex die system?

Part 2 asks:

What are the advantages of continuous shear bolt technology?

Is there another type of connector technology that can be used to eliminate the outlined disadvantages of crimp style technology?

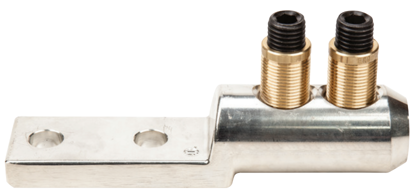
And, Part 3

Brings it all together in a comparison table.

Materials and Methods

Cable connection reliability was determined by examining continuous shear and crimp compression technologies.

The evaluation: an examination based on current cycle tests and technology design evaluation.



Discussion

By looking at continuous shear and crimp compression technologies, this paper aims to identify the solution that offers the highest reliability for cable connections.

Part 1:

How well do we really understand the CSA hex die system and its benefits or is there more to this story than meets the eye? What is a best practice for a utility to qualify the CSA hex die system and what is the best way to implement the CSA hex die system?

Most utilities in Canada have decided to implement and use the CSA hex die system for crimping connectors and lugs. The other widespread used system is the Burndy die system. In the Burndy die system, the die index correlated to the die number is proprietary. In other words, you can buy and use a Burndy-designed connector that works with a Burndy die and that is being crimped with a Burndy tool. From a utility or end user perspective, this may not be ideal, given the fact that one company controls the die, the connector/lug design and the installation tools.

By comparison to the Burndy die system, the CSA hex die system is an "open" system, meaning that the die cross sectional area is published in the CSA C57 standard: "Electric power connectors for use in overhead line conductors". As a result, a connector manufacturer can design a connector that works with the CSA hex die system cross-sectional areas published in the CSA standard. Meaning, the electric utility has many manufacturers to choose from.

Benefits of the CSA hex die system:

- Reduces die stocking costs and confusion related to die part number with its alphanumeric die numbers (CSA 20, 22, 24, 26, 28, 30, 32, 34, 36, 38).
- Simplifies the application because you no longer require die indexes and don't need to do the "die part number to die index" cross-over.
- Allows for competitive die and connector/lug product offerings from multiple manufacturers and suppliers, lowering utility costs, while encouraging competition.
- Allows for standardization with one die system vs. multiple die systems that are not compatible. (There is no direct cross-over of a Bundy die to a CSA hex die or other dies).
- Gives the utility the ability to implement a higher qualify check by using "GO-NO-GO" gauges to verify crimp consistency and die closure by measuring flat-to-flat dimension. (**see figure 4 on page 8**)
- Enhances safety and reliability by providing the ability to simply check the correct die number that was used with a specific installed lug or connector by checking the imprinted die number as opposed to recording die indexes and finding tables to correlate indexes with die numbers.
- Less overall CSA dies are needed. There are only 10 aluminum (AL) dies and 10 copper (CU) dies.

Tech Tip

CSA dies for copper connectors and lugs use the same number designation, followed by "CU". Therefore, if you see, for example, "CSA26CU", you will know that it is narrower compared to the same AL die number for a given tonnage press.

So far, we've gone over the benefits of a CSA hex die system. We also know that the general market trend is moving towards CSA hex die adoption in utilities, but it's important to ask: is there anything that can go wrong?

Let's take a closer look at what could go wrong and what steps electric utilities should take to help mitigate some of the potential issues that may arise when implementing a CSA hex die system.

Disadvantages of CSA hex die systems:

- The only public information available on CSA hex die systems is the cross-sectional area of the dies given in the CSA C 57-2016 standard. The die manufacturing "know-how" and the die design is proprietary to the die manufacturer, so **it is hard to obtain any relevant useful information to help electric utilities enhance quality control.**
- **Slight dimensional changes** in die surface area due to manufacturing inconsistencies or due to exceeding manufacturing tolerances **can lead to incomplete crimps.** This is concerning because "incomplete crimps" means the die is not closed. If a die is not closed upon crimping, there is no guarantee that you will have achieved the calculated theoretical compaction ratio that takes into account the die cross-sectional area, the conductor area and connector area.

