White Paper

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Physical Infrastructure Solutions for Grounding and Bonding

Ensure a Reliable Connection with the Panduit® StructuredGround™ Direct Burial Compression Grounding System

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Introduction

Connection reliability is critical to the long-term integrity of a grounding and bonding system. Traditional compression grounding connector systems offer installation efficiencies over exothermic welding systems and are compliant with IEEE Std. 837. The Institute of Electrical and Electronics Engineers (IEEE) developed this standard as a means of qualifying permanently installed grounding connectors. However, under certain circumstances such as installations that are subject to corrosive forces or repeated freeze-thaw cycles, the reliability of compression grounding systems is often questioned.

IEEE resolved the dilemma of compression connector reliability when it released the *IEEE Standard for Qualifying Permanent Connections Used in Substation Grounding* (IEEE Std. 837-2002), which is more stringent than the preceding version of the standard (IEEE Std. 837-1989). Meeting the IEEE Std. 837-2002 requirements guarantees that a connector– whether exothermic or compression – possesses the long-term performance characteristics necessary for the most demanding grounding applications.

This paper explores the importance of implementing a solution approach to optimize the performance of grounding connector systems. It also explores how the Panduit® StructuredGround™ Direct Burial Compression Grounding System combines the installation efficiencies of a compression system with the long-term reliability of connections that meet IEEE Std. 837-2002.

The Panduit® StructuredGround™ Direct Burial Compression Grounding System

If a grounding system is to last, the issues that put it in danger of failing must be identified and addressed. Risks to ground connectors include:

- The environment where the connectors are installed, such as:
  - Damage from construction equipment before burial or during later site renovations
  - Electromotive forces from fault and lightning surges
  - Freeze-thaw cycles
  - Corrosive forces due to the presence of acids or salts
- Misapplication of the connector during the installation process
- Failure of the inspection process to find installation issues

IEEE Std. 837-2002 specifically addresses the environmental risk factors. The installation and inspection risk issues are addressed through the use of compression connector technology used in the Panduit® StructuredGround™ Direct Burial Compression Grounding System.

Applications for the Panduit® StructuredGround™ Direct Burial Compression Grounding System include the bonding of copper conductors, reinforcing bar (rebar), ground rods, and building steel (see Figure 1).

The 2002 version of IEEE Std. 837 has the most stringent acceptance requirements of any grounding connector test. To demonstrate the ability of the Panduit® StructuredGround™ system to meet long-term reliability goals, the system was subjected to testing per IEEE Std. 837-2002. The following section of this paper outlines the procedures followed and the results generated by these tests.

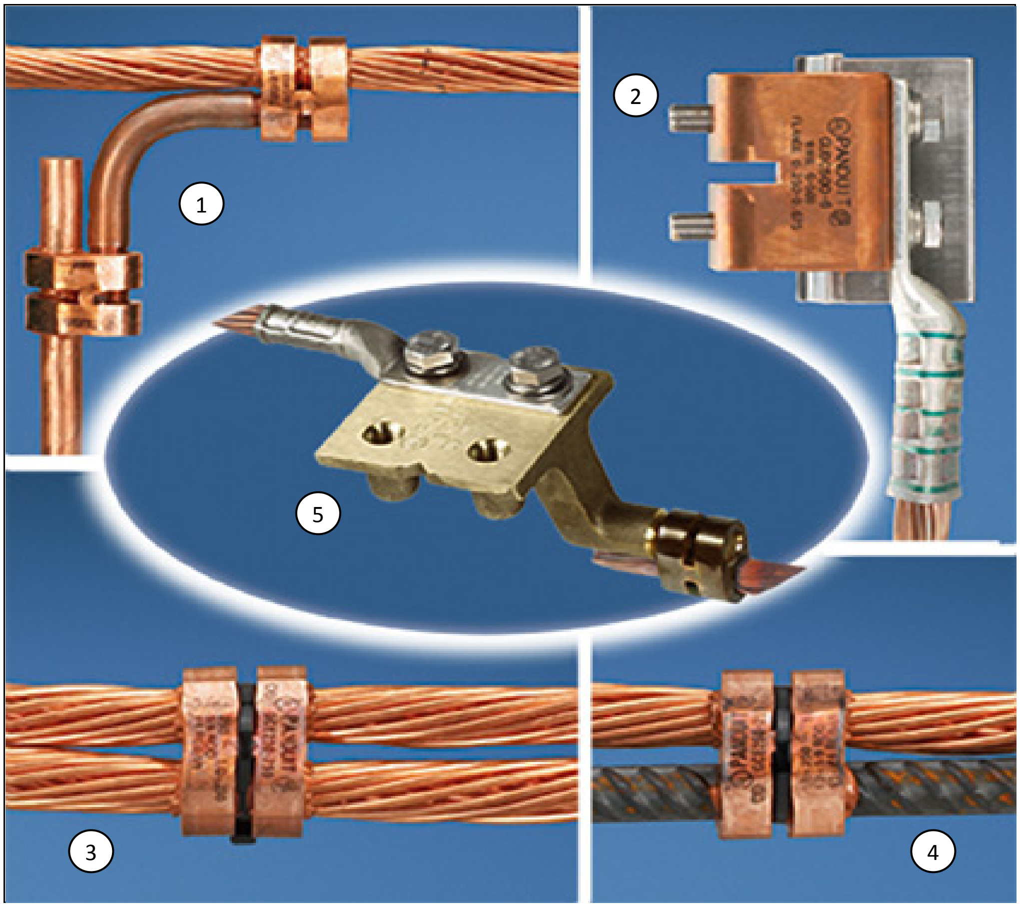


Figure 1. Various Panduit® StructuredGround™ connectors showing the different grounding applications: conductor to (1) rod, (2) building steel, (3) conductor, (4) rebar, and (5) ground plate.

IEEE Std. 837- 2002 Testing

All versions of the standard, including IEEE Std. 837-2002, agree that the best indication of connection degradation is the change of resistance through that connection over time. By measuring the resistance of the connection at the beginning of a test sequence, and then comparing that to the resistance at the end of the sequence, an evaluation can be made as to how much damage the test caused to the connector's integrity. The resistance indicates how much metal-to-metal contact exists between the connector and the conductor. The more metal that is in contact, the lower the electrical resistance will be through the connection. Increases in resistance during the test sequences are proportional to the damage sustained by the connection. Larger changes in resistance indicate that greater damage was done to the connection.

Resistance measurements are taken at the end of the Electromagnetic Force Test (see page 6) and Sequential Testing (see page 7). The previous IEEE Std. 837-1989 allowed a 150% increase in resistance. IEEE Std. 837-2002 only allows resistance increases of 50% after the sequential tests (see Figure 2). These revised acceptance criteria are especially important to prove the corrosion resistance capabilities of the connection system.

