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MEMORANDUM

TO: Code-Making Panel 1

FROM: Sarah Caldwell, *Committee Administrator*

DATE: March 10, 2023

SUBJECT: NEC® Proposed Tentative Interim Amendment (TIA) No. 1695

The attached proposed Tentative Interim Amendment (TIA) Log No. 1695 is being submitted to you for ballot. This proposed TIA was submitted by Peter Graser of Copperweld, American Bimetallic Association and we have received written agreement to the processing of the submitted TIA from David Williams of Delta Charter Township, and Dean Hunter of MN Department of Labor & Industry.

This proposed TIA will be published for public comment in the March/April 2023 issue of *NFPA News* with a Public Comment Closing Date of April 27, 2023. Any public comments received will be circulated to the committee. Finally, the Standards Council will review and consider the issuance of this TIA.

In accordance with Section 5 of the *Regulations Governing the Development of NFPA Standards*, you are being balloted on the technical merits of the proposed TIA and whether this matter is of an emergency nature.

The ballot can now be accessed through the NFPA online ballot system at the following link: [NFPA Ballot Link](#). The link will bring you to your profile page and once you sign in, select the My Committees tab and click on the blue Vote button which will direct you to the ballot site.

Please complete the ballot on or before **March 24, 2023 by 11:59PM (ET)**.

While completing your ballot, please remember the following:

- **A comment is required for both Question No. 1 and Question No. 2 for the online TIA ballot. Comments must accompany all Negative, Abstaining and Agree votes.**
- **If you vote “Agree” on Question 1, simply add “Agree” to the comment field and if you vote “Agree” on Question 2, insert the applicable letter(s) selections in the comment field which can be found in the Instructions box on the ballot site.**

You must hit SUBMIT to SAVE your work. **Note:** the system session will time you out after 45 minutes; any work not submitted at that time will not be saved! You may return to finish or change your ballot at any time up to the closing date. Ballot comments exceeding 4,000 characters must be submitted in a Word document via email, to Sarah Caldwell at scaldwell@nfpa.org.

Note: Please remember that the return of ballots and attendance at committee meetings are required in accordance with the Regulations Governing the Development of NFPA Standards.

NFPA 70®-2023 Edition
National Electrical Code®

TIA Log No.: 1695

Reference: 110.14

Comment Closing Date: April 27, 2023

Submitter: Peter Graser, Copperweld Bimetallic, American Bimetallic Association

www.nfpa.org/70

1. Revise 110.14 to read as follows:

110.14 Electrical Connections. Because of different characteristics of dissimilar metals, devices such as pressure terminal or pressure splicing connectors and soldering lugs shall be identified for the material of the conductor and shall be properly installed and used. Conductors of dissimilar metals shall not be intermixed in a terminal or splicing connector where physical contact occurs between dissimilar conductors unless the device is identified for the purpose and conditions of use. Copper and aluminum, or copper-clad aluminum and aluminum shall be considered dissimilar metals. Copper and copper-clad aluminum shall not be considered dissimilar metals. Materials such as solder, fluxes, inhibitors, and compounds, where employed, shall be suitable for the use and shall be of a type that will not adversely affect the conductors, installation, or equipment.

Connectors and terminals for conductors more finely stranded than Class B and Class C stranding as shown in Chapter 9, Table 10, shall be identified for the specific conductor class or classes.

Substantiation: A critical piece of user information was removed in the 2023 NEC revision cycle. The removal of the parenthetical statement in Section 110.14 Electrical Connections, results in installers and inspectors losing all reference in NFPA 70 that copper-clad aluminum (CCA) and aluminum are dissimilar metals, and that copper and copper-clad aluminum are not dissimilar metals. In the action to remove the parentheticals, the panel created a potential for misapplication and hazard.

For the application of electrical connections, clarity is paramount to ensure safety. Intermixing two dissimilar metals (single-metal copper to single-metal aluminum, or copper-clad aluminum to single-metal aluminum) can lead to galvanic corrosion at points of connection, which has long been considered a hazard by this Code. Extensive laboratory testing, and over a half century of real-world usage, have established that CCA conductors perform safely in electrical connections with copper conductors because of the two material's metallurgical similarity. However, the opposite is not true. CCA cannot safely intermix with aluminum in an AL Only connector. In short, there clearly exists the possibility of wrongfully intermixing single-metal aluminum to CCA if no reference in the NEC exists. The national installation guide, the NEC, should not risk leaving installation guidance to product safety standards.

In the 2020 cycle, panel 1 established that CCA and copper are not dissimilar metals for electrical connection purposes (see the committee statement contained in the substantiation).

Technical substantiation supported this decision. In the 2023 NEC, without a clear reference stating such (having removed the parentheticals), installers are now more inclined to interpret copper-clad aluminum and aluminum to be similar metals because they 1) share ampacity columns in highly referenced tables in article 310 and 2) they share the word “aluminum” in their names and 3) 90% of the cross-sectional area of CCA wire is aluminum, appearing to the user to be “mostly aluminum.” Installers are generally not metallurgists. Consequently, installers are more inclined to make an error without clear text to give direction. Logically, without clear direction stating otherwise, installers are more inclined to wrongfully intermix CCA and aluminum by employing connectors suitable for “aluminum only,” creating a hazardous condition.

Fearing galvanic corrosion, the NEC has spent many decades ensuring that dissimilar metals are never intermixed without employing devices, terminals and splice connectors specifically listed for such use. This proposed text aids clarity, resolves any style manual issues, and is in line with the NEC tradition of making sure dissimilar metals are never connected electrically without properly identified splice and termination methods. The fact that CCA and copper are similar metals is indisputable. This fact maintains consensus on the panel. To avoid hazards, this fact should be clearly stated in text in section 110.14 Electrical Connections.

Emergency Nature: The proposed TIA intends to offer to the public a benefit that would lessen a recognized (known) hazard or ameliorate a continuing dangerous condition or situation. The proposed TIA intends to correct a circumstance in which the revised NFPA Standard has resulted in an adverse impact on a product or method that was inadvertently overlooked in the total revision process or was without adequate technical (safety) justification of the action.

Intermixing copper-clad aluminum (CCA) and aluminum, conductors of two dissimilar metals, can lead to deleterious effects for the installation due to galvanic corrosion at points of termination and splice. This potential is hazardous and indisputable. Our mandate as panel members is to create text that gives clear direction (limiting inferences) to all readers of Code to ensure safe and correct electrical installations. The current text correctly cites that dissimilar metals shall not be intermixed, but it also fails to define which metals employed as conductors in NFPA 70 are similar and dissimilar, leaving Code readers to infer on their own. No other reference exists in the NEC stating that CCA and aluminum are in fact dissimilar metals, and are subject to galvanic corrosion if connected in an Aluminum Only rated connector. There is no more logical place to put such information than in section 110.14 Electrical Connections. To prevent hazardous misuse, it is critical that proper information be communicated to users, put in the most logical place, and written in easily consumable text. This TIA does so.

List of supporting documents for Peter Graser's technical substantiation for a proposed TIA to NFPA 70 regarding Section 110.14 Electrical Connections:

-  01.110.14 PC 1361 SR 8059
-  02.BillKane.MaterialScienceExpert
-  03.1.Westmoreland Galvanic Corrosion in CCA
-  03.T&B UL 486C Thrm Cycling with 2020 PI 2112.Public Doc
-  04.Intertek E228 CCA Thermal Stability i6049.01-106-31-r0
-  05.Intertek E228 Copper Thermal Stability i6049.01-106-31-r0
-  06.Term and Cond Temp Thermocycling Report Part II w_Append
-  07.Terminal and Conductor Temperature Testing Part I Fnl
-  08.Elec Con Analysis nbsbuildingscience63
-  09.UL.COPPER CLAD ALUMINUM APRIL 2 1971 BULLETIN PLUS JAN FAN ARTICLE



Second Revision No. 8059-NFPA 70-2018 [Section No. 110.14 [Excluding any Sub-Sections]]

Because of different characteristics of dissimilar metals, devices such as pressure terminal or pressure splicing connectors and soldering lugs shall be identified for the material of the conductor and shall be properly installed and used. Conductors of dissimilar metals shall not be intermixed in a terminal or splicing connector where physical contact occurs between dissimilar conductors (such as copper and aluminum, ~~copper and copper-clad aluminum, or aluminum~~ or aluminum and copper-clad aluminum), unless the device is identified for the purpose and conditions of use. Materials such as solder, fluxes, inhibitors, and compounds, where employed, shall be suitable for the use and shall be of a type that will not adversely affect the conductors, installation, or equipment.

Connectors and terminals for conductors more finely stranded than Class B and Class C stranding as shown in Chapter 9, Table 10, shall be identified for the specific conductor class or classes.

Submitter Information Verification

Committee: NEC-P01

Submittal Date: Tue Oct 30 14:02:54 EDT 2018

Committee Statement

Committee Statement: Copper and copper-clad aluminum has been deleted from the dissimilar metal list for the application of this requirement.

Response Message: SR-8059-NFPA 70-2018

Public Comment No. 1361-NFPA 70-2018 [Section No. 110.14 [Excluding any Sub-Sections]]

Thornton Tomasetti

Via email: pgraser@copperweld.com

January 3, 2023

Peter Graser
Vice President - Building Wire
COPPERWELD
5141 Virginia Way, Suite 410
Brentwood, TN 37027

RE: ELECTRICAL CONNECTIONS WITH COPPER CLADDED ALUMINUM CONDUCTORS
TT Project No. L22112.00

Dear Mr. Graser:

Thank you for the opportunity to provide a materials science assessment for the above referenced matter. I have attached a copy of my Curriculum Vitae for your reference. At your request I have reviewed some factors around certain electrical connections in the latest revision of the NFPA 70 code. In particular, I reviewed the material issues regarding copper-clad aluminum (CCA) and dissimilar metal connections.

The similarity of two metals electrically connected and exposed to a common environment is determined by their electrochemical potentials, which is a measure of the energy driving corrosion. Metals with different electrochemical potentials in a given environment are considered dissimilar, and when two dissimilar metals are joined in a corrosive environment, they create a galvanic couple.¹ This coupling leads to galvanic corrosion, accelerated corrosion of a metal because of an electrical contact with a more noble metal or nonmetallic conductor. Accelerated corrosion due to dissimilar metal coupling has been observed and studied since at least the 18th century.

Bimetals are components consisting of two metals that are combined to achieve material properties that cannot be obtained with a single metal. A common means of producing bimetal involves coextrusion, the simultaneous extrusion or drawing of two metals to form an integrated product. This process was first developed in 1863 but gained more commercial application in the nuclear industry in the middle of the 20th century.² Coextrusion has been applied in a wide variety of industries, including for electrical applications where CCA is used in wire, rod, and bus bar forms. Thermo-mechanical processing during the production of CCA can produce a metallurgical bond between the copper cladding and aluminum core.³

¹ ASM Handbook, Volume 13 – Corrosion, ASM International, 1983.

² ASM Handbook, Volume 14A – Metalworking: Bulk Forming, 2005.

³ Sasaki, T.T., et al., Scripta Materialia, Volume 63, Issue 5, 2010, pgs. 488-491.

Thornton Tomasetti

RE: ELECTRICAL CONNECTIONS WITH COPPER COATED ALUMINUM CONDUCTORS
TT Project No. L22112.00

Page 2 of 2

When CCA is used in an electrical connection the copper cladding contacts the other components of the connection. As a result, CCA performs more like a solid copper conductor than a solid aluminum conductor. This is most evident in the values of electrical contact resistance for a given contact pressure, where CCA is comparable to copper and significantly less than aluminum.⁴ Variations in contact resistance result from differences in the natural oxide layer that forms on the surface of metals, and the aluminum oxide that forms in ambient conditions has a much higher resistivity than the analogous copper oxide.⁵ Therefore, CCA is similar to solid copper in both its electrical and electrochemical behavior, as was confirmed in thermocycling testing⁶ and galvanic corrosion testing.⁷ Like with a solid copper conductor, connecting a CCA conductor to aluminum creates a dissimilar metal couple and could lead to galvanic corrosion if an electrolyte is present.

Thornton Tomasetti is an engineering firm that optimizes the design and performance of structures, materials, and systems for projects of every size and level of complexity. We are an employee-owned organization of engineers, scientists, architects, and other professionals collaborating from offices worldwide. As a member of our Forensics practice, I am part of a multidisciplinary team with expertise to investigate and analyze a broad range of issues, including metallurgy, strength of materials, and environmental degradation. On behalf of the firm, thank you again for the opportunity to assist in this matter. If you have any additional questions, please do not hesitate to contact me.

Sincerely,

THORNTON TOMASETTI, INC.



William M. Kane
Vice President

⁴ Meese, W.J. and Cilimberg, R.L., *Analysis of Current Technology on Electrical Connections in Residential Branch Circuit Wiring*, U.S. Dept. of Commerce, National Bureau of Standards, March 1975, pg. 7.

⁵ Fan, J.C., *Mechanisms of Building Wire Connection Failure*, A Texas Instruments Engineering, Inc., report, Bulletin No. 516-TB93-1070.

⁶ Eaton Laboratories, *Terminal and Conductor Temperature Testing of 14 AWG Copper-Clad Aluminum and 14 AWG Copper Conductors, Part II – Thermocycling Tests*, November 13, 2020.

⁷ Westmoreland Mechanical Testing & Research, Inc., WMT&R Report 8-70626, August 6, 2018.

WILLIAM KANE, PH.D., P.E.

Vice President



Summary

William Kane joined the Philadelphia Forensics practice at Thornton Tomasetti in 2021, bringing 15 years of experience in failure analysis and prevention. He is a recognized expert in materials and mechanical engineering with concentrations in metallurgy, strength and performance of materials, and environmental degradation. Dr. Kane has consulted on a wide range of issues including medical devices and implants, utility and infrastructure components, consumer products, welding, buildings and structures, construction equipment, piping, industrial and pharmaceutical production equipment, railcars, and automotive components. He has experience in fracture mechanics, microscopy, mechanical testing, corrosion and materials selection. Dr. Kane has taught at the University of Pennsylvania and Drexel University, and has presented extensively in his field, as well as contributed to multiple publications.