Calculating the theoretical compaction ratio:

$$CR = 1 - \frac{S_{die}}{S_{conductor} + S_{connector}}$$

- **Unable to check if a die is dimensionally (i.e.: contact surface, radii, cross sectional area, etc.) within spec or not.** The electric utility can source the exact same CSA die from two different manufacturers and end up with two dies for the same exact tonnage tool. For example, let's say we have two 12T dies A and B that have different widths and seem to have different surface areas that one cannot easily measure and confirm of being correct **(see figure 3 on page 8)**. If this is the case, how does one decide if die A or B will close for the connector it will be used on? The only way to do that, is to conduct qualification trials. This is a large hurdle to overcome if you have many different connectors with slightly different dimensions from multiple manufacturers with dies from different manufacturers as well.
- For CSA hex die systems, the only published information is the die cross-sectional area, but different tonnage tools use different CSA die widths. For example, a CSA24 die will be narrower compared to the same CSA 24 for a 60T tool. This can create some confusion in terms of die selection, especially if the utility uses a large variety of cables and conductor sizes overhead and underground, from small to large AL and CU conductors, and different tonnage tools are required.

Tech Tip

For this reason, it would be useful to stamp the MINIMUM tonnage tool on the connector or lug and on the drawing that can be used to crimp a connector or lug. The minimum tonnage tool stamping is also very useful when it comes to utility distribution applications which mostly only require tools up to 12T. Transmission applications typically require crimping tools in the range of 60 to 150 or even 200T.

- To have a correct crimp in the field, the connector or lug manufacturer **needs to accurately correlate the CSA die width with the tool tonnage**, material hardness (especially for CU connectors), connector manufacturing tolerances etc.

What do we mean by "correct crimp in the field"? This means the die has closed completely with a given tonnage press.

- For a given tonnage press, the CSA die systems should fit with a variety of different crimping tools from different manufacturers. Once again, with the CSA hex die system design being proprietary, it is not unheard of that a CSA die from one manufacturer fits better in a press than the die from another manufacturer. This can happen if one of the die dimensions is at the maximum tolerance and the crimping tool is at a minimum tolerance **(see figures 1 and 2 on page 7). To avoid such issues, a thorough utility approval process (which includes prototyping and installation trials) comprising the validation of die manufacturers, connector and lug manufacturers, and design and crimping press suppliers should be implemented.**
- Dies wear out. For example, dies can be sent back to the manufacturers to accurately measure them and tell the electric utility if the die is still in spec or needs to be replaced. **For this to happen, the utility must have a program in place to monitor and routinely send dies for inspection.**
- The CSA die sizes listed in the CSA C57-2016 standard only show die cross sectional area up to CSA 38. **For larger conductor sizes, no die sizes are published – this critical information is unavailable.** In some cases, utilities have developed their own larger dies for certain applications.
- If an installer uses a CSA die intended for AL applications, as opposed to the correct die for CU connectors (i.e.: CSA 28 vs CSA 28CU), **it could result in an incomplete crimp** because CU dies are narrower compared to the AL dies.

> ***Don't forget: For the same tonnage tool you need a narrower CU die when crimping a harder metal such as CU vs. the wider die for softer AL connectors and conductors.***

Note: some of the above disadvantages also apply to non-CSA dies

Figures

Figure 1:

The green arrow indicates the part of a 6T W die that fits very tightly in the head of the press, while the die on right side of the picture fits okay and is easy to insert and remove from the press head. Upon further investigation it was determined that the heat treatment process slightly increases die dimensions and as a result, the manufacturer has implemented some dimensional adjustments to the die to avoid having the die being stuck in the jaw of the crimping tool. Such issues can be detected and corrected by conducting installation trials involving crimping tools and dies from different manufacturers.

Figure 2:

Shows an MD 6 crimping tool with a W CSA 22 die: when the W die is installed, the BG die will not close, so the installer has to remove the W CSA 22 die from the tool if they intend to crimp with the BG die.

Figures

Figure 3:

Depicts CSA 30CU dies from two different manufacturers. The left die is narrower compared to the die design on the right. The CSA 30CU die on the left also has some larger machined curvatures which reduces the total die surface area compared to the wider die design on the right which has a larger surface area.