IEEE Std. 837 Test Process

The IEEE Std. 837 test process is divided into a three-test sequence that models the environmental risks associated with electrical connectors that cause a grounding system to fail:

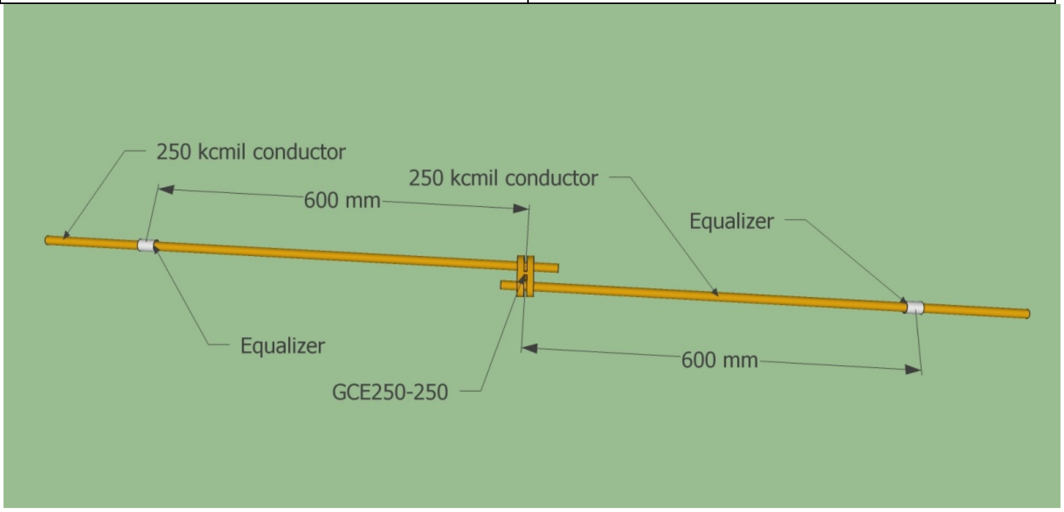
- Mechanical Pullout Test, which models tensile forces that conductors could be exposed to during construction
- Electromagnetic Force (EMF) Test, which is similar to a lightning strike and simulates an utility-scale fault
- A final series of Sequential Tests that models freeze-thaw cycles, corrosive environments, and electrical fault conditions

Each category of tests is performed on a separate set of connectors. Per IEEE Std. 837-2002: "The selection of a hard-drawn conductor, rather than soft-drawn conductor, will result in a more stringent test." Because of this, Panduit used hard-drawn bare conductors as specified by ASTM B-1 for all tests.

Calculating the Allowable Resistance Change

While the IEEE Std. 837-1989 test allowed a resistance change of 150% from the beginning to the end of the sequential tests, IEEE Std. 837-2002 only allows a 50% change in resistance.

IEEE Std. 837-1989	IEEE Std. 837-2002
$Resistance_{final} = Resistance_{initial} \times 2.5$	$Resistance_{final} = Resistance_{initial} \times 1.5$



Resistance measurements were made using a micro-ohmmeter from equalizer to equalizer on a test setup as illustrated above. The use of equalizers and the distance between the equalizers and the connector is dictated by IEEE Std. 837. Resistances were taken at dimples in each equalizer to ensure that the measurements were always conducted in the same location.

Figure 2. The comparison in resistance measurements between IEEE Std. 837-1989 testing and IEEE Std. 837-2002 tests.

The Panduit® StructuredGround™ Direct Burial Grounding System passed all tests. Mechanical Pullout Testing was conducted in our Underwriters Laboratory (UL) accredited lab. Kinectrics North America Inc. in Ontario, Canada was contracted to perform the rest of the IEEE Std. 837-2002 testing. Because Powertech Labs in Surrey, B.C. Canada is the only lab in North America that is capable of producing the waveform required by the IEEE Std. 837-2002 EMF test, Kinectrics subcontracted the EMF test to Powertech Labs.

Mechanical Pullout Testing

An MTS Sintech 20/G tensile tester was used to perform pullout testing on a total of 104 conductor combinations. This test models the tensile forces that conductors could be exposed to during construction. The acceptance criterion for the Mechanical Pullout Test states that there is no visible movement of the conductor with respect to the connector after the prescribed tensile force has been applied to each connector combination.

Four samples of each conductor combination were tested for a total of 416 individual trials. All conductor combinations passed all trials. As an example of a popular connector, the raw data for the GCE250-250 connector is presented in Table 1 to show the tests run and the results achieved.

Table 1. Results of Mechanical Pullout Testing for Panduit GCE250-250 Connectors.

Conductor Combination Tested		**IEEE 837-2002 Min Pullout (lb)**	**Trial Number and Pullout Attained**			
Main	**Tap**		**Trial 1 (lb_f)**	**Trial 2 (lb_f)**	**Trial 3 (lb_f)**	**Trial 4 (lb_f)**
250 kcmil	250 kcmil	1,000	1,513	1,516	1,471	1,658
250 kcmil	1/0	300	1,521	1,256	1,408	1,318
1/0	1/0	300	1,732	1,707	1,456	1,225
1/2" Copper Bond Rod	250 kcmil	500	1,708	1,458	1,124	1,346
1/2" Copper Bond Rod	1/0	300	1,712	1,421	1,412	1,258
5/8" Copper Bond Rod	250 kcmil	1,000	1,783	1,383	1,643	1,589
5/8" Copper Bond Rod	1/0	300	1,477	1,488	1,392	1,514
3/8" Rebar	250 kcmil	300	1,683	1,754	1,757	1,718
3/8" Rebar	1/0	300	1,988	1,651	1,757	2,119
1/2" Rebar	250 kcmil	500	1,745	1,747	1,824	1,589
1/2" Rebar	1/0	500	1,561	1,889	1,923	1,355

Electromagnetic Force (EMF) Testing

The EMF test is performed on a conductor loop having one to four test samples. The purpose of this test is to simulate a utility-scale fault. This assembly is secured to a platform. The conductor is then hooked up to a power source that supplies a 3.76kV$_{RMS}$ potential at a peak value of 2.7 times the fusing (melting) current of the conductor for 200 milliseconds. The wave is applied three times to each test loop, allowing the conductor to cool to at least 100˚C before the next surge is applied. All connectors passed all tests.

Figure 3. EMF test setup at Powertech Labs. Current values ranged from 3.7kA$_{RMS}$ to 70.9kA$_{RMS}$.

The EMF test using GCE250-250 connectors is shown in Figure 3, and was performed under the following conditions:

- Conductor combination: 250 kcmil to 5/8" copper-bonded, steel ground rod
- Control conductor: 5/8" copper-bonded steel ground rod
- Nominal required test current: 17.1 kA$_{RMS}$
- Nominal : X/R: 37
- Nominal required peak current: 46.1 kA$_{PEAK}$

Measured test results are provided in Table 2. Each connection remained intact, with no visible movement of the conductor regarding the connection. The final resistance was less than a 50% increase in the initial value, which means the connectors exceeded the IEEE Std. 837-2002 requirement. For test loop number one, the resistances were taken without allowing the connections to cool completely, indicating that the change in resistance after the test was overstated. However, even without correcting for temperature, the connectors still pass the test.