Areas of technical expertise

- Root Cause Failure Analysis
- Environmental Degradation of Materials
- Materials Science and Engineering

Education

- Ph.D., Materials Science & Engineering, 2005, University of Pennsylvania
- M.S., Materials Science & Engineering, 2003, University of Pennsylvania
- B.S., Materials Science & Engineering, 2001, University of Pennsylvania

Registrations

- Licensed Professional Engineer in DE, MD, NJ, NY, PA, & VA
- Certified Welding Inspector (CWI), American Welding Society
- Certified ASNT ACCP Level II, American Society for Nondestructive Testing

Professional activities

- Member, ASM International
- Member, American Welding Society
- Member, ASTM International
- Board Member, Physical Sciences Technical Advisory Committee, Ben Franklin Technology Partners (BFTP)
- Lecturer, University of Pennsylvania, 2009-2018
- Adjunct Faculty, Drexel University, 2010-2012

Select project experience

Root cause failure analysis

Philadelphia Criminal Justice Center Elevator Failure,

Philadelphia, PA.* Mechanical and metallurgical investigation to determine the cause of an elevator accident.

Arthroscopic Surgery Tool Failure, Ephrata, PA.* Metallurgical analysis of a fractured arthroscopic shaver tool to determine the cause of the failure.

Cervical Plate System Failure Analysis, Philadelphia, PA.* Metallurgical analysis of fractured screws from a medical device to determine the cause of the fracture.

Petroleum Tanker Rupture, Kaysville, UT.* Investigation into the rupture of a DOT tanker that was involved in a motor vehicle accident.

Six Flags Chiller Rollercoaster Wheel Failure, Jackson, NJ.* Investigation into the failure of welded components on an amusement park ride that failed during operation.

Huntington Station Crane Collapse, Alexandria, VA.* Mechanical and metallurgical investigation to determine the cause of a tower crane collapse.

Environmental degradation of materials

Pharmaceutical Water Storage Tank Failure, Philadelphia, PA.* Metallurgical investigation to determine the cause and extent of cracking in a 22,000-gallon distilled water storage tank.

Naudain Street Gas Explosion, Philadelphia, PA.* Metallurgical investigation to determine the cause and extent of pipe corrosion that contributed to a gas leak.

Materials science & engineering

Great Wolf Lodge Premises Investigation, Scotrun, PA.* Materials evaluation of the platform surfaces on an indoor water park feature.

*Denotes work performed with previous employer.

WILLIAM KANE, PH.D., P.E.

Lacrosse Ball Usability Study, Philadelphia, PA.* Materials evaluation examining the effects of aging on lacrosse balls.

Boiler Fitness-for-Service Assessment, Philadelphia, PA.* Investigation to determine the cause of cracking and remaining structural integrity of a steam boiler superheater header.

Sworn testimony

Trial experience

Nelson v. United States, U.S. District Court for the Eastern District of Pennsylvania, 2022.

Wright v. Residence Inn Philadelphia, et al,* Court of Common Pleas, Philadelphia County. 2017.

Osmun v. Pat's King of Steaks, et al,* Court of Common Pleas, Philadelphia County. 2017.

Steinman v. Spinal Concepts, Inc.,* U.S. District Court, Western District of NY. 2013.

State Farm Fire & Casualty Co. v. Carroll Water Systems, Inc., et al,* In the District Court of MD for Carroll County. 2012.

Deposition experience

Viscovich v. Fendi S.R.L., et al, U.S. District Court for the Southern District of NY. 2021.

GATX Corp. v. Georgia Power Co.,* U.S. District Court for the Northern District of GA. 2021.

Malone v. Elsbury Jr., et al,* In the Circuit Court of Harrison County, WV. 2020.

Sherrick v. Sunrise Medical, et al,* Court of Common Pleas, Franklin County, OH. 2020.

Moxham, et al v. M&J Overhead Door LLC, et al,* Superior Court Judicial District of Danbury. 2019.

Lopez v. Ryder Truck Rental, Inc., et al,* Superior Court of NJ, Essex County. 2018.

Evans, et al v. Globus Medical, Inc., et al,* In the Circuit Court of Baltimore County, MD. 2016.

IPSCO Tubulars, Inc. v. Ajax Tocco Magnethermic Corp.,* U.S. District Court for the Eastern District of AR. 2013.

Select papers, lectures and publications

"Preservation and Preparation of Fracture Specimens," ASM Handbook, Volume 12 – Fractography, ASM International. In press as of Sept 2021 (author)

"Tibial tray fracture in a modern prosthesis with retrieval analysis," Arthroplast Today 2018; 4:143-147 (co-author)

"Retrieval and clinical analysis of distraction-based dual growing rod constructs for early-onset scoliosis," The Spine Journal 2017, 17(10): 1506-1518 (co-author)

"Preserving Evidence in a Product Liability Case: Focus on Medical Devices," American Bar Association Litigation Group, Expert Witnesses Committee Article, February 21, 2017 (co-author)

"Mechanical Properties and Their Measurement," ASM International Metallurgy for the Non-Metallurgist course, Coatesville, PA, November 2014 (author)

"Failure Analysis for Medical Device Engineers," ASM International, Materials Park, OH, August 2014 (author)

"Collapse of Jet Center Hangars Under Snow Load," 2014 Structures Congress, American Society of Civil Engineers, Boston, MA, April 2014 (co-author)

"Method of characterizing fretting and corrosion at the various taper connections of retrieved modular components from metal-on-metal total hip arthroplasty. ASTM STP1560: Metal-On-Metal Total Hip Replacement Devices," ASTM International, 2013 (co-author)

"In vivo deformation, surface damage, and biostability of retrieved dynesys systems," Spine, November 2010; 35(23):1310-E1316 (co-author)

"Brittle intergranular fracture of a Ni-based superalloy at high temperatures by dynamic embrittlement," Materials Science and Engineering A 2004; 387-389:409-413, December 15 (co-author)

"MSE 495/496 – Senior Design," University of Pennsylvania, 2012-2018 (lecturer)

"MSE 555 – Environmental Degradation of Materials," University of Pennsylvania, 2012-2016 (lecturer)

"Failure Analysis for Medical Device Engineers," ASM International, 2017 (lecturer)

"Fretting and corrosion at the taper connections of retrieved modular components from metal-on-metal total hip arthroplasty," Talk 13, Symposium on Metal-on-Metal Total Hip Replacement Devices, Phoenix, AZ, May 8, 2012 (co-presenter)

"Oxygen-induced dynamic embrittlement in nickel-based superalloys, Interfacial Engineering for Optimized Properties III," MRS 2004; 819:111-120 (co-presenter)

CONTACT

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Metallurgical Laboratory Report

Customer:	Multiple		
Subject:	Galvanic Corrosion in CCA		
Date:	8/9/18		

Analysis By:	Bill Lewey - Metallurgist
Authored By:	Bill Lewey - Metallurgist
Requested By:	Peter Graser

Hypothesis/Purpose:

Hypothesis: When properly connected in an electrical circuit, CCA will act like a solid copper conductor with no galvanic corrosion occurring as a result of the metallurgical bond of the bimetal.

The purpose of this test is to determine the effects of galvanic corrosion in CCA when coupled with copper in an electrolyte solution by measuring the galvanic voltage that occurs between the two metals. Reference tests are made between known similar and dissimilar metals in order to bring scale and perspective to the results.

Test Method

A test was conducted by **Westmoreland Mechanical Testing & Research Inc.** (third party metallurgical and materials testing lab) to determine if galvanic corrosion would occur when CCA is connected to pure copper in an electrolyte solution. The test method used was based on ASTM G71-81(2014) and a description of the test is provided in the attached test report.

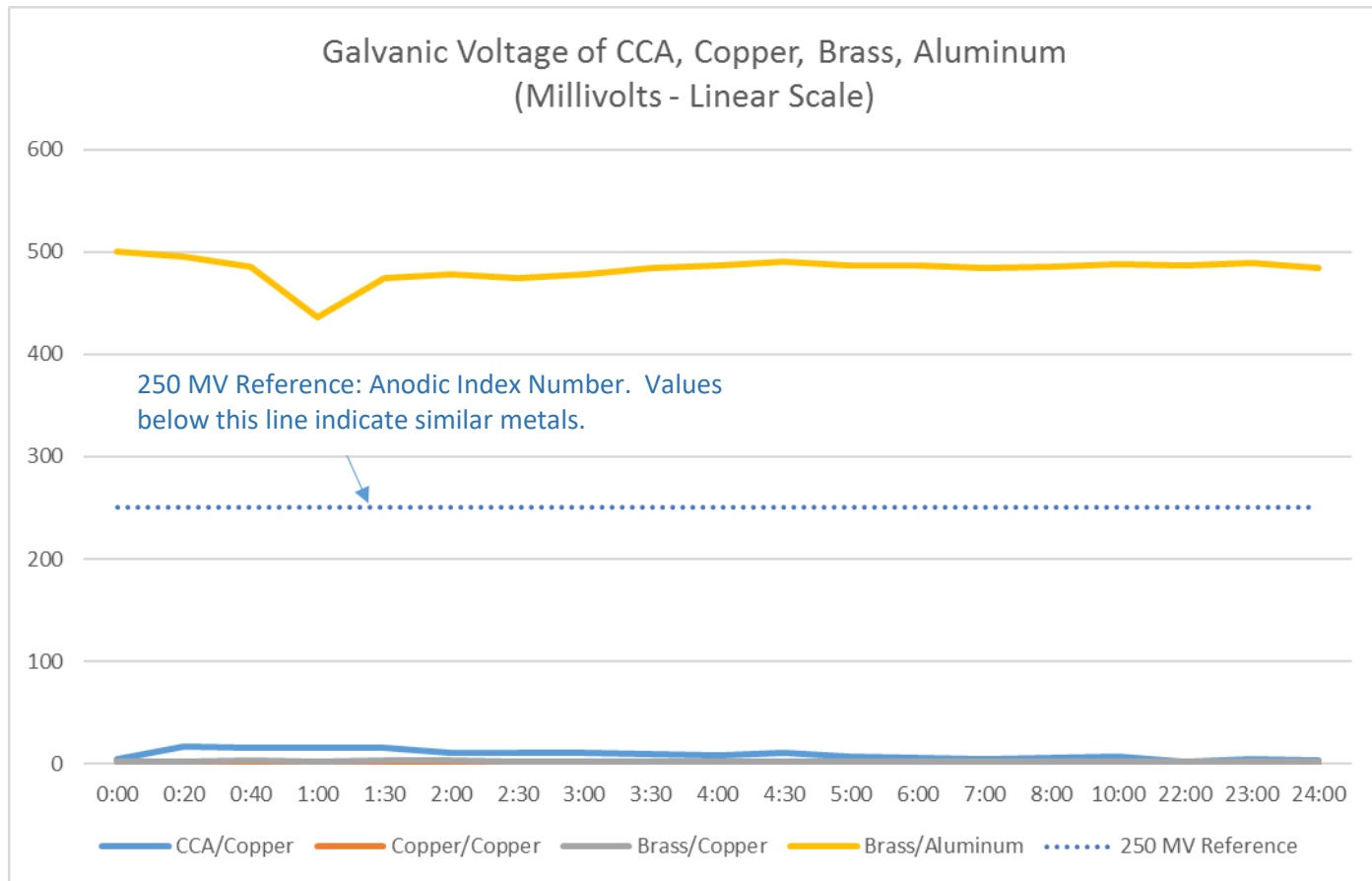
Copperweld conducted additional tests per ASTM G71-81(2014) using a copper/copper connection, a copper/brass connection and an aluminum/brass connection for comparison. Copperweld's tests were conducted using the same method used by Westmoreland.

Results of the testing are shown in the table and graph below.

Conclusion

The galvanic voltage measured between CCA and copper connected in an electrolyte solution was found to be only slightly higher than the voltage measured between a copper/copper connection and a copper/brass connection. The voltage measured between dissimilar aluminum/brass was more than 50 times higher than the CCA and copper.

CCA was shown to perform galvanically similar to single-metal copper.



Lab Galvanic Connection	Westmoreland CCA/Copper	Copperweld Copper/Copper	Copperweld Brass/Copper	Copperweld Brass/Aluminum
Time(Hr:Min)	Galvanic Current (mV)	Galvanic Current (mV)	Galvanic Current (mV)	Galvanic Current (mV)
0:00	4.43	2.48	2.44	499.89
0:20	16.47	2.21	2.32	496.03
0:40	15.42	1.03	2.55	486.17
1:00	15.26	1.75	2.46	436.62
1:30	15.27	0.62	2.64	474.96
2:00	11.01	0.52	2.68	478.6
2:30	10.15	0.95	2.48	475.06
3:00	11.02	0.57	2.47	478.29
3:30	9.81	0.66	2.4	483.96
4:00	8.58	1.22	2.24	487.13
4:30	10.12	1.58	2.15	490.85
5:00	6.98	0.93	2.28	486.3
6:00	5.75	0.95	2.06	487.1
7:00	4.75	0.59	2.09	485.01
8:00	4.97	0.47	2.13	485.98
10:00	6.93	0.56	2.1	488.5
22:00	1.52	0.74	2.14	486.91
23:00	3.81	0.68	2.1	489.63
24:00	3.45	0.77	2.11	484.59
Average Voltage	8.72	1.01	2.30	483.24
Weight Loss	.002 gm	.0015 gm	.0011 gm	.0012 gm
Visual Exam	Slight discoloration, no corrosion visible	Slight discoloration, no corrosion visible	Slight discoloration, no corrosion visible	Slight discoloration, no corrosion visible



Westmoreland Mechanical Testing & Research, Inc.
P.O. Box 388; 221 Westmoreland Drive
Youngstown, PA 15696-0388 U.S.A.
Telephone: 724-537-3131 Fax: 724-537-3151
Website: www.wmtr.com E-Mail: admin@wmtr.com
WMT&R is a technical leader in the material testing industry

06 August 2018

Copperweld Bimetallies
254 Cotton Mill Road
Fayetteville, TN 37334

Page 1 of 1

WMT&R Report 8-70626
P.O. No. 042640
WMT&R Quote No. QN183134

Attention: Bill Lewey

Subject: Galvanic corrosion testing of submitted sample per ASTM G71-81(2014) and purchase order requirements.