Figure 4:

Shows four crimps. The two crimps to the right are completed with the wider CSA30CU die from manufacturer "A". Another crimp is completed with a CSA30CU die from manufacturer "C" which is slightly narrower compared to the width of the die of manufacturer "A". The fourth crimp is completed with a CSA30CU die from manufacturer "B" which is narrower compared to the dies from manufacturers "A" and "C". For the three crimps (two with dies from manufacturer "A", one crimp from manufacturer "C"), the GNG-08 (GO-NO-GO gauge) used to verify the crimps **does not fit**, indicating that the die did not close completely. The GNG-08 measures the flat-to-flat distance of a crimp. The only crimp where the GNG-08 fits over the crimp, is the crimp completed with the CSA30CU die from manufacturer "B", **which manages to better compress the connector and have the die close completely thus achieving calculated design compression ratio**. This also highlights **the importance of using GNG** gauges in verifying the completed crimps. Without a GNG gauge, all four crimps shown seem satisfactory based on visual inspection only. In addition, this highlights the importance of heat cycling testing to assess standard compliance and evaluate product performance. Maybe connectors installed with dies from all three manufacturers "A", "B" and "C" pass the test sequence or maybe some fail. It is impossible to reach the correct conclusion without testing.

Part 1: Summary

The CSA hex die system offers several benefits and advantages compared to the Burndy die system as discussed. Despite these benefits, it is not a foolproof system and electric utilities still do not have full control of such a system in terms of quality or correct installation in the field since the CSA die dimensions are proprietary to the die manufacturer and thus prevents the electric utilities from fully dimensionally checking the dies before releasing them for use in the field. Slight variation in manufacturing tolerances from one crimping tool manufacturer to another and one die manufacturer to another and small dimensional differences or variations in material hardness of the connectors/lugs can determine the outcome between a successful or failed installation.

One cannot help but wonder how many crimps are there in the field like the three crimps shown **on page 8** where the GNG gauge does not fit and what is the long term impact of such a connection?

If a utility needs to completely transition from a Burndy die system to a CSA die system it needs to carefully manage such a change and develop standards that address the crimping tools being approved, the approved CSA die manufacturers and the CSA die compatible connectors and lugs manufacturers it intends to use. Based on my experience developed over the years while working with a number of Canadian utilities, the importance of installing multiple prototypes during qualification and making sure that all approved dies from different manufacturers work with approved crimping tools from multiple manufactures and the different connector and lug designs from different sources of supply cannot be emphasized enough.

As can be seen, there is no magic formula that allows utilities to transition from a Burndy die system to a CSA hex die system quickly and seamlessly, there will be hurdles and obstacles. Certain conditions need to be met for this implementation to take place and a detailed transition plan is important.

Part 2:

What are the advantages of continuous shear bolt technology? Is there another type of connector technology that can be used to eliminate the outlined disadvantages of crimp style technology?

Let's examine the benefits of continuous shear bolt technology.

As discussed in Part 1 of this paper, when it comes to implementing a crimp die system (i.e.: CSA hex die system), there are certain technology limitations related to installation (crimping with dies and presses), difficulty of implementing an efficient quality control system, and assessing long-term performance that ultimately translate into higher system operating costs over the long run.

There are many studies and reports that describe and quantify the costs in different countries that power connection failures produce in distribution and transmission networks. Crimp power connections do have a long history of failures and this is an increasing trend further accelerated by new cable designs (i.e.: new more compact conductor stranding types) that are hard to accommodate with existing limited crimp technology connector designs.[1], [2]

Fortunately, the power connection technology has evolved, and alternative technologies have emerged. Shear bolt technologies were introduced in Europe, more than 20 years ago. This emerging trend has seen increased acceptance due to the many benefits it provides, and the improved performance compared to crimp type technologies.[3], [4]

In terms of connectors that use shear bolt technology there are two types of designs available on the market today:

1. **Step shear (also referred to as multi-step/stage or groove)**
2. **Continuous shear**