Table 2. Results of EMF Testing for Panduit GCE250-250 Connectors.

Test Loop Number	Current Surge No.	Current				Result
		RMS (kA_{RMS})	Peak (kA_{PEAK})	Peak/RMS	Duration (ms)	
1	1	17.3	47.3	2.73	212	Pass
	2	17.3	47.2	2.73	213	Pass
	3	17.3	46.8	2.71	213	Pass
2	1	17.4	47.1	2.71	212	Pass
	2	17.2	46.8	2.72	212	Pass
	3	17.3	46.8	2.71	212	Pass

Test Loop Number	When Measured	Connector Resistance (μΩ)			Connector Temperature (˚C)
		Left	Control	Right	
1	Before surge 1	439	747	433	6.3
	After surge 3	464	821	630	30.9
	Relative % change	6	10	45	--
2	Before surge 1	466	1,007	466	13.2
	After surge 3	462	1,000	462	10
	Relative % change	1	1	1	--

Sequential Testing

For the Series of Sequential Tests, all of the connectors undergo current-temperature cycling and freeze-thaw tests. The connectors are then split into two groups: half go through the salt spray and fault current test, and the other half undergo acid and fault current tests (see Figure 4).

Current-Temperature Cycling

The Current -Temperature Cycling test consists of a test loop with applied connectors. A section of the loop that has no connector is termed the “control.” Current is applied to raise the temperature of the control to 350˚C. This temperature is held for one hour, after which the loop is allowed to cool down to the ambient temperature before the next current is applied. The test is repeated for twenty-five cycles. A photograph of the test setup is shown in Figure 5.

The stated objective of the test is to ensure the conformance to resistance criteria of connections subjected to temperature changes caused by fluctuating currents. The high temperatures achieved also serve to remove excess anti-oxidants that could otherwise block corrosive elements from attacking the joint between the connector and the conductor during subsequent tests in the series. Therefore, the order that the tests appear in the sequence is important because it systematically provides exposure to the most difficult conditions. In Figure 6 the connectors do not get as hot as the control conductor when current is applied. This is because the connectors have more mass than the conductor alone, and this extra mass, when combined with the tightness of the IEEE Std. 837-2002 crimp, acts as a heat sink, proving that the connectors have more current-carrying capability than the conductors to which they are attached.

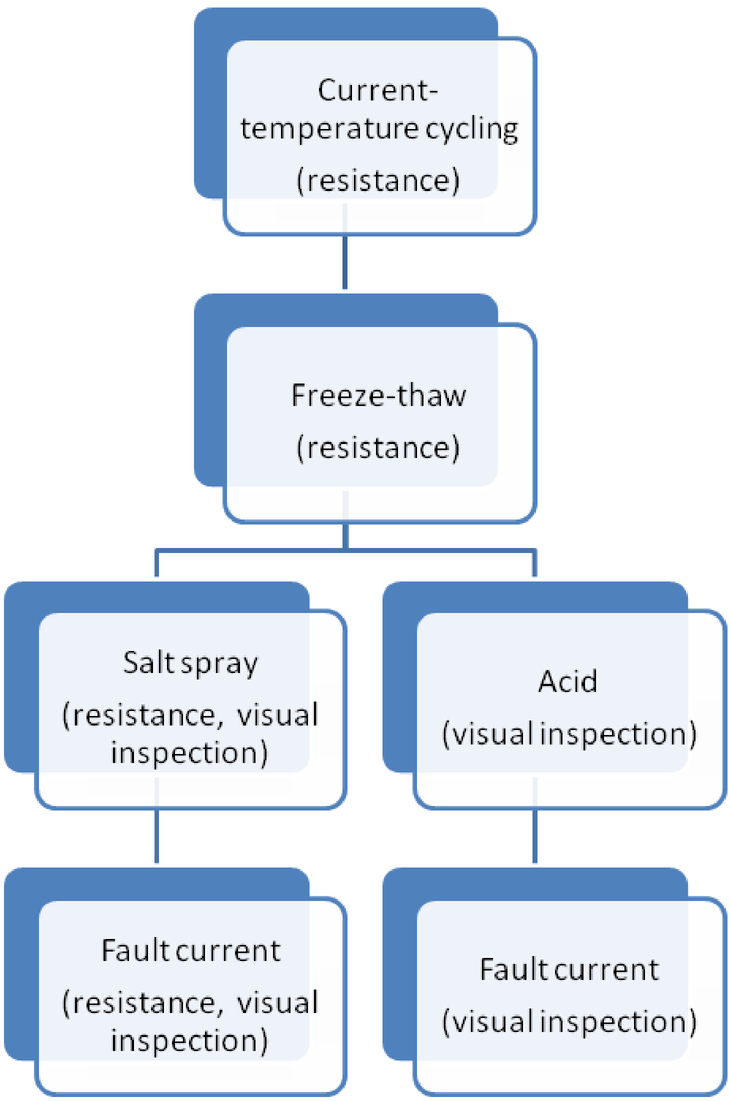


Figure 4. Series of Sequential Tests. Acceptance criteria for each test is noted in parentheses.