Introduction: One (1) lot, consisting of one (1) 9 gauge copper clad aluminum wire and one (1) flat copper strip, was received at Westmoreland Mechanical Testing and Research, Incorporated, for galvanic corrosion testing per ASTM G71-81 (2014) and purchase order requirements. Prior to exposure, both parts were cleaned with reagent alcohol and the copper clad aluminum wire was weighed. The copper clad aluminum anode was bent in a U shape and positioned in the electrolyte solution such that a thirty (30) cm length of wire was exposed. The flat copper cathode was positioned such that 35 cm² of surface area was exposed. The parts were positioned one (1) cm apart. The parts were exposed to a 3.5% NaCl in deionized water solution for a continuous period of 24 hours. The galvanic voltage generated was measured initially and periodically throughout the test. Upon completion of the test, a final voltage was measured, the specimens were cleaned, the copper clad aluminum wire was weighed, and the specimens were given a visual examination.

Results:

CORROSION – Galvanic Corrosion Testing per ASTM G71-81 (2014) and Purchase Order Requirements

REQUIREMENTS: Report

(Test Log No. 725BQH)

No corrosion was visible on the surface of the copper clad aluminum anode.

Weight loss 0.002g

Time (Hr:Min)	Galvanic Current (mV)
0:00	4.43
0:20	16.47
0:40	15.42
1:00	15.26
1:30	15.27
2:00	11.01
2:30	10.15
3:00	11.02
3:30	9.81
4:00	8.58
4:30	10.12
5:00	6.98
6:00	5.75
7:00	4.75
8:00	4.97
10:00	6.93
22:00	1.52
23:00	3.81
24:00	3.45

If you have any questions concerning this report, please feel free to contact me. If I am unavailable, you may also speak with Mr. Andrew M. Wisniewski, Metallographic/Chemical Analysis Manager.

At your service

Scott Sylvester
Assistant Analytical Manager

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Public Input No. 2112-NFPA 70-2017 [Section No. 110.14 [Excluding any Sub-Sections]]

. . Electrical connections shall comply with the following:

(A) Conductors . . Electrical connections of conductors shall comply with the following:

(1) Connector Identification. Because of different characteristics of dissimilar metals, devices such as pressure terminal or pressure splicing connectors and soldering lugs shall be identified for the material of the conductor and shall be properly installed and used. ~~Conductors~~ **(2) Dissimilar Metals.** Conductors of dissimilar metals shall not be intermixed in a terminal or splicing connector where physical contact occurs between dissimilar conductors (such as copper and aluminum, copper and copper-clad aluminum, or aluminum and copper-clad aluminum), unless the device is identified for the purpose and conditions of use. ~~Materials~~ **(3) Suitability for Use .** Materials such as solder, fluxes, inhibitors, and compounds, where employed, shall be suitable for the use and shall be of a type that will not adversely affect the conductors, installation, or equipment. **(4) Finely Stranded Conductors** .

Connectors and terminals for conductors more finely stranded than Class B and Class C stranding as shown in Chapter 9, Table 10, shall be identified for the specific conductor class or classes. Remaining sections to be renumbered to (B) through (E).

Additional Proposed Changes

<u>File Name</u>	<u>Description</u>	<u>Approved</u>
CCA_UL486C_twist_on_connector_test_at_TnB_08-09-11.pdf	486 C Test Report for CCA thermal stability and compatibility with Connecting to Cu	✓

Statement of Problem and Substantiation for Public Input

Copper-clad aluminum with the outer covering of copper does not have contact as a dissimilar metal when installed in pressure wire or pressure splicing connectors. The metal to metal contact is copper to copper. It should be noted that by its design the copper cladding on copper clad aluminum is metallurgically bonded to the aluminum core. Testing completed to UL 486C has shown that there is no issue with copper-clad aluminum being connected to copper in pressure wire and pressure splicing connectors. The prohibition for direct connection of copper to aluminum and aluminum to copper-clad aluminum as dissimilar metals is correct except where the device is listed and identified for that application. The revisions into subsections for the exiting charging paragraph into a list format improves clarity and readability for what are four different requirements. The existing sections in the 2017 NEC numbered 110.14(A) through 110.14(D) to be renumbered as 110.14(B) through 110.14(E). No technical changes intended for sections 110.14(A) through 110.14(D).

While this allowance may enter the Code in this section, the requirements that circuit breakers, connectors, device and end use equipment would have to be identified for use with copper-clad aluminum conductors is still in place.

This Public Input is one of 19 being submitted for consideration in the 2020 NEC cycle to expand the potential use of copper-clad aluminum conductors

Related Public Inputs for This Document

<u>Related Input</u>	<u>Relationship</u>
Public Input No. 2111-NFPA 70-2017 [Section No. 110.5]	
Public Input No. 2110-NFPA 70-2017 [Definition: Copper-Clad Aluminum Conductors.]	

Submitter Information Verification**Submitter Full Name:** Peter Graser**Organization:** Copperweld**Street Address:****City:****State:****Zip:****Submittal Date:** Thu Aug 10 20:20:06 EDT 2017**Copyright Assignment**

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SOUTHAVEN LABORATORY TEST REPORT

8735 Hamilton Road, Southaven, MS 38671

TO: Rodolfo Elizondo	T&B PROJECT #: HM400098	UL Project #:	N/A
FACILITY: Southwind	RECEIVED: 3/31/2011	UL File #:	N/A
UL 486C Fifth Edition September 7, 2004 (Revision Date: August 25, 2006)			

DESCRIPTION OF TEST SAMPLES:

Marrette 739 and 65 twist on wire connectors

DESCRIPTION/ PURPOSE OF TEST:

Performed tests per UL486C

-Clause 7.2 (Current Cycling Test)

-Clause 7.3 (Static Heating sequence)

SUMMARY:

All samples passed.

ENVIRONMENTAL STATEMENT:

Unless specified otherwise in the individual Methods, the test shall be conducted under the following environmental conditions. Confirmation of these conditions shall be recorded at the time the test is conducted.

Ambient Temp. (°C) 23±5°C Relative Humidity (%) 50±20% Barometric Pressure (mBar) N/A

REPORTED BY: Mike Henry/Zach Winters	DATE:	APPROVED BY: James Baker	DATE: 8-9-11
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T&B Project Number: HM400098

Room Temp. (°C): 21.4

UL Project Number: N/A

Room Humidity (%RH): 55

UL File Number: N/A

Test Date: 2011-06-02

Sample Received Date: 2011-03-31

Tested By (Print): Mike Henry/ Zach Winters

Sample Source: DC Canada

Witness/Approval:

Catalog Number(s): 739P

Description: Twist on Wire Connectors without Oxide Inhibitor

Standard - NMX-J-548-ANCE-2004 • C22.2 NO. 188-04 • UL 486C (September 7, 2004)

CURRENT CYCLING (CLAUSE 7.2 - September 7, 2004)

Procedure: The specimen sets per Clause 8.2 shall complete 500 cycles of equal current-on and current-off operations for the time and current specified in Table 6. Upon completion of the current-cycling test no connector shall exceed 125°C temperature rise and the stability factor shall not exceed ± 10 .

Main Wire Size/Type: #12 Sol Cu, THHN or THWN, 90 deg C, 600V

Tap Wire Size/Type: #12 Sol CCA, THHN or THWN, 90 deg C, 600V

Strip Length (in.): 11/16"

Torque (in-lbf): 5

Installation Tool: N/A

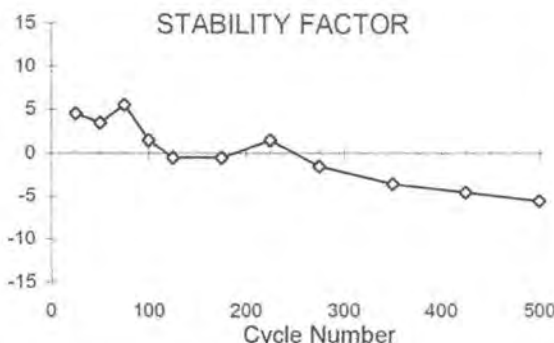
Number of Crimps: N/A

Die: N/A

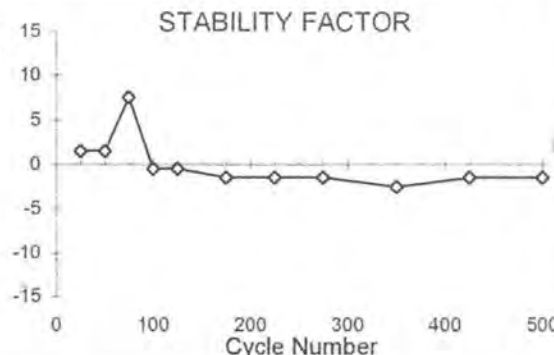
Cycling-Current (A): 43

SAMPLE 9

Cycle Number	Actual (°C)	Control (°C)	Ambient (°C)	Heat Rise (°C)	Dev	"S" Factor	
25	86	94	27	59	-8	4.5	
50	83	92	25	58	-9	3.5	
75	78	85	27	51	-7	5.5	
100	83	94	27	56	-11	1.5	
125	81	94	27	54	-13	-0.5	
175	81	94	25	56	-13	-0.5	
225	83	94	26	57	-11	1.5	
275	81	95	26	55	-14	-1.5	
350	79	95	26	53	-16	-3.5	
425	78	95	25	53	-17	-4.5	
500	76	94	25	51	-18	-5.5	

**SAMPLE 10**

Cycle Number	Actual (°C)	Control (°C)	Ambient (°C)	Heat Rise (°C)	Dev	"S" Factor	
25	85	94	27	58	-9	1.5	
50	83	92	25	58	-9	1.5	
75	82	85	27	55	-3	7.5	
100	83	94	27	56	-11	-0.5	
125	83	94	27	56	-11	-0.5	
175	82	94	25	57	-12	-1.5	
225	82	94	26	56	-12	-1.5	
275	83	95	26	57	-12	-1.5	
350	82	95	26	56	-13	-2.5	
425	83	95	25	58	-12	-1.5	
500	82	94	25	57	-12	-1.5	



Notes: Cycle #75 the door had been left open resulting in the change of the control cable temperature.

Equip. (TFE #)	3	1656	1519	1515	3222	441	1061	519	3314		
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T&B Project Number: HM400098

Room Temp. (°C): 21.4

UL Project Number: N/A

Room Humidity (%RH): 55

UL File Number: N/A

Test Date: 2011-06-02

Sample Received Date: 2011-03-31

Tested By (Print): Mike Henry/ Zach Winters

Sample Source: DC Canada

Witness/Approval:

Catalog Number(s): 739P

Description: Twist on Wire Connectors without Oxide Inhibitor

Standard - NMX-J-548-ANCE-2004 • C22.2 NO. 188-04 • UL 486C (September 7, 2004)

CURRENT CYCLING (CLAUSE 7.2 - September 7, 2004)

Procedure: The specimen sets per Clause 8.2 shall complete 500 cycles of equal current-on and current-off operations for the time and current specified in Table 6. Upon completion of the current-cycling test no connector shall exceed 125°C temperature rise and the stability factor shall not exceed ± 10 .

Main Wire Size/Type: #12 Sol Cu, THHN or THWN, 90 deg C, 600V

Tap Wire Size/Type: #12 Sol CCA, THHN or THWN, 90 deg C, 600V

Strip Length (in.): 11/16"

Torque (in-lbf): 5

Installation Tool: N/A

Number of Crimps: N/A

Die: N/A

Cycling-Current (A): 43

SAMPLE 11

Cycle Number	Actual (°C)	Control (°C)	Ambient (°C)	Heat Rise (°C)	Dev	"S" Factor	
25	97	94	27	70	3	1.5	
50	97	92	25	72	5	3.5	
75	93	85	27	66	8	6.5	
100	95	94	27	68	1	-0.5	
125	95	94	27	68	1	-0.5	
175	94	94	25	69	0	-1.5	
225	94	94	26	68	0	-1.5	
275	94	95	26	68	-1	-2.5	
350	94	95	26	68	-1	-2.5	
425	95	95	25	70	0	-1.5	
500	95	94	25	70	1	-0.5	

SAMPLE 12

Cycle Number	Actual (°C)	Control (°C)	Ambient (°C)	Heat Rise (°C)	Dev	"S" Factor	
25	90	94	27	63	-4	0.7	
50	90	92	25	65	-2	2.7	
75	87	85	27	60	2	6.7	
100	91	94	27	64	-3	1.7	
125	91	94	27	64	-3	1.7	
175	87	94	25	62	-7	-2.3	
225	88	94	26	62	-6	-1.3	
275	87	95	26	61	-8	-3.3	
350	87	95	26	61	-8	-3.3	
425	88	95	25	63	-7	-2.3	
500	88	94	25	63	-6	-1.3	

Notes: Cycle #75 the door had been left open resulting in the change of the control cable temperature.

Equip. (TFE #)	3	1656	1519	1515	3222	441	1061	519	3314		
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T&B Project Number: HM400098

Room Temp. (°C): 21.4

UL Project Number: N/A

Room Humidity (%RH): 55

UL File Number: N/A

Test Date: 2011-06-02

Sample Received Date: 2011-03-31

Tested By (Print): Mike Henry/ Zach Winters

Sample Source: DC Canada

Witness/Approval:

Catalog Number(s): 65P

Description: Twist on Wire Connectors with Oxide Inhibitor

Standard - NMX-J-548-ANCE-2004 • C22.2 NO. 188-04 • UL 486C (September 7, 2004)

CURRENT CYCLING (CLAUSE 7.2 - September 7, 2004)

Procedure: The specimen sets per Clause 8.2 shall complete 500 cycles of equal current-on and current-off operations for the time and current specified in Table 6. Upon completion of the current-cycling test no connector shall exceed 125°C temperature rise and the stability factor shall not exceed ± 10 .