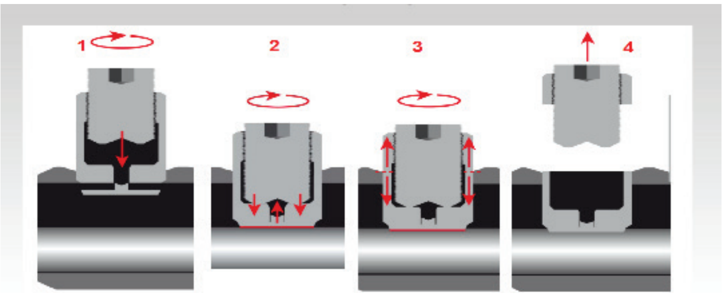
The step shear technology has some inherent technology disadvantages:

- ⊗ Requires different torques at each step.
- ⊗ Hard to accommodate and test a variety of conductor stranding and configurations with only a limited number of shear steps (typically 5 maximum).
- ⊗ Only a portion of the torque is converted in useful contact force, the rest is head friction between bolt head and conductor.
- ⊗ Variation of friction force with conductor material, hardness and surface that leads to variation of contact force being dependent on conductor material type. This increases the risk of not having a high enough contact force on AL conductors (since friction is higher), but a higher force on CU conductors (since friction is lower) etc.
- ⊗ In some designs, the smallest conductors are subject to the highest force and largest conductors to the smallest force, when it should be the opposite.
- ⊗ Some designs may require special tools for installation.
- ⊗ Bolts may shear above outer surface and as a result sharp edges and protrusions need to be filed away.

The continuous shear bolt technology eliminates all the listed disadvantages. But, before we explore the design benefits of this technology let's take a look first at how it works.

How continuous shear bolt technology works:

1. A standard Allen key is used to drive the steel insert into the continuous brass shear bolt.
2. As torquing continues, the pressure plate (friction disk) at the bolt bottom breaks away and the bolt turns on the plate protecting the conductor.
3. When shear torque is reached, the shear bolt is stretched axially and breaks off (steel insert with top brass bolt portion removed).
4. The bolt is designed to break evenly and below the connector body.



Technology Spotlight:

3M™ Mechanical Shearbolt Connectors and Lugs offer easy installation without crimp tools or dies. They cover a large range of sizes and can be used with copper or aluminum conductors. They're also designed to shear off just below the outer surface of the connector body to eliminate the need to file and can be packaged with our 3M™ Cold Shrink Splice and Termination Kits.

Watch me install a 3M™ Cold Shrink QS-III Medium Voltage Splice Kit with a 3M™ Mechanical Shearbolt Connector.

Watch me install a 3M™ Cold Shrink QT-III Silicone Rubber Skirted Termination with a 3M™ Mechanical Lug.

Design benefits of continuous shear bolt technology:

Electrical contact fundamentals: force vs. resistance and contact "a" spots: A good example to better understand contact technology is to explore the metallic contact area between two aluminum bus bars or lug pads that are overlapped to enable current flow. This looks like an ideal contact since the two bus bars are in direct contact with each other and by increasing the overlap area we can increase the surface that allows current transfer.

In reality, a microscopic look at the apparent contact area (the geometric area where the two bus bars overlap) shows that the **true electrical contact area** is formed by a combination of peaks and valleys generated by the protruding surface asperities that enable current flow through the peaks of the two surfaces that are in contact. It is only these peaks (irregular protrusions) of one surface (bus bar) that meet the peaks of the other surface (bus bar) that create true **contact "a" spots.**[2] The entire current flow only occurs through these peaks or "a-spots", which are irregularities of material surfaces that give us the much needed electrical contact points and they only make up **approximately up to 5% of mechanical or apparent surface area (overlapping area of the two bus bars in our example) and range in size from sub-microns to tens of microns.**[1], [2]

In other words, **electricity has to flow through this narrow passage, constricted contact points generated by surface contacting asperities (peaks) and it is important that these contact "a-spots" be maintained in the long run at a low resistance and without degradation, otherwise melting and thermal runaway failures can occur.**