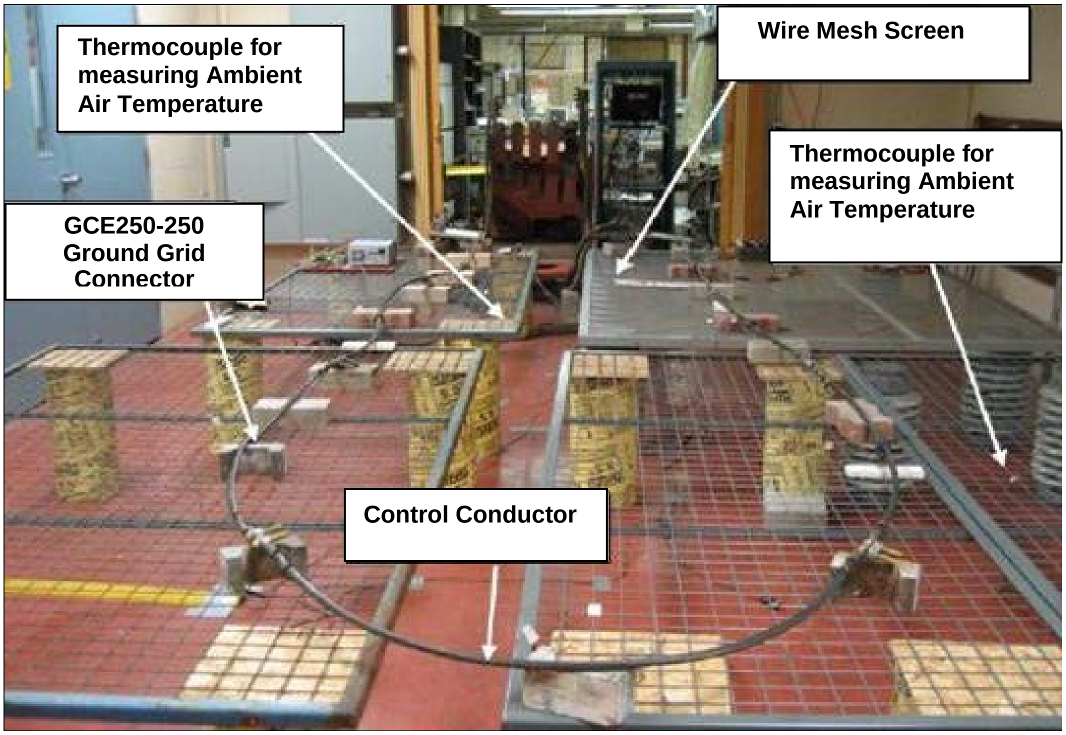


Figure 5. Current-temperature cycling test setup as performed by Kinectrics.

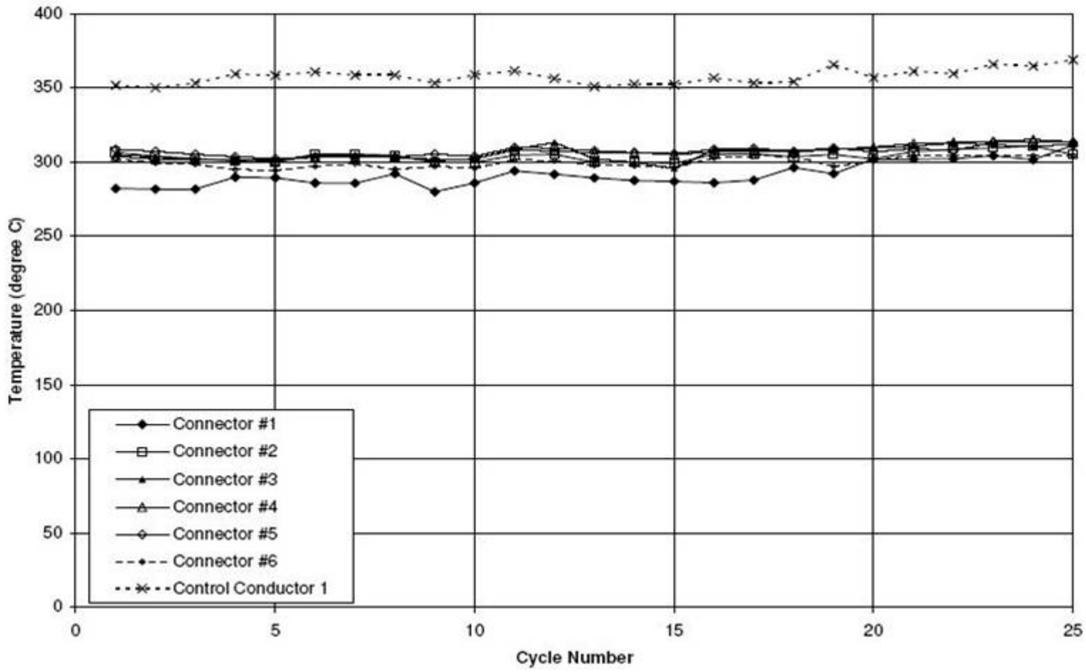


Figure 6. Temperature measurement of control and test samples. During this test, the connectors ran approximately 50˚C cooler than the control conductor. Compression connectors have more mass and therefore have more current-carrying capability than the conductor to which they are attached.

Freeze -Thaw Test

Ideally, the grounding system is installed below the frost line, but connectors are often installed where they are subjected to freeze and thaw cycles. The IEEE Std. 837 test recognizes this and accounts for it by subjecting the samples to ten freeze-thaw cycles. The freeze-thaw test is an attempt to work water into the joint between the connector and the conductor. If water gets into this area when the system is frozen, the water will expand as it turns into ice, opening up the joint between the conductor and the connector. If the test is successful in damaging the joint, this damage will be uncovered by the resistance checks that are done before and after the test. Test setup is shown in Figure 7.

Corrosion Tests

The corrosion tests come next. Test samples are split evenly into two groups. The first connector group is subjected to a salt spray test performed in accordance with ASTM B117-97. The salt spray test models connector installation in soils having high salt content. The second connector group is submerged in a solution of nitric acid (HNO_3) and distilled water (10% by volume) until there is a 20% reduction in cross-sectional area (as determined by weight). This test explores the ability of a connector to withstand installation in a highly corrosive environment, and is meant to examine whether the connector will survive the useful life of the conductor. Test setups are shown in Figure 8.

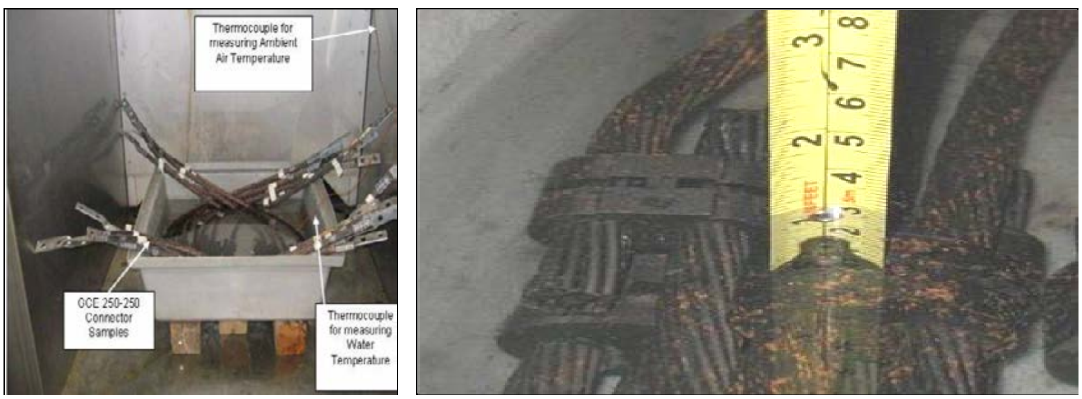


Figure 7. Connectors in water for freeze-thaw testing. The temperature is lowered to at least -10°C, and then raised to at least 20°C. The IEEE Std. 837 test requires that ten freeze-thaw cycles be completed.

Figure 8. Corrosion test setup groups. Salt spray (left) and acid tests (right).