Main Wire Size/Type: #12 Sol Cu, THHN or THWN, 90 deg C, 600V

Tap Wire Size/Type: #12 Sol CCA, THHN or THWN, 90 deg C, 600V

Strip Length (in.): 1/2"

Torque (in-lbf): 5

Installation Tool: N/A

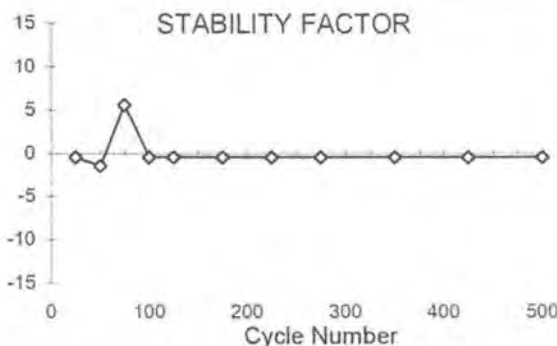
Number of Crimps: N/A

Die: N/A

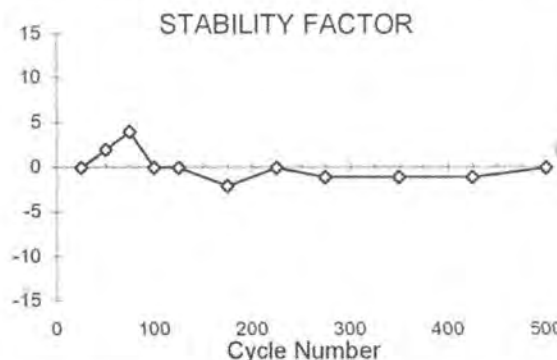
Cycling-Current (A): 43

SAMPLE 25

Cycle Number	Actual (°C)	Control (°C)	Ambient (°C)	Heat Rise (°C)	Dev	"S" Factor	
25	83	94	27	56	-11	-0.5	
50	80	92	25	55	-12	-1.5	
75	80	85	27	53	-5	5.5	
100	83	94	27	56	-11	-0.5	
125	83	94	27	56	-11	-0.5	
175	83	94	25	58	-11	-0.5	
225	83	94	26	57	-11	-0.5	
275	84	95	26	58	-11	-0.5	
350	83	94	25	58	-11	-0.5	
425	84	95	25	59	-11	-0.5	
500	83	94	25	58	-11	-0.5	

**SAMPLE 26**

Cycle Number	Actual (°C)	Control (°C)	Ambient (°C)	Heat Rise (°C)	Dev	"S" Factor	
25	83	94	27	56	-11	-0.1	
50	83	92	25	58	-9	1.9	
75	78	85	27	51	-7	3.9	
100	83	94	27	56	-11	-0.1	
125	83	94	27	56	-11	-0.1	
175	81	94	25	56	-13	-2.1	
225	83	94	26	57	-11	-0.1	
275	83	95	26	57	-12	-1.1	
350	82	94	25	57	-12	-1.1	
425	83	95	25	58	-12	-1.1	
500	83	94	25	58	-11	-0.1	



Notes: Cycle #75 the door had been left open resulting in the change of the control cable temperature.

Equip. (TFE #)	3	1656	1519	1515	3222	441	1061	519	3314		

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T&B Project Number: HM400098

Room Temp. (°C): 21.4

UL Project Number: N/A

Room Humidity (%RH): 55

UL File Number: N/A

Test Date: 2011-06-02

Sample Received Date: 2011-03-31

Tested By (Print): Mike Henry/ Zach Winters

Sample Source: DC Canada

Witness/Approval:

Catalog Number(s): 65P

Description: Twist on Wire Connectors with Oxide Inhibitor

Standard - NMX-J-548-ANCE-2004 • C22.2 NO. 188-04 • UL 486C (September 7, 2004)

CURRENT CYCLING (CLAUSE 7.2 - September 7, 2004)

Procedure: The specimen sets per Clause 8.2 shall complete 500 cycles of equal current-on and current-off operations for the time and current specified in Table 6. Upon completion of the current-cycling test no connector shall exceed 125°C temperature rise and the stability factor shall not exceed ± 10 .

Main Wire Size/Type: #12 Sol Cu, THHN or THWN, 90 deg C, 600V

Tap Wire Size/Type: #12 Sol CCA, THHN or THWN, 90 deg C, 600V

Strip Length (in.): 1/2"

Torque (in-lbf): 5

Installation Tool: N/A

Number of Crimps: N/A

Die: N/A

Cycling-Current (A): 43

SAMPLE 27

Cycle Number	Actual (°C)	Control (°C)	Ambient (°C)	Heat Rise (°C)	Dev	"S" Factor	
25	73	94	27	46	-21	-0.3	
50	72	92	25	47	-20	0.7	
75	69	85	27	42	-16	4.7	
100	73	94	27	46	-21	-0.3	
125	74	94	27	47	-20	0.7	
175	72	94	25	47	-22	-1.3	
225	73	94	26	47	-21	-0.3	
275	72	95	26	46	-23	-2.3	
350	73	94	25	48	-21	-0.3	
425	73	95	25	48	-22	-1.3	
500	73	94	25	48	-21	-0.3	

SAMPLE 28

Cycle Number	Actual (°C)	Control (°C)	Ambient (°C)	Heat Rise (°C)	Dev	"S" Factor	
25	82	94	27	55	-12	-0.5	
50	81	92	25	56	-11	0.5	
75	79	85	27	52	-6	5.5	
100	82	94	27	55	-12	-0.5	
125	83	94	27	56	-11	0.5	
175	82	94	25	57	-12	-0.5	
225	82	94	26	56	-12	-0.5	
275	82	95	26	56	-13	-1.5	
350	81	94	25	56	-13	-1.5	
425	82	95	25	57	-13	-1.5	
500	82	94	25	57	-12	-0.5	

Notes: Cycle #75 the door had been left open resulting in the change of the control cable temperature.

Equip. (TFE #)	3	1656	1519	1515	3222	441	1061	519	3314		

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T&B Project Number: HM400098

Room Temp. (°C): 21.4

UL Project Number: N/A

Room Humidity (%RH): 55

UL File Number: N/A

Test Date: 2011-06-02

Sample Received Date: 2011-03-31

Tested By (Print): Mike Henry/ Zach Winters

Sample Source: DC Canada

Witness/Approval:

Catalog Number(s): 739P

Description: Twist on Wire Connectors without Oxide Inhibitor

Standard - NMX-J-548-ANCE-2004 • C22.2 NO. 188-04 • UL 486C (September 7, 2004)

CURRENT CYCLING (CLAUSE 7.2 - September 7, 2004)

Procedure: The specimen sets per Clause 8.2 shall complete 500 cycles of equal current-on and current-off operations for the time and current specified in Table 6. Upon completion of the current-cycling test no connector shall exceed 125°C temperature rise and the stability factor shall not exceed ± 10 .

Main Wire Size/Type: #10 Sol CCA, THHN or THWN, 90 deg C, 600V

Tap Wire Size/Type: #10 Sol CCA, THHN or THWN, 90 deg C, 600V

Strip Length (in.): 11/16"

Torque (in-lbf): 5

Installation Tool: N/A

Number of Crimps: N/A

Die: N/A

Cycling-Current (A): 60

SAMPLE 13

Cycle Number	Actual (°C)	Control (°C)	Ambient (°C)	Heat Rise (°C)	Dev	"S" Factor	
25	111	98	22	89	13	-2.8	STABILITY FACTOR
50	113	97	22	91	16	0.2	
75	112	97	23	89	15	-0.8	
100	113	93	23	90	20	4.2	
125	117	96	23	94	21	5.2	
175	112	96	24	88	16	0.2	
225	111	97	24	87	14	-1.8	
275	112	94	24	88	18	2.2	
350	111	96	24	87	15	-0.8	
425	112	97	24	88	15	-0.8	
500	111	100	24	87	11	-4.8	

SAMPLE 14

Cycle Number	Actual (°C)	Control (°C)	Ambient (°C)	Heat Rise (°C)	Dev	"S" Factor	
25	114	98	22	92	16	0.2	STABILITY FACTOR
50	115	97	22	93	18	2.2	
75	115	97	23	92	18	2.2	
100	116	93	23	93	23	7.2	
125	113	96	23	90	17	1.2	
175	114	96	24	90	18	2.2	
225	115	97	24	91	18	-1.5	
275	116	94	24	92	22	2.5	
350	117	96	24	93	21	1.5	
425	120	97	24	96	23	3.5	
500	121	100	24	97	21	1.5	

Notes:

Equip. (TFE #)	37	1356	1355	1061	519	1439	3314	1656	443		

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T&B Project Number: HM400098

Room Temp. (°C): 21.4

UL Project Number: N/A

Room Humidity (%RH): 55

UL File Number: N/A

Test Date: 2011-06-02

Sample Received Date: 2011-03-31

Tested By (Print): Mike Henry/ Zach Winters

Sample Source: DC Canada

Witness/Approval:

Catalog Number(s): 739P

Description: Twist on Wire Connectors without Oxide Inhibitor

Standard - NMX-J-548-ANCE-2004 • C22.2 NO. 188-04 • UL 486C (September 7, 2004)

CURRENT CYCLING (CLAUSE 7.2 - September 7, 2004)

Procedure: The specimen sets per Clause 8.2 shall complete 500 cycles of equal current-on and current-off operations for the time and current specified in Table 6. Upon completion of the current-cycling test no connector shall exceed 125°C temperature rise and the stability factor shall not exceed ± 10 .

Main Wire Size/Type: #10 Sol CCA, THHN or THWN, 90 deg C, 600V

Tap Wire Size/Type: #10 Sol CCA, THHN or THWN, 90 deg C, 600V

Strip Length (in.): 11/16"

Torque (in-lbf): 5

Installation Tool: N/A

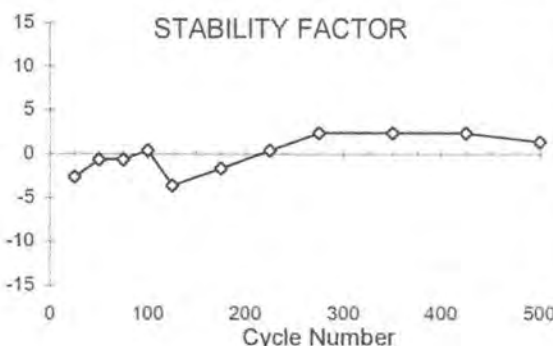
Number of Crimps: N/A

Die: N/A

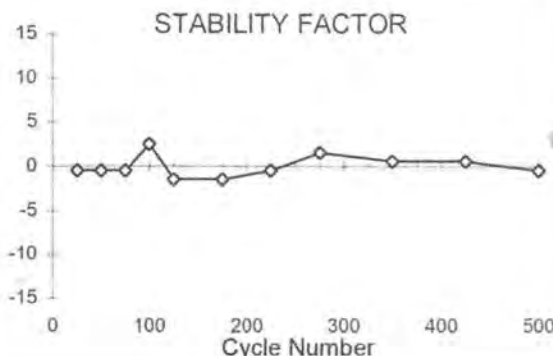
Cycling-Current (A): 60

SAMPLE 15

Cycle Number	Actual (°C)	Control (°C)	Ambient (°C)	Heat Rise (°C)	Dev	"S" Factor	
25	124	98	22	102	26	-2.6	
50	125	97	22	103	28	-0.6	
75	125	97	23	102	28	-0.6	
100	122	93	23	99	29	0.4	
125	121	96	23	98	25	-3.6	
175	123	96	24	99	27	-1.6	
225	126	97	24	102	29	0.4	
275	125	94	24	101	31	2.4	
350	127	96	24	103	31	2.4	
425	128	97	24	104	31	2.4	
500	130	100	24	106	30	1.4	

**SAMPLE 16**

Cycle Number	Actual (°C)	Control (°C)	Ambient (°C)	Heat Rise (°C)	Dev	"S" Factor	
25	116	98	22	94	18	-0.5	
50	115	97	22	93	18	-0.5	
75	115	97	23	92	18	-0.5	
100	114	93	23	91	21	2.5	
125	113	96	23	90	17	-1.5	
175	113	96	24	89	17	-1.5	
225	115	97	24	91	18	-0.5	
275	114	94	24	90	20	1.5	
350	115	96	24	91	19	0.5	
425	116	97	24	92	19	0.5	
500	118	100	24	94	18	-0.5	



Notes:

Equip. (TFE #)	37	1356	1355	1061	519	1439	3314	1656	443		

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T&B Project Number: HM400098

Room Temp. (°C): 21.4

UL Project Number: N/A

Room Humidity (%RH): 55

UL File Number: N/A

Test Date: 2011-06-02

Sample Received Date: 2011-03-31

Tested By (Print): Mike Henry/ Zach Winters

Sample Source: DC Canada

Witness/Approval:

Catalog Number(s): 65P

Description: Twist on Wire Connectors with Oxide Inhibitor

Standard - NMX-J-548-ANCE-2004 • C22.2 NO. 188-04 • UL 486C (September 7, 2004)

CURRENT CYCLING (CLAUSE 7.2 - September 7, 2004)

Procedure: The specimen sets per Clause 8.2 shall complete 500 cycles of equal current-on and current-off operations for the time and current specified in Table 6. Upon completion of the current-cycling test no connector shall exceed 125°C temperature rise and the stability factor shall not exceed ± 10 .