The integrity of the contact spots can be achieved and maintained by using a certain surface roughness in order to maximize number and dimensions of “a” spots, by using an appropriate metal surface finish etc. Degradation of “a” spots can occur as well due to temperature increase (associated with higher current flow), which in turn leads to more oxidation, corrosion, fretting and stress relaxation. Lower contact resistance can be achieved by increasing the contact force by crimping or bolting. However, there is a limit to the force increase because at a certain point, saturation is achieved, and further force increase does not continue to lower the resistance. At the same time, the contact resistance does not instantly increase once application of the force has ceased and a good electrical contact has been created. Only if the force falls below a certain limit, do we see the contact resistance increase.[1], [2]

Understanding contact physics, helps us realize that initially when the contact is made, we need to achieve the saturation point (maximum force with minimum contact resistance) but also able to maintain a certain minimum force over the life of the electrical connection for an adequate performance.

Due to other factors like for example material flow in conductor material, the contact force will decrease over time (i.e.: contact aging), which is why it is important to compensate with elastic design features/components (i.e.: spring washers for bolted connections).

Another factor contributing to electrical contact degradation is the formation of aluminum oxide film layers (occur when aluminum is in contact with oxygen from the atmosphere) which is non-conductive.

As a result, aluminum electrical contacts created as a result of using crimp technology are subject to continuous degradation due to material flow (connector and conductor), oxidizing of aluminum or lack of elastic features incorporated etc. What this means from a continuous shear bolt technology design perspective is that electrical contacts can be improved by incorporating defined, engineered contact points and lines rather than apparent mechanical geometric areas (not true electrical areas).[1]

Design considerations – material flow, heat aging, elasticity, tensile strength: A good example to advance our discussion about the superior design of the continuous shear bolt technology is the case of bolted lugs (terminals). It is recommended to not only dry and wet wire brush the aluminum conductor before crimping the barrel but also to wire brush the pad side that gets connected to the bus bar to increase the contact “a-spots”. To protect the outer surface from oxidation we can use a contact paste. **In order for the applied torque to result in the optimal contact force, bolts should be greased.**

All these considerations are considered and incorporated in the continuous shear bolt technology. The bolts are greased, and the connector bore has the transverse grooves greased as well to help protect against oxidation.

We know that heat ages and degrades electrical connections – given that most material properties are temperature related. Electrical resistance also increases with thermal load, thus further degrading the connection and shortening life expectancy. Heating and cooling cycles also affect the material flow and recovery which if correctly considered will dictate the correct initial design contact force. In addition, since material flow results in decreasing clamping force over time, a good design will consider a certain loss of force over time, but not below a minimum level as to compromise the long-term reliability of the connection. **This is why continuous shear bolt technology incorporates material choices and properties, as well as elasticity into it’s design. By comparison compression connectors once installed (crimped) are rigid, have no elastic design elements build in and due to the inherent nature of the technology are poorly equipped to deliver long term performance.[1]**

Other important design elements are related to the length, thickness and width of the connector body and the correlation of these dimensions to the contact force do **not produce permanent plastic deformation of the connector body at installation.** As previously explained, in the continuous shear bolt technology, by design, sufficient contact force is determined to allow for a low enough long-term contact resistance, which also mitigates the temperature-induced elongation of the conductor. This design element is important since conductor elongation due to heat leads to fretting (micro movements between conductor and contact parts), which can lead to failures due to contact degradation if not mitigated against.

Furthermore, the design of the continuous shear bolt technology allows for the connectors to “breathe thermally” and be elastic, and as a result a certain balance needs to be achieved between force and elasticity. This is achieved by using an aluminum body that has a thermal expansion rate like the aluminum conductor and by controlling the elastic deformation of the aluminum connector body: as the bolt tightens, **the connector body elastically deforms at defined points. As a result, this type of design counters material flow and settling and allows the different material subcomponents to breathe thermally, which in turn mitigate contact aging. [1]**