After undergoing these initial tests, each group of test connectors is then subjected to three surge currents to determine whether the ground system would hold up to substation-type electrical faults after decades of being buried in the ground. Ninety percent of the fusing current is applied for 10 seconds. Between surges, the connectors are allowed to cool to 100°C or less. Test setups are illustrated in Figure 9. If the connectors have been damaged by the previous tests, the mechanical jarring created by the application of fault current will further open up the joint between the connector and conductor, increasing the resistance of the connection.

The Panduit® StructuredGround™ connectors passed the Series of Sequential Tests. An example of a connector that completed the acid sequence test is shown in Figure 10. Measured results of both the salt spray and acid sequence tests for the GCE250-250 connectors are in Table 3. While the samples that went through acid sequence were not required to have a resistance test, these values were measured, and no significant increase in resistance was observed.

Figure 9. Fault current test layout for the acid sequence and salt spray samples.

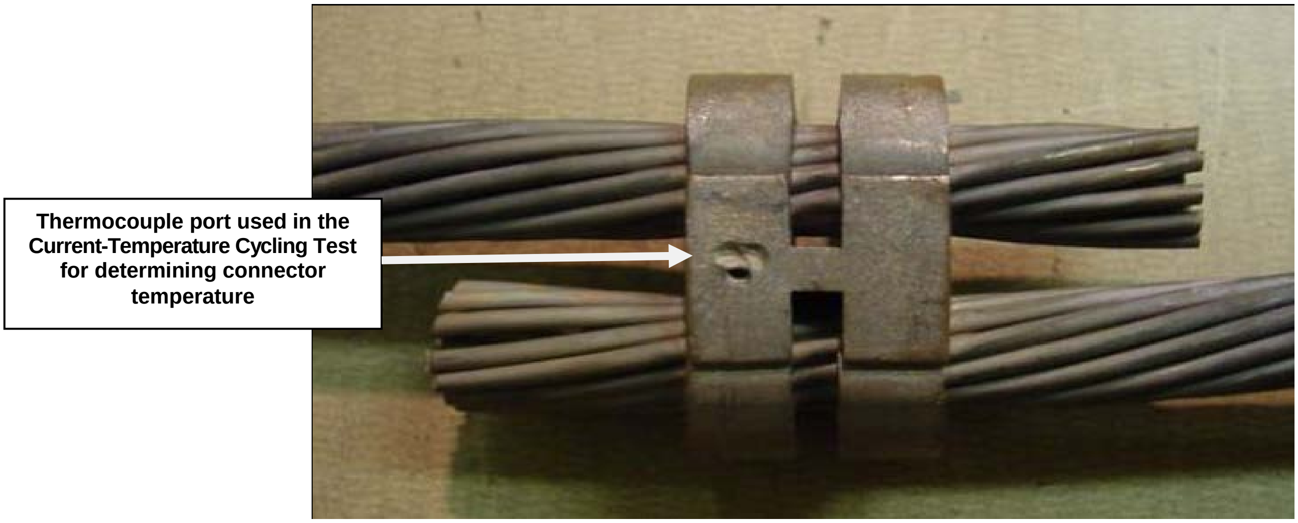


Figure 10. This connector has completed the acid sequence test.

Table 3. Results of Corrosion Testing for Panduit GCE250-250 Connectors.

Subtest: Acid Sequence	**Connector #2 (mΩ)**	**Connector #4 (mΩ)**	**Connector #6 (mΩ)**	**Connector #10 (mΩ)**	**Connector #11 (mΩ)**	**Connector #12 (mΩ)**	**Control #1 (mΩ)**
Initial resistance (A)	0.1832	0.1848	0.1849	0.1801	0.1783	0.1811	0.1693
After current-temperature cycling	0.1681	0.1681	0.1670	0.1676	0.1670	0.1675	0.1691
After freeze-thaw cycling (B)	0.2066	0.2096	0.2099	0.1829	0.1915	0.1928	0.1689
Ratio (B/A)	1.13	1.13	1.14	1.02	1.07	1.06	1.00
Outcome	PASS	PASS	PASS	PASS	PASS	PASS	N/A

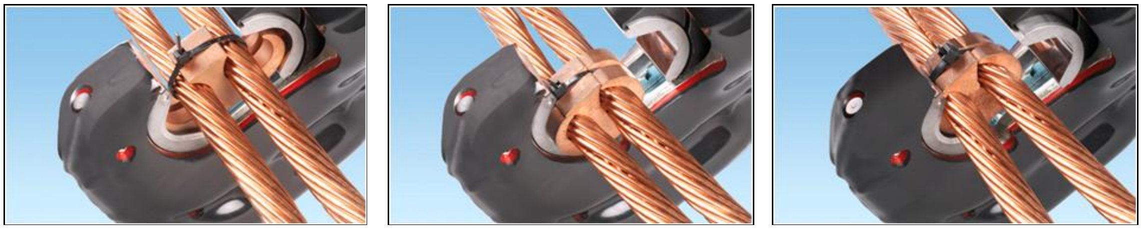
Subtest: Salt Spray Sequence	**Connector #1 (mΩ)**	**Connector #3 (mΩ)**	**Connector #5 (mΩ)**	**Connector #7 (mΩ)**	**Connector #8 (mΩ)**	**Connector #9 (mΩ)**	**Control #2 (mΩ)**
Initial resistance (A)	0.1862	0.1807	0.1842	0.1827	0.1840	0.1781	0.1699
After current-temperature cycling	0.1675	0.1683	0.1692	0.1673	0.1683	0.1671	0.1683
After freeze-thaw cycling	0.2166	0.2065	0.2159	0.1964	0.2075	0.1900	0.1676
After salt spray	0.1956	0.2311	0.2465	0.1986	0.2198	0.1887	0.1686
After fault current (B)	0.2238	0.2359	0.2123	0.2473	0.2498	0.2525	0.1703
Ratio (B/A)	1.20	1.31	1.15	1.35	1.36	1.42	1.00
Outcome	PASS	PASS	PASS	PASS	PASS	PASS	N/A

Achieving Results with the Panduit® StructuredGround™ Direct Burial Compression Grounding System

The key to passing IEEE Std. 837-2002 lies in the combination of the specific connector designs and the patent pending crimping process used to apply the connectors. The result of this crimping process is a tighter connection that provides better resistance to corrosive elements than any other compression system. Achieving the IEEE Std. 837-2002 crimp is a three step process.

1. The first step is to crimp the connector normally, as would be done for any other connector. After the first crimp is complete, the connection meets the requirements of UL 467, *Grounding and Bonding Equipment*.
2. The second step involves two patented features that are unique to the Panduit system: the slot on the connector, and the locating rib on the die (see Figure 11). Align the slot, which runs through the middle of the connector, with the locating rib, which is on the far side of the die, and crimp the part a second time. During this second crimp, the full tonnage of the tool is placed on only one-half of the connector, providing additional connector compression.
3. For the third step of the process, the connector is re-located to the original crimping position within the tool, and the part is crimped again. This time, all compressive force is placed on the half of the connector that was not crimped in step two. A side-by-side graphic of the crimp process is shown in Figure 12.