Main Wire Size/Type: #10 Sol CCA, THHN or THWN, 90 deg C, 600V

Tap Wire Size/Type: #10 Sol CCA, THHN or THWN, 90 deg C, 600V

Strip Length (in.): 1/2"

Torque (in-lbf): 5

Installation Tool: N/A

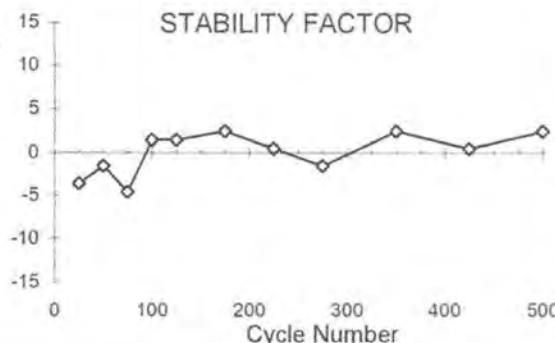
Number of Crimps: N/A

Die: N/A

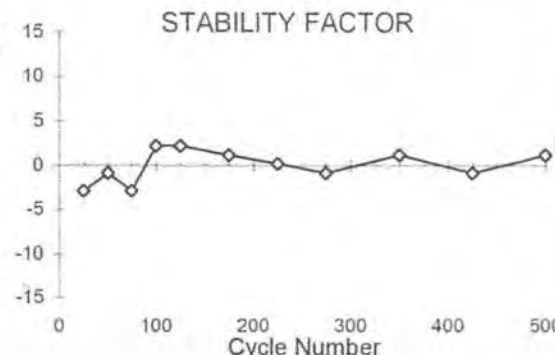
Cycling-Current (A): 60

SAMPLE 29

Cycle Number	Actual (°C)	Control (°C)	Ambient (°C)	Heat Rise (°C)	Dev	"S" Factor	
25	103	98	22	81	5	-3.5	
50	104	97	22	82	7	-1.5	
75	101	97	23	78	4	-4.5	
100	103	93	23	80	10	1.5	
125	106	96	23	83	10	1.5	
175	107	96	24	83	11	2.5	
225	106	97	24	82	9	0.5	
275	101	94	24	77	7	-1.5	
350	107	96	24	83	11	2.5	
425	106	97	24	82	9	0.5	
500	111	100	24	87	11	2.5	

**SAMPLE 30**

Cycle Number	Actual (°C)	Control (°C)	Ambient (°C)	Heat Rise (°C)	Dev	"S" Factor	
25	109	98	22	87	11	-2.8	
50	110	97	22	88	13	-0.8	
75	108	97	23	85	11	-2.8	
100	109	93	23	86	16	2.2	
125	112	96	23	89	16	2.2	
175	111	96	24	87	15	1.2	
225	111	97	24	87	14	0.2	
275	107	94	24	83	13	-0.8	
350	111	96	24	87	15	1.2	
425	110	97	24	86	13	-0.8	
500	115	100	24	91	15	1.2	



Notes:

Equip. (TFE #)	37	1356	1355	1061	519	1439	3314	1656	443		

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T&B Project Number: HM400098

Room Temp. (°C): 21.4

UL Project Number: N/A

Room Humidity (%RH): 55

UL File Number: N/A

Test Date: 2011-06-02

Sample Received Date: 2011-03-31

Tested By (Print): Mike Henry/ Zach Winters

Sample Source: DC Canada

Witness/Approval:

Catalog Number(s): 65P

Description: Twist on Wire Connectors with Oxide Inhibitor

Standard - NMX-J-548-ANCE-2004 • C22.2 NO. 188-04 • UL 486C (September 7, 2004)

CURRENT CYCLING (CLAUSE 7.2 - September 7, 2004)

Procedure: The specimen sets per Clause 8.2 shall complete 500 cycles of equal current-on and current-off operations for the time and current specified in Table 6. Upon completion of the current-cycling test no connector shall exceed 125°C temperature rise and the stability factor shall not exceed ± 10 .

Main Wire Size/Type: #10 Sol CCA, THHN or THWN, 90 deg C, 600V

Tap Wire Size/Type: #10 Sol CCA, THHN or THWN, 90 deg C, 600V

Strip Length (in.): 1/2"

Torque (in-lbf): 5

Installation Tool: N/A

Number of Crimps: N/A

Die: N/A

Cycling-Current (A): 60

SAMPLE 31

Cycle Number	Actual (°C)	Control (°C)	Ambient (°C)	Heat Rise (°C)	Dev	"S" Factor	STABILITY FACTOR
25	102	98	22	80	4	-3.3	
50	103	97	22	81	6	-1.3	
75	102	97	23	79	5	-2.3	
100	106	93	23	83	13	5.7	
125	104	96	23	81	8	0.7	
175	104	96	24	80	8	0.7	
225	105	97	24	81	8	0.7	
275	101	94	24	77	7	-0.3	
350	105	96	24	81	9	1.7	
425	103	97	24	79	6	-1.3	
500	106	100	24	82	6	-1.3	

SAMPLE 32

Cycle Number	Actual (°C)	Control (°C)	Ambient (°C)	Heat Rise (°C)	Dev	"S" Factor	STABILITY FACTOR
25	102	98	22	80	4	0.4	
50	102	97	22	80	5	1.4	
75	100	97	23	77	3	-0.6	
100	97	93	23	74	4	0.4	
125	99	96	23	76	3	-0.6	
175	102	96	24	78	6	2.4	
225	102	97	24	78	5	1.4	
275	96	94	24	72	2	-1.6	
350	102	96	24	78	6	2.4	
425	98	97	24	74	1	-2.6	
500	101	100	24	77	1	-2.6	

Notes:

Equip. (TFE #)	37	1356	1355	1061	519	1439	3314	1656	443		

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T&B Project Number: HM400098
 UL Project Number: N/A
 UL File Number: N/A
 Sample Received Date: 2011-03-31
 Sample Source: DC Canada
 Catalog Number(s): 739P
 Description: Twist on Wire Connectors without Oxide Inhibitor

Room Temp. (°C): 21.4
 Room Humidity (%RH): 55
 Test Date: 2011-06-02
 Tested By (Print): Mike Henry/ Zach Winters
 Witness/Approval:

Standard - NMX-J-548-ANCE-2004 • C22.2 NO. 188-04 • UL 486C (September 7, 2004)

STATIC-HEATING SEQUENCE (CLAUSE 7.3 - September 7, 2004)

Secureness • Static-Heat Rise • Pullout

Procedure:

The connectors were assembled to aluminum conductor and subjected to the static heating sequence of tests under the conditions outlined.

Main Wire Size/Type: #12 Sol Cu, THHN or THWN, 90 deg C, 600V
 Tap Wire Size/Type: #12 Sol CCA, THHN or THWN, 90 deg C, 600V
 Strip Length (in.): 11/16" Bushing Diameter (in.): 3/8
 Installation Tool: N/A Secureness Height (in.): 11
 Die: N/A Secureness Weight (lbf): 1.5
 Torque (in-lbf): 3.5 Secureness Duration (min): 30
 Number of Crimps: N/A Temperature Rise Limit (°C): 50
 Static Heat Current (A): 30 Duration of Pull (min): 1
 Required Pull (lbf): 35

Sample Number			1	2	3	4
*Initial Static Heating	Connector Temp. Readings Taken > 10 min. apart (°C)	1	57	51	56	60
		2	57	52	55	60
		3	57	52	55	60
	Ambient Temp. (°C)		20			
	Heat Rise (°C)		37	32	36	40
Met S.H. Rqmt? (Yes/No)			Yes	Yes	Yes	Yes
Met Secureness Rqmt. (Yes/No)			Yes	Yes	Yes	Yes
*Repeat Static Heating	Connector Temp. Readings Taken > 10 min. apart (°C)	1	49	52	41	53
		2	51	53	41	53
		3	51	54	41	53
	Ambient Temp. (°C)		20			
	Heat Rise (°C)		31	34	21	33
Met S.H. Rqmt? (Yes/No)			Yes	Yes	Yes	Yes
Met Pullout Rqmt. (Yes/No)			Yes	Yes	Yes	Yes
Ultimate Pullout (lbf) -Internal Use -						

*Additional temperature readings, if applicable, will be listed in the notes.

Notes:

Equip. (TFE #)	3204	2799	3242	1103	3222	2001	3110	1305	1233	218	1491
3031											

T&B Project Number: HM400098 Room Temp. (°C): 21.4
 UL Project Number: N/A Room Humidity (%RH): 55
 UL File Number: N/A Test Date: 2011-06-02
 Sample Received Date: 2011-03-31 Tested By (Print): Mike Henry/ Zach Winters
 Sample Source: DC Canada Witness/Approval:
 Catalog Number(s): 65P
 Description: Twist on Wire Connectors with Oxide Inhibitor

Standard - NMX-J-548-ANCE-2004 • C22.2 NO. 188-04 • UL 486C (September 7, 2004)

STATIC-HEATING SEQUENCE (CLAUSE 7.3 - September 7, 2004)

Secureness • Static-Heat Rise • Pullout

Procedure:

The connectors were assembled to aluminum conductor and subjected to the static heating sequence of tests under the conditions outlined.

Main Wire Size/Type: #12 Sol Cu, THHN or THWN, 90 deg C, 600V
 Tap Wire Size/Type: #12 Sol CCA, THHN or THWN, 90 deg C, 600V
 Strip Length (in.): 1/2" Bushing Diameter (in.): 3/8
 Installation Tool: N/A Secureness Height (in.): 11
 Die: N/A Secureness Weight (lbf): 1.5
 Torque (in-lbf): 3.5 Secureness Duration (min): 30
 Number of Crimps: N/A Temperature Rise Limit (°C): 50
 Static Heat Current (A): 35 Duration of Pull (min): 1
 Required Pull (lbf): 30

Sample Number			17	18	19	20
*Initial Static Heating	Connector Temp. Readings Taken > 10 min. apart (°C)	1	51	49	49	47
		2	51	49	49	48
		3	51	49	50	49
	Ambient Temp. (°C)		23			
	Heat Rise (°C)		28	26	27	26
Met S.H. Rqmt? (Yes/No)			Yes	Yes	Yes	Yes
Met Secureness Rqmt. (Yes/No)			Yes	Yes	Yes	Yes
*Repeat Static Heating	Connector Temp. Readings Taken > 10 min. apart (°C)	1	49	48	46	48
		2	49	49	46	49
		3	50	49	46	49
	Ambient Temp. (°C)		21			
	Heat Rise (°C)		29	28	25	28
Met S.H. Rqmt? (Yes/No)			Yes	Yes	Yes	Yes
Met Pullout Rqmt. (Yes/No)			Yes	Yes	Yes	Yes
Ultimate Pullout (lbf) -Internal Use -						

*Additional temperature readings, if applicable, will be listed in the notes.

Notes:

Equip. (TFE #)	3204	2799	3242	1103	3222	2001	3110	1305	1233	218	1491
3031											

T&B Project Number: HM400098 Room Temp. (°C): 21.4
 UL Project Number: N/A Room Humidity (%RH): 55
 UL File Number: N/A Test Date: 2011-06-02
 Sample Received Date: 2011-03-31 Tested By (Print): Mike Henry/ Zach Winters
 Sample Source: DC Canada Witness/Approval:
 Catalog Number(s): 739P
 Description: Twist on Wire Connectors without Oxide Inhibitor

Standard - NMX-J-548-ANCE-2004 • C22.2 NO. 188-04 • UL 486C (September 7, 2004)

STATIC-HEATING SEQUENCE (CLAUSE 7.3 - September 7, 2004)

Secureness • Static-Heat Rise • Pullout

Procedure:

The connectors were assembled to aluminum conductor and subjected to the static heating sequence of tests under the conditions outlined.

Main Wire Size/Type: #10 Sol CCA, THHN or THWN, 90 deg C, 600V
 Tap Wire Size/Type: #10 Sol CCA, THHN or THWN, 90 deg C, 600V
 Strip Length (in.): 11/16" Bushing Diameter (in.): 3/8
 Installation Tool: N/A Secureness Height (in.): 11
 Die: N/A Secureness Weight (lbf): 1.5
 Torque (in-lbf): 5 Secureness Duration (min): 30
 Number of Crimps: N/A Temperature Rise Limit (°C): 50
 Static Heat Current (A): 40 Duration of Pull (min): 1
 Required Pull (lbf): 40

Sample Number			5	6	7	8
*Initial Static Heating	Connector Temp. Readings Taken > 10 min. apart (°C)	1	54	55	57	50
		2	54	56	58	50
		3	54	56	58	50
	Ambient Temp. (°C)		19			
	Heat Rise (°C)		35	37	39	31
Met S.H. Rqmt? (Yes/No)			Yes	Yes	Yes	Yes
Met Secureness Rqmt. (Yes/No)			Yes	Yes	Yes	Yes
*Repeat Static Heating	Connector Temp. Readings Taken > 10 min. apart (°C)	1	53	52	53	41
		2	54	53	54	41
		3	54	53	54	43
	Ambient Temp. (°C)		19			
	Heat Rise (°C)		35	34	35	24
Met S.H. Rqmt? (Yes/No)			Yes	Yes	Yes	Yes
Met Pullout Rqmt. (Yes/No)			Yes	Yes	Yes	Yes
Ultimate Pullout (lbf) -Internal Use -						

*Additional temperature readings, if applicable, will be listed in the notes.

Notes:

Equip. (TFE #)	3204	2799	3242	4	945	2001	3110	1305	1233	218	1491
3031											

T&B Project Number: HM400098
 UL Project Number: N/A
 UL File Number: N/A
 Sample Received Date: 2011-03-31
 Sample Source: DC Canada
 Catalog Number(s): 65P
 Description: Twist on Wire Connectors with Oxide Inhibitor

Room Temp. (°C): 21.4
 Room Humidity (%RH): 55
 Test Date: 2011-06-02
 Tested By (Print): Mike Henry/ Zach Winters
 Witness/Approval:

Standard - NMX-J-548-ANCE-2004 • C22.2 NO. 188-04 • UL 486C (September 7, 2004)

STATIC-HEATING SEQUENCE (CLAUSE 7.3 - September 7, 2004)

Secureness • Static-Heat Rise • Pullout

Procedure:

The connectors were assembled to aluminum conductor and subjected to the static heating sequence of tests under the conditions outlined.