As discussed in Part 1 of this paper, in terms of crimping technology, the industry is using symmetrical crimping types (CSA hex dies, Burndy U dies, etc.). Other types of crimps (i.e.: indent crimping) are also available. Such crimp installations result in conductor flow in the axial direction and reduced stranding cross-sectional area as a result. The force that is applied with the symmetrical crimping technology needs to be balanced with the tensile strength requirements of the application. With the continuous shear bolt technology the bolts have a **bottom straight plate or friction disk;** not convex bottom like with some step shear designs that drill themselves into the conductor strands, thus lowering tensile strength by removing strand material during installation. This helps **apply pressure in a more uniform way and the applied force is high enough to achieve electrical performance in the long run, moderate enough to provide elasticity and still high enough to satisfy minimum class 2 mechanical requirements.**

The friction disk does not rotate. When the bolt makes contact with the conductor, the bolt gets tightened, the friction disk only applies force to the conductor instead of rotating against the conductor strands. As a result, there is **minimal friction between the bolt and conductor thus maximizing applied force which transfers most of the torque in high contact force necessary for a long term electrical performance**.

In addition, **transverse grooves are machined at the bottom off the connector bore that increase tensile strength and improve cross-line conductivity of stranded conductors and improve current flow from inner to outer conductor strands. 3M QCI test reports reveal tensile strength test results in the range of 58% to 91%, far exceeding minimum requirements of 40% RTS.**[3]

Part 2: Summary

Continuous shear bolt technology uses an optimized thread design with an increased pitch that provides a number of benefits such as applying a **higher contact force on the conductor, lowering friction on the thread (thus transferring more torque to the contact area rather than wasting it on friction) and lowering shear-off forces, thus easing installation.**

Part 3:

Comparison table: shear bolt technology vs. crimp compression

Continuous Shear Bolt Connectors	Crimp Compression	Observations and References
Design		
Superior design for long-term performance and reliability. Design and correlation to performance easy to understand and evaluate through testing.	Based on **known best practices design guidelines** used across industry but allows for variations from one manufacturer to another. Hard for the end user to evaluate design, reliability and performance.	Reference 4 on page 16
Continuous shear bolt design; bolts shear off at pre-determined values thus eliminating field variability and potential errors.	Installs by **crimping using dies and presses**	
Bottom **friction disk** helps maximize contact force for long term electrical performance. The force applied is also optimized to allow for elastic connector/contact behavior and enables class 2 mechanical requirements. The bolt force presses the conductor against the connector body wall creating a good connection. At the same time, the friction disk protects and preserves the integrity of the conductor strands.	N/A	Reference 3 on page 16

Optimized bolt thread transfers more force to the contact area, reduces friction on the threads and lowers shear off forces.	N/A	
Elasticity incorporated into design to mitigate aging and ensure long term performance.	Rigid final installed product subject to material flow, relaxation etc. **limited by technology.**	
Mitigation of contact aging through incorporation of design elements to allow for thermal breathing, elastic body deformation at installation and material choices to maximize elastic properties.	**Hard to incorporate design contact aging mitigation mechanisms** other than standard design best practices (i.e.: compression ratio within certain ranges, use of certain alloys).	
Thermal breathing incorporated into design correct balance between force and elasticity mitigating against material flow and settling.	N/A	
Improved electrical contact by incorporating pre-defined engineered contact points and lines.	N/A	
Greased bolts to maximize contact force and torque. **Greased transverse grooves** to prevent oxidation.	N/A	
Transverse connector bore grooves to improve electrical contact and tensile strength.	N/A	
Range-taking capability, reducing inventory.	One size connector per conductor size resulting in **large product families** with **increased inventories.**	
Better heat dissipation due to increased outer diameter (designed for largest conductor from range and increased wall thickness to allow for thread engagement).	**Heat dissipation** related to connector outer diameter and age degradation dependent.	Reference 4 on page 16
Contact force by design: sufficient contact force for maintaining long term contact resistance and mitigating against the temperature induced elongation of the conductor.	N/A	
Solid connector middle wall (oil stop/watertight design) comes standard.	Most standard compression connectors have a **pressure fit wall that is not watertight.** User needs to specify "oil stop or watertight" design.	