Figure 11. Locating (a) rib on crimp die and (b) slot in connector.



Step One—normal crimp

Step Two—align slot in connector with locating rib on die to crimp half of part a second time

Step Three—move the die back to the normal crimping location on the connector to crimp other half a second time

Figure 12. IEEE Std. 837™-2002 crimp – a three step process.

Figure 13 shows a connector that was crimped through steps one and two. As shown in the photo, the second crimp provides an additional 3/8" compression (approximately 9mm). The two sections that comprise Figure 14 show the effects of additional compression inside the crimp pocket. Gaps between the conductor and connector body are minimized, inhibiting corrosive elements from entering the crimp pocket and causing connection degradation.

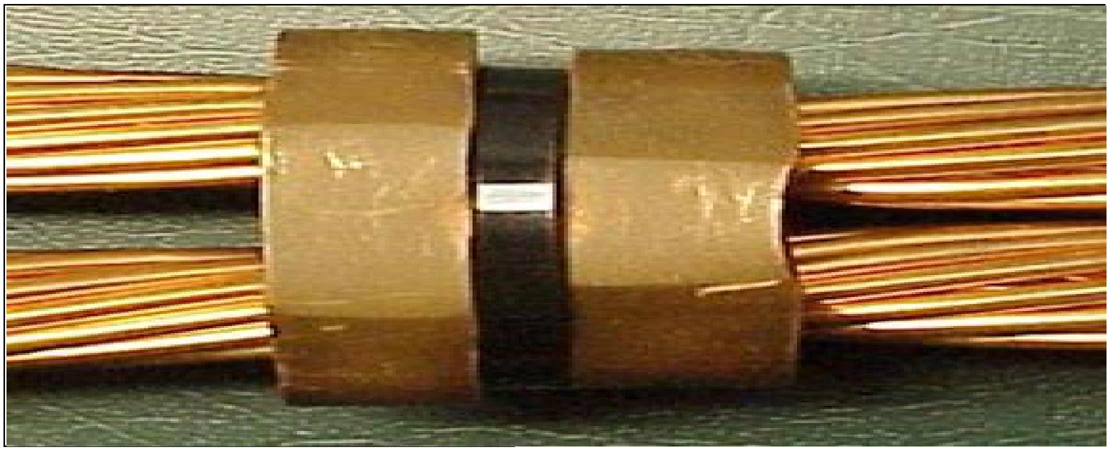


Figure 13. Connector crimped through steps one and two, showing the additional compression achieved by the enhanced crimping process.

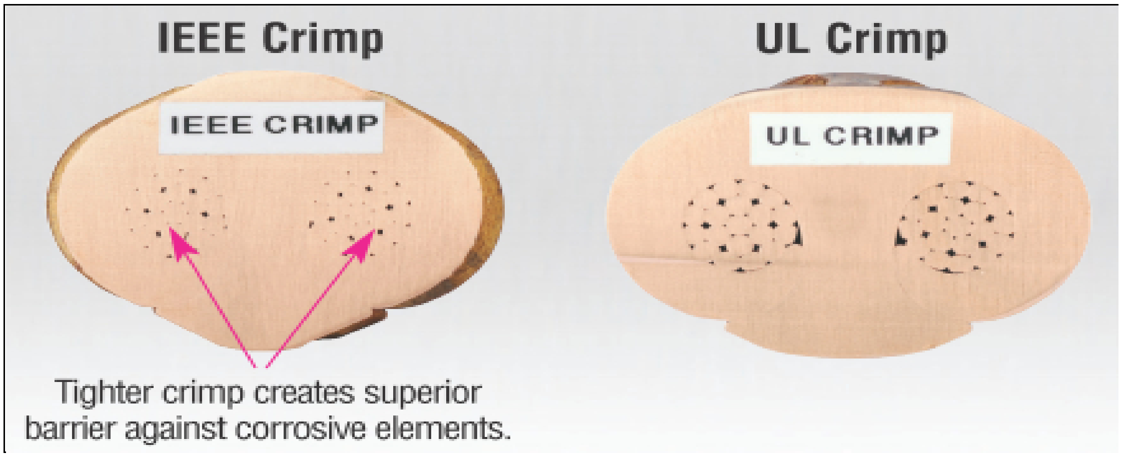


Figure 14. Connector sectioned after a normal crimp, and connector sectioned after the IEEE Std. 837-2002 process, showing a tighter barrier against corrosive elements.

Preventing Installation Errors through Robust Connection System Design

Although fundamental connector technology is robust, a ground system failure can occur due to the misapplication of the connectors. Three common issues related to the installation of grounding connectors include:

1. Compression connector installations may suffer due to the misalignment of the connector within the tool, resulting in a crimp that does not cover the full width of the part
2. Installing the connector with the wrong tool, which is a common concern with both compression and exothermic connector installations
3. Confusion over which conductors can be connected with any given connector

If a connector is misaligned in the crimping tool, the result will be a connection that has less surface contact area, increasing the connection resistance and decreasing the pull-out strength of the connection. The locator dies shown in Figure 11 address the connector misalignment issue. The installer slides the part into the jaws of the tool until the locator on the die stops the part. Because of the locator die, installers are guaranteed a full-width crimp every time.

Panduit® StructuredGround™ connectors utilize a patented anti-oxidant and conductive grit compound to improve pullout performance. Other compression grounding systems require the installer to pre-crimp (emboss) ground rods before applying compression grounding connectors. The gritted anti-oxidant in the Panduit® StructuredGround™ system eliminates the pre-crimping process, preventing a situation where the installer forgets to apply the pre-crimp, which results in a crimp that does not meet any version of IEEE Std. 837.

The Panduit® StructuredGround™ Direct Burial Compression Grounding System connectors retain their UL Listing, CSA Certification, and IEEE Std. 837-2002 compliance with select competitors' tools and Panduit dies. Not only does this flexibility result in a cost savings for installers who can continue using tools they already have, but it reduces the potential for error that may occur if a part is installed with the wrong tool. The Panduit enhanced crimp process meets the new performance requirements, providing unmatched verification of corrosion resistance. Also, the connector is marked with a color code that matches the color code on the installation dies, as shown in Figure 15, simplifying die selection and further reducing the chance for error.