Main Wire Size/Type: #10 Sol CCA, THHN or THWN, 90 deg C, 600V
 Tap Wire Size/Type: #10 Sol CCA, THHN or THWN, 90 deg C, 600V
 Strip Length (in.): 1/2" Bushing Diameter (in.): 3/8
 Installation Tool: N/A Secureness Height (in.): 11
 Die: N/A Secureness Weight (lbf): 1.5
 Torque (in-lbf): 5 Secureness Duration (min): 30
 Number of Crimps: N/A Temperature Rise Limit (°C): 50
 Static Heat Current (A): 40 Duration of Pull (min): 1
 Required Pull (lbf): 40

Sample Number			21	22	23	24
*Initial Static Heating	Connector Temp. Readings Taken > 10 min. apart (°C)	1	56	55	49	58
		2	56	57	49	59
		3	58	57	50	59
	Ambient Temp. (°C)		22			
	Heat Rise (°C)		36	35	28	37
Met S.H. Rqmt? (Yes/No)		Yes	Yes	Yes	Yes	
Met Secureness Rqmt. (Yes/No)			Yes	Yes	Yes	Yes
*Repeat Static Heating	Connector Temp. Readings Taken > 10 min. apart (°C)	1	54	60	58	59
		2	55	59	58	59
		3	54	59	57	59
	Ambient Temp. (°C)		23			
	Heat Rise (°C)		32	37	35	36
Met S.H. Rqmt? (Yes/No)		Yes	Yes	Yes	Yes	
Met Pullout Rqmt. (Yes/No)			Yes	Yes	Yes	Yes
Ultimate Pullout (lbf) -Internal Use -						

*Additional temperature readings, if applicable, will be listed in the notes.

Notes:

Equip. (TFE #)	3204	2799	3242	4	945	2001	3110	1305	1233	218	1491
3031											

THOMAS & BETTS - Southaven Laboratory Test Facility Equipment List

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Tested By: Mike Henry/Zach Winters

T&B PROJECT #: N/A

UL File #: N/A

Date: 6/2/11

UL Project #: N/A

TFE NUMBER	EQUIPMENT DESCRIPTION	MANUFACTURER	SERIAL NUMBER	ACCURACY	LAST CALIBRATION DATE	CALIBRATION CYCLE	RANGE
4	AMMETER (A.C.)	WESTON	181104	.75%	1/6/11	1 YEAR	0 - 10A
37	AMMETER (A.C.)	WESTON	181393	.75%	6/24/10	1 YEAR	0 - 5A
945	C.T. 50.5	SIMPSON		2%	2/1/11	3 YEARS	C.T. 50.5
2001	TEMPERATURE INDICATOR	DORIC	363617	SEE MANUAL	6/28/10	1 YEAR	-200°C to 933°C
2799	TORQUE DRIVER	TOHNICHI	03800E		1/7/11	1 YEAR	0.1 to 5 in lb
3204	HYGRO-THERMOMETER	MANNIX	N/A	C++or-0.5%, H=-5	11/25/09	1 YEAR	RH=10%to95%, T=-58Fto 158F
3222	C.T. 50.5	SIMPSON	N/A	0	1/21/08	3 YEARS	C.T. 50.5
3242	CLAMP AMMETER	FLUKE	92858041	0	3/1/10	1 YEAR	See Notes
3110	WEIGHT (1.5 LB CYLINDER)	T&B	N/A	+ - 2%	4/25/08	5 YEARS	Marked exact
1305	SECURENESS MACHINE	T&B		SEE MANUAL	1/0/00	0	0
1233	TIMER (60 MINUTES, GRA-LAB UNIVERSAL)	DIMCO-GRAY CO.			8/19/10	1 YEAR	0-60 MIN X 1 SEC
218	TENSILE MACHINE	TINIUS OLSEN	120868	SEE MANUAL	5/11/10	1 YEAR	Push/Pull, load cell range
1491	SPEED INDICATOR	TINIUS OLSEN	133763	SEE MANUAL	5/11/10	1 YEAR	Digital Readout
3031	LOAD CELL (2,400 POUNDS)	TINIUS OLSEN	088221		5/11/10	1 YEAR	-2400 to 2400 lbf
3	AMMETER (A.C.)	WESTON	180165	.75%	5/3/10	1 YEAR	0 - 10A
37	AMMETER (A.C.)	WESTON	181393	.75%	6/24/10	1 YEAR	0 - 5A
1355	TIMER	TENOR		SEE MANUAL	1/0/00	0	0
1515	TIMER	TENOR		SEE MANUAL	1/0/00	0	0
3222	C.T. 50.5	SIMPSON	N/A	0	1/21/08	3 YEARS	C.T. 50.5
1356	TIMER	TENOR		SEE MANUAL	1/0/00	0	0

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T&B PROJECT #:

Date:

UL Project #:

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COPPERWELD BIMETALLICS TEST REPORT

SCOPE OF WORK

ASTM E228 LINEAR THERMAL EXPANSION EVALUATION OF 14, 12, AND 10 AWG GAGE
COPPER CLAD ALUMINUM (CCA) WIRE

REPORT NUMBER

I6049.01-106-31 R0

TEST DATES

07/12/18 - 07/19/18

ISSUE DATE

08/10/18

RECORD RETENTION END DATE

07/26/22

PAGES

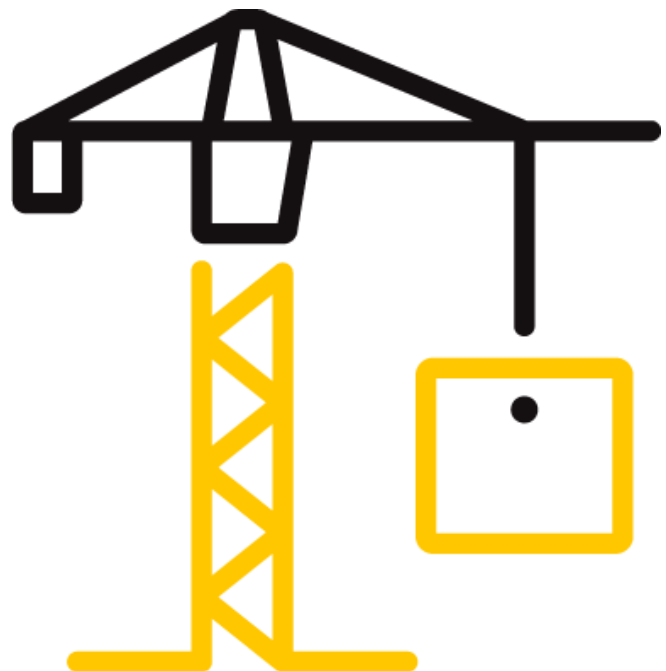
11

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ATI 00231 (09/05/17)

RT-R-AMER-Test-2827

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TEST REPORT FOR COPPERWELD BIMETALLICS

Report No.: I6049.01-106-31 R0

Date: 08/10/18

REPORT ISSUED TO

COPPERWELD BIMETALLICS

254 Cotton Mill Road

Fayetteville, Tennessee 37334

SECTION 1

SCOPE

Products: 14, 12, and 10 AWG gage Copper Clad Aluminum (CCA) Wire

Intertek Building & Construction (B&C) was contracted by Copperweld Bimetallics to evaluate 14, 12, and 10 AWG gage Copper Clad Aluminum (CCA) Wire in accordance with ASTM E228 for Linear Thermal Expansion properties. Results obtained are tested values and were secured by using the designated test methods. Testing was conducted at the Intertek B&C test facility in York, Pennsylvania.

This report does not constitute certification of this product nor an opinion or endorsement by this laboratory.

SECTION 2

SUMMARY OF TEST RESULTS

COPPER CLAD ALUMINUM (CCA) WIRE AWG GAGE	CLTE (mm/mm/°C) 25°C to 150°C TEMPERATURE RANGE
14	1.55E-05
12	2.16E-05
10	2.78E-05

For INTERTEK B&C:

COMPLETED BY:	Joseph M. Brickner
TITLE:	Laboratory Supervisor Materials Laboratory
SIGNATURE:	
DATE:	08/10/18

JMB:dmc/jp

REVIEWED BY:	Dawn M. Chaney
TITLE:	Technician Team Lead Materials laboratory
SIGNATURE:	
DATE:	08/10/18

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TEST REPORT FOR COPPERWELD BIMETALLICS

Report No.: I6049.01-106-31 R0

Date: 08/10/18

SECTION 3

TEST METHOD

The specimens were evaluated in accordance with the following:

ASTM E228-17, *Standard Test Method for Linear Thermal Expansion of Solid Materials with a Push-Rod Dilatometer*

SECTION 4

MATERIAL SOURCE

The test materials were provided by Copperweld Bimetallics. The following were received: Three (3), nominally 76 mm copper clad aluminum wire specimens in 14, 12, and 10 AWG gage. Refer to the product description photo in Section 10. The materials were tested as received except for smoothing the cut ends of each specimens. Representative test specimens will be retained by Intertek B&C for a minimum of four years from the test completion date.

SECTION 5

LIST OF OFFICIAL OBSERVERS

NAME	COMPANY
Joseph M. Brickner	Intertek B&C
Dawn M. Chaney	Intertek B&C

TEST REPORT FOR COPPERWELD BIMETALLICS

Report No.: I6049.01-106-31 R0

Date: 08/10/18

SECTION 6

TEST PROCEDURE

All conditioning of test specimens and test conditions were at standard laboratory conditions unless otherwise reported. Refer to the test related photos in Section 10.

ASTM E228 - Linear Thermal Expansion

One specimen for each wire gage was measured for initial length using a 6" digital caliper (ICN: 65688) and placed in the bottom of an outer glass dilatometer tube with an inner glass tube resting on it. An aluminum support cylinder was utilized to keep the wire oriented in a vertical position. The dilatometer tube was suspended in a heated environment utilizing a muffle furnace (ICN: Y002864) and subjected to exposure conditions of nominally 25°C, 90°C, 120°C, and 150°C. At the equilibrium of each temperature condition, specimen temperature was measured using a thermocouple reader (ICN: 62101) and a measurement was recorded from a digital indicator (ICN: INT00193) resting on top of the inner tube. The Linear Thermal Expansion between each temperature range was calculated.

SECTION 7

TEST SPECIMEN DESCRIPTIONS

TEST PROCEDURE	NUMBER OF SPECIMENS	NOMINAL SPECIMEN DIMENSIONS	VISUAL CHARACTERISTICS
ASTM E228 Linear Thermal Expansion	1 each	75 mm x 14, 12, and 10 gage wire thickness	Copper Clad Aluminum wire

TEST REPORT FOR COPPERWELD BIMETALLICS

Report No.: I6049.01-106-31 R0

Date: 08/10/18

SECTION 8

TEST RESULTS

ASTM E228 - Linear Thermal Expansion

Copper Clad Aluminum (CCA) Wire - 14 Gage

All Temperatures

LENGTH (mm)	75.56			
TARGET TEMPERATURE (°C)	25	90	120	150
ACTUAL TEMPERATURE (°C)	25.4	90.9	119.4	150.1
GAGE READING (mm)	6.6070	6.6510	6.6960	6.7530
ΔT (°C)		65.5	28.5	30.7
ΔL (mm)		0.0440	0.0450	0.0570
$\Delta L/\Delta T$ (mm/°C)		6.72E-04	1.58E-03	1.86E-03
CLTE (mm/mm/°C)		8.89E-06	2.09E-05	2.46E-05

25°C to 150°C Temperature Range

LENGTH (mm)	75.56	
TARGET TEMPERATURE (°C)	25	150
ACTUAL TEMPERATURE (°C)	25.4	150.1
GAGE READING (mm)	6.6070	6.7530
ΔT (°C)		124.7
ΔL (mm)		0.1460
$\Delta L/\Delta T$ (mm/°C)		1.17E-03
CLTE (mm/mm/°C)		1.55E-05

TEST REPORT FOR COPPERWELD BIMETALLICS

Report No.: I6049.01-106-31 R0

Date: 08/10/18

Copper Clad Aluminum (CCA) Wire - 12 Gage

All Temperatures

LENGTH (mm)	87.07			
TARGET TEMPERATURE (°C)	25	90	120	150
ACTUAL TEMPERATURE (°C)	22.4	90.9	123.1	152.9
GAGE READING (mm)	5.9840	6.1160	6.1640	6.2290
ΔT (°C)		68.5	32.2	29.8
ΔL (mm)		0.1320	0.0480	0.0650
$\Delta L/\Delta T$ (mm/°C)		1.93E-03	1.49E-03	2.18E-03
CLTE (mm/mm/°C)		2.21E-05	1.71E-05	2.51E-05

25°C to 150°C Temperature Range

LENGTH (mm)	87.07	
TARGET TEMPERATURE (°C)	25	150
ACTUAL TEMPERATURE (°C)	22.4	152.9
GAGE READING (mm)	5.9840	6.2290
ΔT (°C)		130.5
ΔL (mm)		0.2450
$\Delta L/\Delta T$ (mm/°C)		1.88E-03
CLTE (mm/mm/°C)		2.16E-05

TEST REPORT FOR COPPERWELD BIMETALLICS

Report No.: I6049.01-106-31 R0

Date: 08/10/18

Copper Clad Aluminum (CCA) Wire - 10 Gage

All Temperatures

LENGTH (mm)	78.54			
TARGET TEMPERATURE (°C)	25	90	120	150
ACTUAL TEMPERATURE (°C)	24.0	91.9	120.0	148.2
GAGE READING (mm)	5.5590	5.6940	5.7530	5.8200
ΔT (°C)		67.9	28.1	28.2
ΔL (mm)		0.1350	0.0590	0.0670
$\Delta L/\Delta T$ (mm/°C)		1.99E-03	2.10E-03	2.38E-03
CLTE (mm/mm/°C)		2.63E-05	2.78E-05	3.14E-05

25°C to 150°C Temperature Range

LENGTH (mm)	78.54	
TARGET TEMPERATURE (°C)	25	150
ACTUAL TEMPERATURE (°C)	24.0	148.2
GAGE READING (mm)	5.5590	5.8200
ΔT (°C)		124.2
ΔL (mm)		0.2610
$\Delta L/\Delta T$ (mm/°C)		2.10E-03
CLTE (mm/mm/°C)		2.78E-05

SECTION 9

CONCLUSION

The requested test method did not contain specific performance requirements.