Installation

Easy installation. Installs with a hand wrench or a battery-operated impact wrench.	A multitude of heavy, large, expensive installation **crimping tools** (manual, hydraulic, battery powered) are used leading to high inventory of tool variety (different tonnages, torques etc.) that need to be checked, maintained, replaced.	
No die system. Only three standards, off the shelf hex key/socket sizes used, simple installation ensure installation consistency and lower long-term operational cost. **Achieves same results every time.**	**Variety of dies from multiple manufacturers,** many times incorrectly interchanged and crossed over that lead to failures in the field due to incorrect crimping.	
Easy setup: fast, easy insertion of hex key /socket in wrench.	**Set up for installation is time consuming and prone to errors.** (multiple dies for CU and AL connectors, easy to lose on the job site or pick the incorrect die, that come at a certain cost with increased lead times that need to fit and work with specific tools and tonnages and are not interchangeable between manufacturers).	

Wire brushing of AL conductors **not required** due to build in transverse grooves.	Performance heavily dependent on correct **wire brushing** of AL conductors.	Reference 4 on page 16
No need for oxide inhibitor.	Performance heavily dependent on use of **oxide inhibitor** for AL conductor connections.	Reference 3 and 4 on page 16
Crimping not applicable. **Manufacturing controlled torque and shear without field required expertise and know-how. Final installed product and long-term performance is not skill dependent.** Always shears off below the outer surface (without protruding parts or sharp edges) **Achieves same results every time.**	**Crimping** is required and **crimping errors** may include: • Incorrect dies • Not enough crimps • Too many crimps (i.e.: if crimp overlapping allowed, how much?) • Crimps not rotated (can lead to banana effect) • None or not enough growth allowance (AL) due to expansion (need to redo installation or compromise insulation) • Incorrect crimp positioning (i.e.: too close or crushing connector middle wall) • Removing all or some oxide inhibitor in the field (assumes correct amount applied in manufacturing) decreasing life expectancy • Failure to remove sharp edges after crimping (can cut into insulating layers)	
Centering rings to improve concentricity of conductor with connector bore.	**Not needed (conductor and connector are concentric)**	
No ergonomic issues reported. Installs with a hand wrench or a battery-operated impact wrench using standard off the shelf hex sockets. A holding tool is not required, but available for convenience and if preferred.	**Ergonomics issues:** • Presses not calibrated – either used without proper force or time-consuming calibration conducted leading to installation delays • Correct dies not readily available in the field – leads to usage of incorrect dies or time-consuming purchases of correct dies • Large, heavy tools hard to work with that may not fit between the phases of 3 core cables or in tight places (direct burial or small manholes etc.) • May require assistance from second installer	
All shear bolt connectors/lugs **come with easy-to-follow installation instructions.**	Does not come with installation instructions. Die type is marked on the connector. Press and tonnage not marked.	

Application

Connector designed with **increased outer diameter** for largest cable size in the range also benefits from **thick wall thickness** to satisfy thread engagement, thus providing better heat dissipation, makes it **more suitable for challenging applications** such as high load applications. The same connector design is used for LV, MV and HV applications thus simplifying selection and eliminating confusion.	**Repeated heat cycling:** There is no clearly defined criteria for correct connector **selection** based on applications. Mostly the selection is based on conductor size and type. Connector features such as “short” or “long” barrel are not clearly defined. Should you select the same connector for a 500 kcmil strand-filled 35 kV windfarm splice subject to repeated daily sharp load variations compared to a 500 kcmil 600 V RW90 cable splice?	Reference 4 on page 16 (shear bolt connector operating at lower temp for the same ampacity compared to compression connectors)