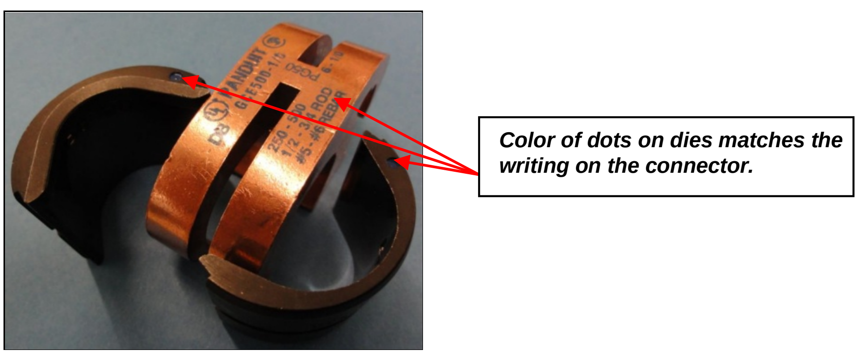


Figure 15. Color codes matching the connector with the die that installs the part minimize confusion related to installation tooling.

One final area of clarification regarding part selection relates to identifying which connectors are required for different conductor combinations. While exothermic welding is very specific—molds only accommodate connections of a specific conductor to another specific conductor – each connector in the Panduit compression system accommodates a wide range of conductor sizes and types (e.g. copper conductor, ground rod, and reinforcing bar).

While an exothermic installation may require dozens of molds, the entire Panduit system for copper conductor sizes from #6 solid to 500kcmil, ½" ground rod up to ¾" ground rod, and #3 rebar up to #6 rebar, is accommodated with only twelve connectors and three die sets. Most installations require only a few part numbers to be completed. Limiting the part numbers required to complete a project results in less time devoted to inventory maintenance.

In addition to handling a wide range of conductors, each Panduit compression tap is marked with the range of conductors it accommodates on the pocket into which the conductor is inserted (see Figure 16). Such markings speed installation and eliminate uncertainty over which conductors may be inserted into each crimp pocket.

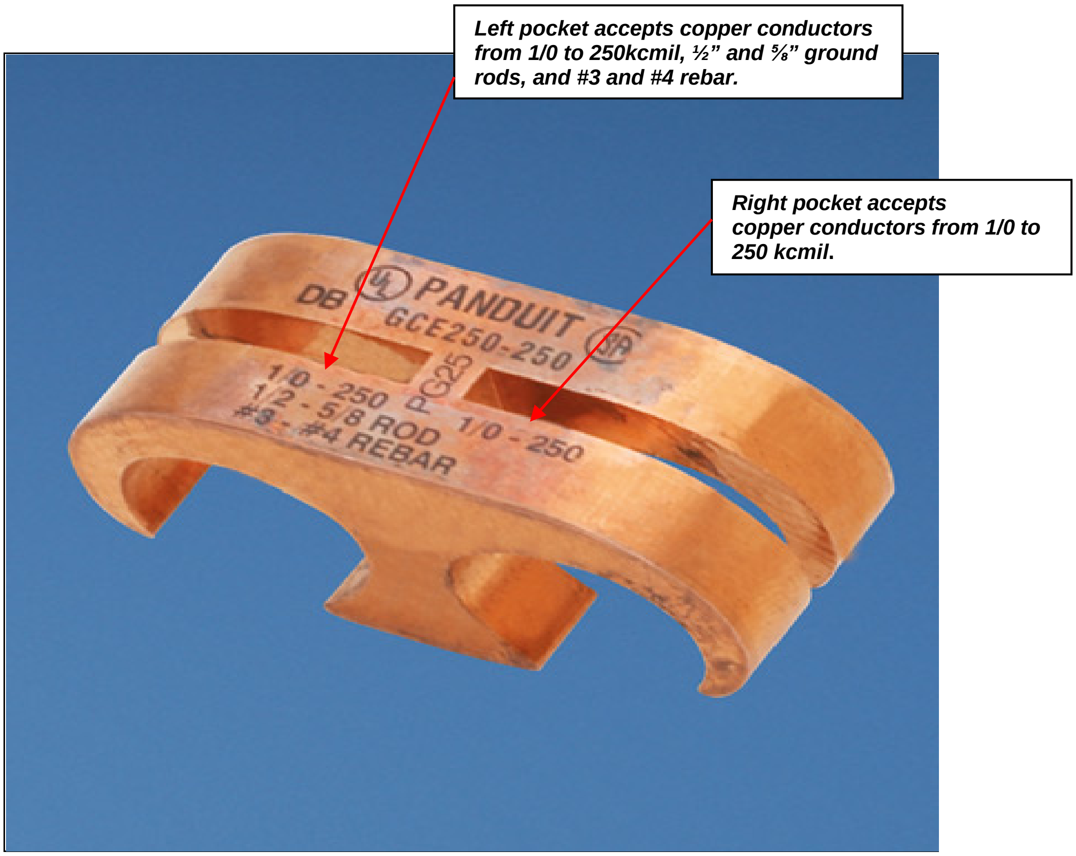


Figure 16. The conductor that the connector accepts is marked on each pocket.

Inspecting the Connection

Besides the fire and burn risks associated with exothermic welding, which are nonexistent with compression systems, it is very difficult to inspect an exothermic weld. The photos in Figure 17 are from the *Installers and Inspectors Guide for Cadweld Electrical Connections*, a leading exothermic manufacturer, and illustrate the difficulty in determining the difference among acceptable connections.

Most installers cannot tell visually why the top left connector in Figure 17 is better than the bottom left connector. Many people would be more inclined to accept the bad connector on the bottom left and reject the good connector on the top right. Due to the difficulty of inspection, most installers hit the connections with a hammer, if anything is done to inspect the weld at all. If the connector does not fall off when struck, it is assumed to be good. The consequence of this process is that bad connections get buried. The example in Figure 18 is an exothermic weld that the installer believed was good and would have buried had the connection not broken off when positioning the conductor for a second weld nearby.