TEST REPORT FOR COPPERWELD BIMETALLICS

Report No.: I6049.01-106-31 R0

Date: 08/10/18

SECTION 10

PHOTOGRAPHS



Photo No. 1

Copper Clad Aluminum - Specimen Detail



Photo No. 2

ASTM E228 - Equipment Detail

TEST REPORT FOR COPPERWELD BIMETALLICS

Report No.: I6049.01-106-31 R0

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**Photo No. 3****ASTM E228 - Length Measurement Equipment Detail****Photo No. 4****ASTM E228 - Specimen Support Detail**

TEST REPORT FOR COPPERWELD BIMETALLICS

Report No.: I6049.01-106-31 R0

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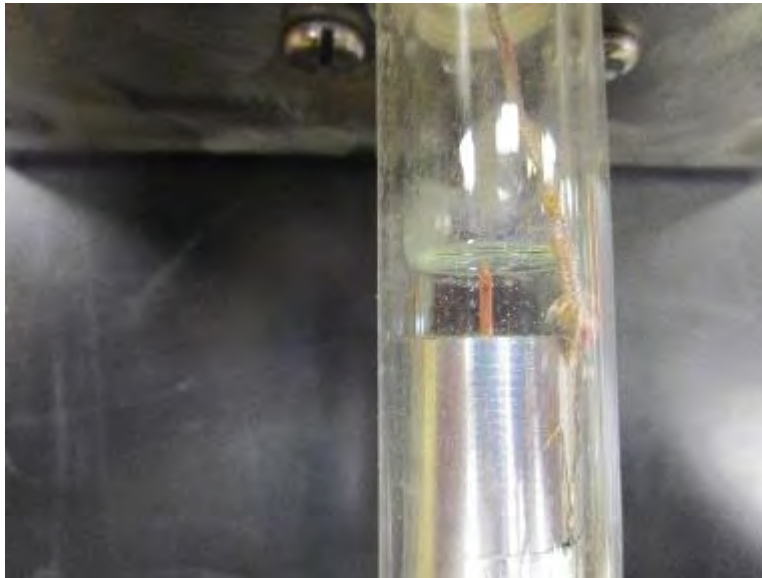


Photo No. 5

ASTM E228 - Specimen Temperature Measurement Detail



Photo No. 6

ASTM E228 - Linear Expansion Measurement Equipment Detail



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SECTION 11

REVISION LOG

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0	08/10/18	N/A	Original Report Issue

COPPERWELD BIMETALLICS TEST REPORT

SCOPE OF WORK

ASTM E228 LINEAR THERMAL EXPANSION EVALUATION OF 14, 12, AND 10 AWG GAGE
ELECTROLYTIC TOUGH PITCH (ETP) COPPER WIRE

REPORT NUMBER

I6049.02-106-31 R0

TEST DATES

07/19/18 - 07/26/18

ISSUE DATE

08/10/18

RECORD RETENTION END DATE

07/26/22

PAGES

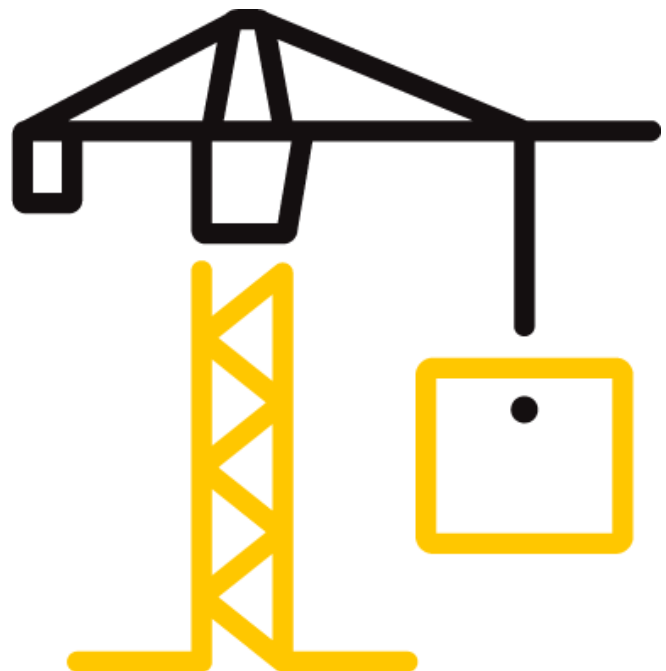
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DOCUMENT CONTROL NUMBER

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RT-R-AMER-Test-2827

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Date: 08/10/18

REPORT ISSUED TO

COPPERWELD BIMETALLICS

254 Cotton Mill Road

Fayetteville, Tennessee 37334

SECTION 1

SCOPE

Products: 14, 12, and 10 AWG gage Electrolytic Tough Pitch (ETP) Wire

Intertek Building & Construction (B&C) was contracted by Copperweld Bimetallics to evaluate 14, 12, and 10 AWG gage Electrolytic Tough Pitch (ETP) Wire in accordance with ASTM E228 for Linear Thermal Expansion properties. Results obtained are tested values and were secured by using the designated test methods. Testing was conducted at the Intertek B&C test facility in York, Pennsylvania.

This report does not constitute certification of this product nor an opinion or endorsement by this laboratory.

SECTION 2

SUMMARY OF TEST RESULTS

ELECTROLYTIC TOUGH PITCH (ETP) COPPER WIRE AWG GAGE	CLTE (mm/mm/°C) 25°C to 150°C TEMPERATURE RANGE
14	1.32E-05
12	1.82E-05
10	1.53E-05

For INTERTEK B&C:

COMPLETED BY:	Joseph M. Brickner	REVIEWED BY:	Dawn M. Chaney
TITLE:	Laboratory Supervisor Materials Laboratory	TITLE:	Technician Team Lead Materials laboratory
SIGNATURE:		SIGNATURE:	
DATE:	08/10/18	DATE:	08/10/18

JMB:dmc/jlp

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SECTION 3**TEST METHOD**

The specimens were evaluated in accordance with the following:

ASTM E228-17, *Standard Test Method for Linear Thermal Expansion of Solid Materials with a Push-Rod Dilatometer*

SECTION 4**MATERIAL SOURCE**

The test materials were provided by Copperweld Bimetallics. The following were received: Three (3), nominally 76 mm electrolytic tough pitch copper wire specimens in 14, 12, and 10 AWG gage. Refer to the product description photo in Section 10. The materials were tested as received except for smoothing the cut ends of each specimen. Representative test specimens will be retained by Intertek B&C for a minimum of four years from the test completion date.

SECTION 5**LIST OF OFFICIAL OBSERVERS**

NAME	COMPANY
Joseph M. Brickner	Intertek B&C
Dawn M. Chaney	Intertek B&C

TEST REPORT FOR COPPERWELD BIMETALLICS

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SECTION 6

TEST PROCEDURE

All conditioning of test specimens and test conditions were at standard laboratory conditions unless otherwise reported. Refer to the test related photos in Section 10.

ASTM E228 - Linear Thermal Expansion

One specimen for each wire gage was measured for initial length using a 6" digital caliper (ICN: 65688) and placed in the bottom of an outer glass dilatometer tube with an inner glass tube resting on it. An aluminum support cylinder was utilized to keep the wire oriented in a vertical position. The dilatometer tube was suspended in a heated environment utilizing a muffle furnace (ICN: Y002864) and subjected to exposure conditions of nominally 25°C, 90°C, 120°C, and 150°C. At the equilibrium of each temperature condition, specimen temperature was measured using a thermocouple reader (ICN: 62101) and a measurement was recorded from a digital indicator (ICN: INT00193) resting on top of the inner tube. The Linear Thermal Expansion between each temperature range was calculated.

SECTION 7

TEST SPECIMEN DESCRIPTIONS

TEST PROCEDURE	NUMBER OF SPECIMENS	NOMINAL SPECIMEN DIMENSIONS	VISUAL CHARACTERISTICS
ASTM E228 Linear Thermal Expansion	1 each	75 mm x 14, 12, and 10 gage wire thickness	Electrolytic Tough Pitch Copper wire

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SECTION 8

TEST RESULTS

ASTM E228 - Linear Thermal Expansion

Electrolytic Tough Pitch (ETP) Copper Wire - 14 Gage

All Temperatures

LENGTH (mm)	75.60			
TARGET TEMPERATURE (°C)	25	90	120	150
ACTUAL TEMPERATURE (°C)	28.7	91.3	122.7	151.2
GAGE READING (mm)	5.6440	5.7220	5.7470	5.7710
ΔT (°C)		62.6	31.4	28.5
ΔL (mm)		0.0780	0.0250	0.0240
$\Delta L/\Delta T$ (mm/°C)		1.25E-03	7.96E-04	8.42E-04
CLTE (mm/mm/°C)		1.57E-05	1.01E-05	1.06E-05

25°C to 150°C Temperature Range

LENGTH (mm)	75.60	
TARGET TEMPERATURE (°C)	25	150
ACTUAL TEMPERATURE (°C)	28.7	151.2
GAGE READING (mm)	5.6440	5.7710
ΔT (°C)		122.5
ΔL (mm)		0.1270
$\Delta L/\Delta T$ (mm/°C)		1.04E-03
CLTE (mm/mm/°C)		1.32E-05

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Electrolytic Tough Pitch (ETP) Copper Wire - 12 Gage

All Temperatures

LENGTH (mm)	79.19			
TARGET TEMPERATURE (°C)	25	90	120	150
ACTUAL TEMPERATURE (°C)	28.6	92.4	120.5	150.5
GAGE READING (mm)	6.5840	6.6790	6.7190	6.7580
ΔT (°C)	63.8			
ΔL (mm)	0.0950			
ΔL/ΔT (mm/°C)	1.49E-03			
CLTE (mm/mm/°C)	1.88E-05			

25°C to 150°C Temperature Range

LENGTH (mm)	79.19	
TARGET TEMPERATURE (°C)	25	150
ACTUAL TEMPERATURE (°C)	28.6	150.5
GAGE READING (mm)	6.5840	6.7580
ΔT (°C)	121.9	
ΔL (mm)	0.1740	
ΔL/ΔT (mm/°C)	1.43E-03	
CLTE (mm/mm/°C)	1.82E-05	

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Electrolytic Tough Pitch (ETP) Copper Wire - 10 Gage

All Temperatures

LENGTH (mm)	78.31			
TARGET TEMPERATURE (°C)	25	90	120	150
ACTUAL TEMPERATURE (°C)	28.5	88.5	118.4	149.7
GAGE READING (mm)	5.5180	5.5800	5.6270	5.6630
ΔT (°C)	60.0			
ΔL (mm)	0.0620			
ΔL/ΔT (mm/°C)	1.03E-03			
CLTE (mm/mm/°C)	1.32E-05			

25°C to 150°C Temperature Range

LENGTH (mm)	78.31	
TARGET TEMPERATURE (°C)	25	150
ACTUAL TEMPERATURE (°C)	28.5	149.7
GAGE READING (mm)	5.5180	5.6630
ΔT (°C)	121.2	
ΔL (mm)	0.1450	
ΔL/ΔT (mm/°C)	1.20E-03	
CLTE (mm/mm/°C)	1.53E-05	

SECTION 9

CONCLUSION

The requested test method did not contain specific performance requirements.

TEST REPORT FOR COPPERWELD BIMETALLICS

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SECTION 10

PHOTOGRAPHS

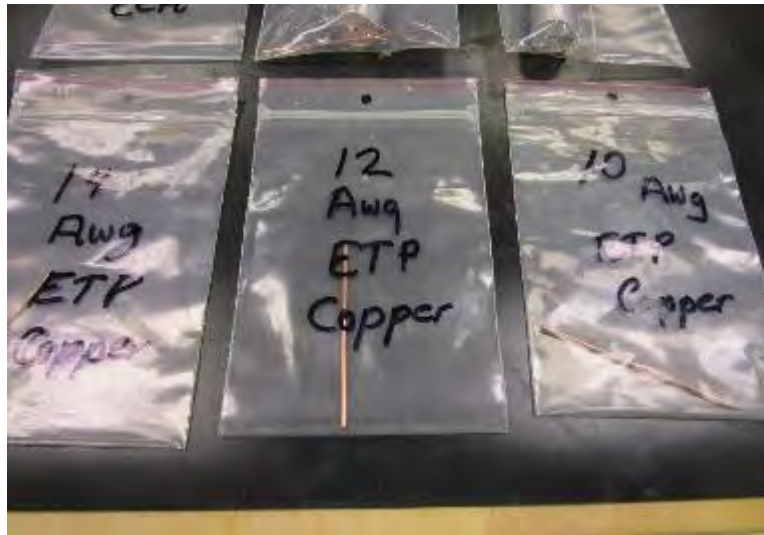


Photo No. 1
Electrolytic Tough Pitch - Specimen Detail



Photo No. 2
ASTM E228 - Equipment Detail

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**Photo No. 3****ASTM E228 - Length Measurement Equipment Detail****Photo No. 4****ASTM E228 - Specimen Support Detail**

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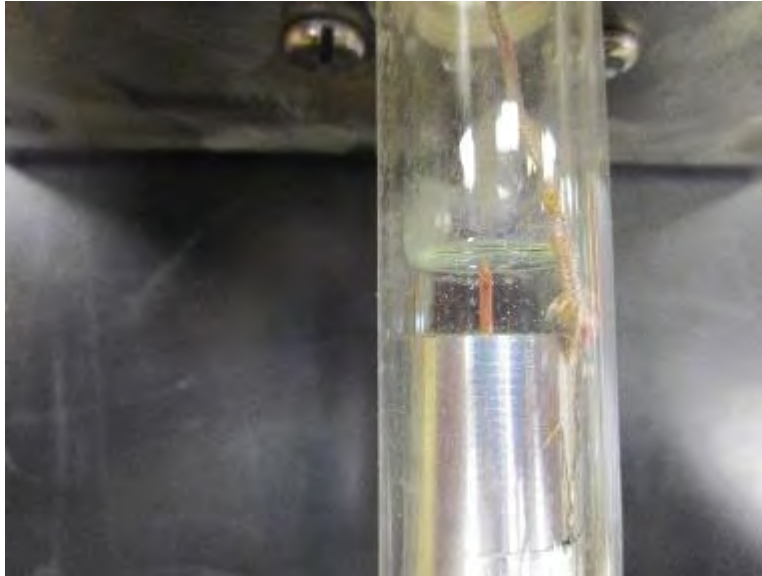


Photo No. 5

ASTM E228 - Specimen Temperature Measurement Detail



Photo No. 6

ASTM E228 - Linear Expansion Measurement Equipment Detail



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SECTION 11

REVISION LOG

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0	08/10/18	N/A	Original Report Issue

Terminal and Conductor Temperature Testing of 14 AWG Copper-Clad Aluminum and 14 AWG Copper Conductors

Part II – Thermocycling Tests

For

Bimetallics Task Group

Conducted at

Eaton Laboratories
Menomonee Falls, Wisconsin

Report by

Chuck Mello
on behalf of Bimetallics Task Group

Report Date

November 13, 2020

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1.0 Introduction and Purpose

At the direction of the NFPA Standards Council in their Decisions D#19-2 and D#19-23, a Bimetallics Task Group of balanced interest was appointed. The scope was to review the proposed changes to the 2020 edition of the *NEC*® that relate to copper-clad aluminum conductors and recommend changes through tentative interim amendment(s) and/or to provide public inputs for the next revision cycle.