Connector-designed based on counter measures to mitigate natural material flow and recovery, thermal aging etc. such as elasticity built-in and **retaining of minimal contact force for long term performance.**	**High constant load:** Utility aging grids are subject to higher loads for prolonged or continuous periods of time which only accelerates the thermal aging thus decreasing reliability and shortening life expectations for compression connectors.	
Class 2 (semi-tension min. 40%RTS) rated but test results reveal results far exceeding minimum 40% RTS requirement.	**Mechanical duty class** selection: • Class 2 (semi-tension min. 40% RTS) • Class 3 (non-tension min. 5% RTS) Difficult for end user to select correct duty class (most of the off-the-shelf connectors do not indicate duty class)	Reference 3 on page 16
Range-taking. 3 connectors cover all applications #2 AWG – 1000 kcmil.	**No range-taking capability**	
Accommodates **any stranding and conductor configuration** (including nonstandard ones such as trapezoidal, flex/extra-flex, solid etc.)	**Cable stranding and conductor configuration.** Most standard applications refer to concentric stranding round power conductors. Some applications (i.e.: flex or extra-flex conductors) require special construction connectors.	
Same connector design performs very well **for both Al and CU** conductor applications due to the robust range-taking design and increased wall thickness and elasticity incorporated in the design.	Usually **different connector** designs for **AL conductor** and **CU conductor** applications.	

Testing

Tested to: **ANSI C 119.4** **IEC 61238-1** (1000 cycles; resistance factor measurements and 6 short circuits tests)	Usually tested to: **ANSI C 119.4** (100 cycles - CCST* method or 500 cycles CCT** method; short circuit optional/informative only) **CSA C 57**. (similar to ANSI C 119.4 heat cycling testing and mechanical duty testing; short circuit optional/informative only)	IEC 61238-1 represents a more severe type testing compared to ANSI C 119.4 or CSA C 57 to which most of the compression connectors are tested
All three connectors QCI 2-250; QCI 350-750; QCI 500-1000 **have been** electrically (thermal cycling) **tested** on largest conductor size from the range and mechanically (pull-out) tested on both smallest and largest conductor size. Since only 3 connectors cover the entire range from #2 AWG to 1000 kcmil, **ALL connectors are tested** and there is no need to rely on ambiguous definitions for "same family" of connectors to qualify untested connectors.	**Testing based on "family" qualification** require a minimum of 3 sizes to be tested **(smallest, mid-size and largest)**. Any other sizes in between not tested but assumed that they will adequately perform since they are part of the "same family". Aside from maintaining the same material for entire family it is impossible to accurately technically define what the "same family" is (given that each connector in the family has different dimensions based on size).	Reference 3 on page 16

Price

Price per unit higher compared to compression connectors. However, **lowers long-term cost of ownership due to superior design, less failures, less installation/tooling costs etc.**	**Lower price per unit** compared to shear bolt connectors. **Higher long-term cost of ownership over service life.**	Reference 1 on page 16

*CCST-current cycle submersion test
**CCT-current cycle test

Results

Continuous shear bolt technology offers numerous design benefits that cannot be provided by the compression or step shear technology that translates into installation and long-term superior performance benefits. Scientific design elements such as pre-defined contact points, incorporated elasticity, mitigation of contact aging, optimization of contact force etc. incorporated into the design produce a superior connector compared to existing technologies. Comparative heat cycling testing shows that continuous shear bolt connectors operate at lower temperatures, will thermally age less and last longer compared to AL compression connectors under the same test conditions.

The ease and consistency of installation, range-taking capability, and elimination of additional tooling costs (dies, presses), combined with the capability to accommodate both CU and AL conductor stranding, are serious considerations that make continuous shear bolt technology the top choice connection option for both industrial and utility applications.

Conclusion

Technological advances in the continuous shear bolt technology provide multiple benefits that enhance the safety and reliability of the network and eliminate many of the compression crimp technology disadvantages, thus lowering the total cost of ownership in the long run.

Technologies such as the continuous shear bolt play and even more vital role in an aging utility infrastructure that not only requires substantial upgrades but also offers new project construction options for a more robust and reliable, electrical network.

For more information about 3M electrical products and solutions, contact us at 3Menergysolutions@mmm.com.

References (literature cited)

1. Pfisterer CONNEX. Focus on contact, November 2018.
2. Timron Scientific Consulting Inc. Workshop on the performance and reliability of power connections, Toronto, Ontario Canada, 4-5 February 2002.
3. 3M test reports: CRQCI2-250; CRQCI350-750; CRQCI500-1000, June 2010.
4. Taylor, Bill. Long term current cycling of connectors under joints, 3M White Paper. No data available.

Important notice

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