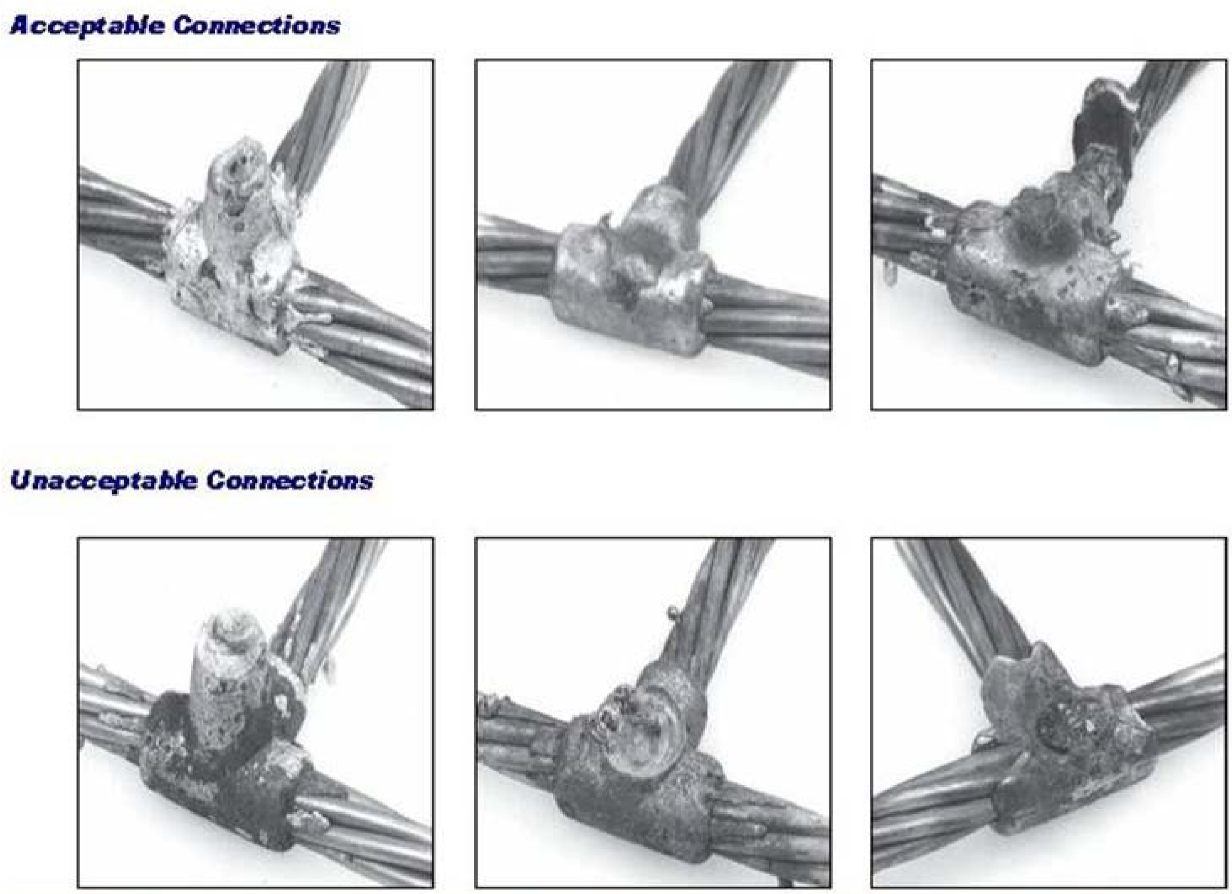


Figure 17 - Good and bad exothermic welds. It is difficult to tell the difference between acceptable and unacceptable connections.

Figure 18. Example of a bad (i.e. broken) exothermic weld that would have been accepted but for a chance discovery. The installer thought this weld was acceptable upon visual inspection.

By contrast, the Panduit system is fully inspectable. When crimped once, the Panduit® StructuredGround™ Direct Burial Compression Grounding System embosses the part a single time. When the IEEE Std. 837-2002 crimping process is completed, the part is embossed two times. Whoever inspects the installation can tell whether the connection meets the specification just by looking at the embossing, as shown in Figure 19.

Table 4 compares compression and exothermic grounding systems.

Part crimped one time embosses die numbers once

Part crimped to IEEE Std.837-2002 is embossed two times

Figure 19. The Panduit® StructuredGround™ Direct Burial Compression Grounding System is comprised of connectors that can be fully inspected, minimizing the risk that a connector that does not meet the engineering specification would be buried.

Table 4. Comparison of Compression and Exothermic Grounding Systems.

Feature	StructuredGround™ Compression	Exothermic
Reliability for Demanding Applications		
IEEE Std. 837-2002	Yes	No - Some exothermic systems meet IEEE Std. 837-1989, but exothermic systems exist that do not meet any version of IEEE Std. 837
UL 467, Grounding and Bonding Equipment	Yes	Yes
Irreversible connection	Yes	Yes
Installation		
Flameless installation process	Yes	No
Efficient installation	Yes - Installs in one-third the time of exothermic welding, has only three dies to maintain, no hot work permits, and no waiting for connections to cool	No – In addition to the time required to perform the connection, mold selection and maintenance, more time is needed to obtain hot work permits and wait for connections to cool (45 to 60 minutes after the last connection is complete to ensure that fires do not start)
Installation in various weather conditions	Yes - Weather conditions do not affect installation	No -May experience problems in wet, cold, or windy environments
Inspectability		
Visual inspection indicators	Yes, die numbers are embossed for easy inspection	No, difficult to inspect. Most installers hit with a hammer and look to see if the weld remains attached to the conductor

Conclusion

Trouble-free installation is paramount to long-term system reliability and this paper has detailed the thoroughness of the IEEE Std. 837 test sequences. It has also shown how the changes made to the acceptance criteria between the 1989 and the 2002 versions of the 837 test standard allowed the development of a system whose corrosion resistance is unlike that of any compression system previously available.

First, the harsh environments in which grounding systems are installed must be simulated in a comprehensive test process to prove the connector's capabilities. Next, potential installation errors must be eliminated by incorporating solutions to common problems into the product design. Finally, an easy-to-implement verification process must be developed that proves connectors are installed properly.

Comprehensive, integrated technology from Panduit addresses the grounding and bonding needs of the entire infrastructure. As a solution architecture, the Panduit® StructuredGround™ Direct Burial Compression Grounding System is complemented by a range of installation tooling, design software, and services.

For long-term reliability, always specify that grounding connectors must be compression wherever possible, and that those compression connectors must meet IEEE Std. 837-2002.

Referenced Standards

- IEEE Std. 837-2002, “IEEE Standard for Qualifying Permanent Connections Used in Substation Grounding”, 2002.
- Ontario Hydro Technologies, “Substation Grounding Connectors, IEEE Std., 837-1989 Test Series”
- Report No. C-95-EST-193-P
- ASTM B-1 “Standard Specification for Hard-Drawn Copper Wire”, 2007
- ASTM B117-97 “Standard Practice for Operating Salt Spray (Fog) Apparatus, 2001
- Installers and Inspectors Guide for Cadweld Electrical Connections, 2005.
- UL 467, “Grounding and Bonding Equipment”, 2007

Disclaimer

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About Panduit

Panduit is a world-class developer and provider of leading-edge solutions that help customers optimize the physical infrastructure through simplification, increased agility and operational efficiency. Panduit’s Unified Physical Infrastructure℠ (UPI) based solutions give enterprises the capabilities to connect, manage and automate communications, computing, power, control and security systems for a smarter, unified business foundation. Panduit provides flexible, end-to-end solutions tailored by application and industry to drive performance, operational and financial advantages. Panduit’s global manufacturing, logistics, and e-commerce capabilities along with a global network of distribution partners help customers reduce supply chain risk. Strong technology relationships with industry leading systems vendors and an engaged partner ecosystem of consultants, integrators and contractors together with its global staff and unmatched service and support make Panduit a valuable and trusted partner.

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