As the task group conducted the work, it was determined that testing data had been provided substantiating the ampacity of 14 AWG copper-clad aluminum but a number of related questions about 14 AWG copper-clad aluminum applications arose regarding terminal temperatures when applied to circuit breakers, wire splicing devices and device terminals. A testing plan was developed, reviewed over several task group meetings, and accepted by the task group to address the terminal temperature questions. This testing was completed at the Eaton Corporation laboratory facilities in Menomonee Falls, Wisconsin. The helpful assistance of Mr. Tom Domitrovich, Mr. Kevin Arnold, Mr. James Parrett, and Mr. Steve Averbek with Eaton Corporation is greatly appreciated in arranging for and executing the testing.

A Part I report for the static heating and flexing tests was issued on August 28, 2020 to the Bimetallics Task Group. The Part I report was also included as an attachment to applicable public inputs developed by the Bimetallics Task Group that were due to NFPA by September 7, 2020.

This Part II test report provides the testing arrangement, testing procedures and results for the thermocycling testing part of the testing program. The testing detailed in this report commenced August 28, 2020 and completed on October 16, 2020. The separation of the reports was necessary to meet the NFPA deadline of September 10, 2020 to submit public inputs.

The purpose of this testing was to provide data, as requested by the Bimetallics Task Group, to understand certain installation and operating conditions when considering the application of 14 AWG copper-clad aluminum conductors at the proposed ampacity for branch circuits. The testing that was completed also included 14 AWG copper conductors based on its *NEC*® ampacity for comparison and performance. The basis for comparison was at the 60°C ampacity rating for copper (15 amps) and the proposed 60°C ampacity rating for copper-clad aluminum (10 amps). The testing included in the Part I and Part II reports was designed to represent a typical installation to determine the following:

- 1) The temperature (temperature rise) on the terminals and conductor immediately adjacent to a 10 Amp and 15 Amp molded case circuit breaker, under normal and identified abnormal static heating (steady state) conditions
- 2) The temperature (temperature rise) on wire-splicing devices (e.g., Ideal Wire Nuts® or similar), and conductor immediately adjacent, commonly used for splicing in junction or device boxes or attaching leads from utilization equipment, under normal and abnormal conditions
- 3) The temperature (temperature rise) on wiring devices (single receptacle as representative) and conductor immediately adjacent under normal and abnormal static heating (steady state) conditions

- 4) The temperature (temperature differential) and the thermal stability (stability factor) on wire-splicing devices (e.g., Ideal Wire Nuts® or similar), and conductor immediately adjacent, commonly used for splicing in junction or device boxes or attaching leads from utilization equipment, at $2\frac{2}{3}$ times rated conductor ampacity under thermal cycling conditions
- 5) The temperature (temperature rise) and the thermal stability (stability factor) on wiring devices (single receptacle as representative) and conductor immediately adjacent, at $2\frac{2}{3}$ times rated conductor ampacity under thermal cycling conditions
- 6) Conductor retention on wiring devices after abnormal thermal-cycling
- 7) The flexing durability of 14 AWG copper-clad aluminum when installed and removed from a single-gang device box

Since the various product standards do not presently have requirements, procedures or parameters for 14 AWG copper-clad aluminum, the testing being conducted was based on the proposed 10-ampere branch circuit rating at 60°C and percentage multipliers taken from the applicable standards. Where the standard does not provide a percentage value, then the current for the testing was interpolated from the values for relative copper and/or aluminum conductors from the standard. The values for testing of 14 AWG copper were taken from the applicable product safety standards with an ampacity basis of 15 Amps at 60°C

It is to be understood this more extreme testing is being conducted solely to provide specific performance data and information as requested by the task group. The testing does not provide performance evaluation methodology or data normally conducted for certification of any of the components used for this testing.

It should be noted that the thermal cycling and pull testing conducted here was derived from performance evaluations solely applicable to self-contained device terminations and are never performed to list end-products having terminations suitable solely for either copper conductors or for copper-clad aluminum conductors used in devices that are not self-contained. The intent of the Task Group was to evaluate added attributes and more severe parameters differences not normally conducted that might reveal any underlying performance deficiencies, thereby alleviating by absence or confirming by presence any concerns regarding essential safety margins.

If 14 AWG copper-clad aluminum is accepted into the 2023 *NEC*®, then numerous UL standards will need to be revised for the 10-ampere ampacity and further evaluation testing may need to be completed under the incremental requirements established in those standards. The end-product standards' evaluation programs are predicated upon compliance with the *National Electrical Code*®, including permitted conductor sizes and associated ampacities, as published. The testing for certification therefore could differ from what was provided here. The goal again was to provide information for a typical installation specific to terminal temperatures. The changes to UL standards will not begin to occur until 14 AWG copper-clad aluminum has been recognized for installation in the *NEC*®.

To provide a basis to consider the test results for 14 AWG copper-clad aluminum, duplicate test set ups were constructed using 14 AWG copper conductors. These end-products have established terminal capacity based upon a given conductor size. The “apples-to-apples” comparison was conducted at the given 14 AWG size but at the ampacity associated with each conductor material at that 14 AWG size. The only difference in the thermocycling setup for 14 AWG copper therefore is the 15-Ampere basis for the testing. This additional testing data provides a direct comparison in the same environment and same test arrangement at the 60°C ampacity values for each of these two conductor types and assemblies.

2.0 Testing Arrangement and Setup

The testing was conducted in a suitable facility with environmental controls and documented monitoring. The facility was free from extraneous changes in ambient temperature and from having random air flow (drafts) through the testing area. Based on input from the task group, the supply air ducts in the area were either turned off or air flow diverted from the testing area, see photo 1 in Appendix F. Ambient temperature was maintained between 20°C and 25°C and recorded with thermocouples positioned in the testing area while temperature testing was completed.

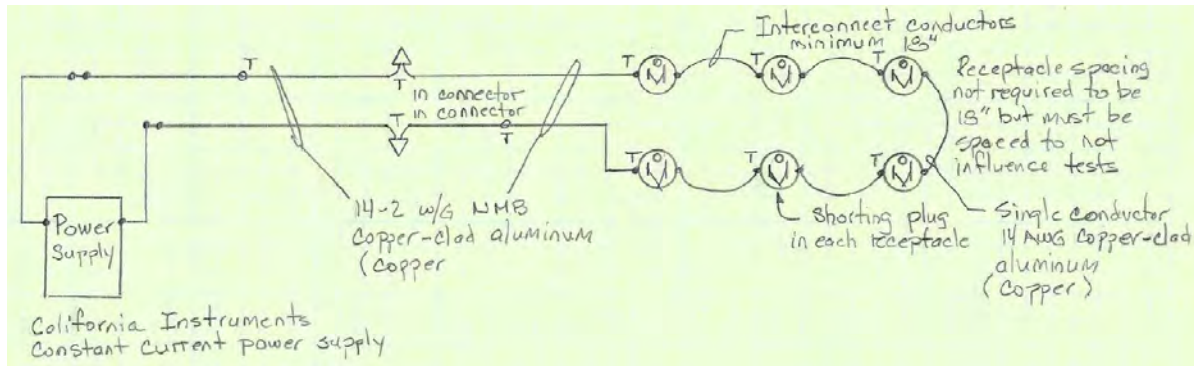


Figure 1 – Typical Test Circuit Diagram

The Eaton facility, being a division within a manufacturing company of wiring devices and circuit breakers, has laboratory technicians that are very familiar with testing of circuit components and equipment to various applicable UL standards.

The test circuit diagram shown in Figure 1 above provides the basic layout of one (1) testing circuit consisting of the conductor (14 AWG copper-clad aluminum or copper NM-B cable) two (2) wire-splicing devices, and six (6) single receptacles. For the thermocycling testing, the circuit breakers used for the previous test circuit setups were removed and the 14 AWG conductors connected directly to the power supply bus. To complete the thermocycling testing the two test circuits for copper-clad aluminum were connected in series on one test board and connected to one power supply. The two 14 AWG copper circuits were connected in series on a separate test board and connected to one power supply. Photos 1 through 8 in Appendix F show the general test setup for completing the thermocycling testing. The thermocycling testing of all four test circuits was run simultaneously.

Each of the four (4) circuits have, the wire splicing devices on the black and white wire as described below, and three (3) each of receptacles from two of the manufacturers.

For example, one circuit setup had:

- 14 AWG copper-clad aluminum NM-B conductors
- Mfg. 4 and mfg.5 wire splicing devices respectively, on the black and white conductors
- Three each of the mfg. 8 and mfg. 9 receptacles, and
- 14 AWG THHN copper-clad aluminum conductors for interconnection of the receptacles

These components were connected together to form a complete circuit. The second setup for 14 AWG copper-clad aluminum has the same assembly but with mfg.6 and mfg.7 wire splicing devices and with mfg. 10 and mfg.11 receptacles. The third and fourth setups were the same as 1 and 2 except using 14 AWG copper conductors.

Due to testing of the respective conductors with wire-splicing devices and receptacles together, the test arrangement was different than what may be used for certification testing of a single type of device. The test purpose was to approximate an actual installation under laboratory type conditions and not to establish certification type testing for any one device.

For the thermocycling test, the two power supplies used were programmable constant current power supply sources. Each power supply was connected to one of the combined series circuits and provided the current level specified for the tests being conducted.

For each of the four circuits the following description is provided, see circuit diagram in figure 1 and photos 1 through 8 in Appendix F:

- 1) The four (4) circuits were mounted on an insulating sheet approximately 4 feet high and 8 feet wide. The partition had suitable framing to provide structural support for the partition to be in a vertical orientation to the floor. One board was for copper-clad aluminum and the other board was for copper conductors.
- 2) During all testing, suitable barrier tape, safety cones, barriers, or other means was in place in accordance with the laboratory safety procedures to keep unauthorized persons out of the area and away from exposed live parts.
- 3) The individual conductors and devices were arranged horizontally with approximately 12 inches of vertical spacing between each horizontal assembly. Staples, or other fastening devices, such as cable ties, were used to keep the NM-B cable aligned with the respective test assembly.
- 4) From the power supply connection terminal approximately 4 feet of 14-2 NM-B cable was installed and supported as provided above. From this center junction another 2 feet of 14-2 NM-B cable (copper-clad aluminum or copper as applicable) was installed. The junction in the middle had approximately 6 inches of exposed conductor and a splice completed with yellow wire-splicing devices as provided for the black, white conductors. The following was applied to the two setups for the copper-clad aluminum conductors respectfully and repeated for the copper conductor setups.
 - a) The black wire for the first circuit set of three used a mfg. 4 yellow wire-splicing devices
 - b) The white wire for the first circuit set of three used an mfg. 5 yellow Wire Nuts®
 - c) The black wire of the second circuit set of three used a mfg. 6 yellow wire-splicing devices
 - d) The white wire of the second circuit set of three used a mfg. 7 yellow wire-splicing devices

The manufacturer and location of the wire-splicing devices used was recorded for each test circuit.

- 5) Six (6) receptacles were installed at the end of each horizontal assembly.
- a) The first set of circuits of copper-clad aluminum or of copper had three (3) mfg. 11 receptacles and then three (3) receptacles from mfg. 8 all connected in series.
 - b) The second circuit of copper-clad aluminum or of copper had three (3) receptacles from mfg. 10 and then three (3) receptacles from mfg. 9 all connected in series.

The receptacles were spaced a minimum of six (6) inches apart horizontally and/or vertically and were interconnected with a minimum of eighteen (18) inches of 14 AWG solid THHN copper-clad aluminum or copper conductors respectfully.

The receptacles were mounted to the wall surface with screws, so that the face of the receptacle was approximately 1½ inches from the insulating board partition surface.

For each manufacturer the receptacles were connected to terminals as follows:

- a) One receptacle had the conductors installed at each wire binding screw and the conductors were wrapped counterclockwise around the screw shank under the screw head, for ⅔ to ¾ of wire binding screw circumference. See photo 6 in Appendix F for typical installation.
- b) The second receptacle had the conductors installed into one side back terminal (entry hole) of the pressure plate terminal. See photo 7 in Appendix F for typical installation.
- c) The third receptacle had two conductors installed into each back-side pressure plate terminal as follows: one conductor of the test circuit into each side (hot and neutral) of the pressure plate terminal and one additional short conductor of equal diameter and material into the other side (entry hole) of the same pressure plate terminal. The second conductor was to fill the slot only and is not required for any other purpose than to balance the mechanical clamping forces applied. See photo 8 in Appendix F for typical installation.

Each receptacle had a shorting plug installed as follows:

- a) The ungrounded (BLACK) and grounded (WHITE) contacts of each receptacle being tested were connected together by a mated attachment plug having rigidly-attached solid blades.
 - b) The terminals of each attachment plug were short-circuited by the shortest feasible length of 14 AWG stranded copper conductor from type SJ flexible cord.
 - c) The flexible cord shorting conductor was mechanically terminated into the pressure plate terminals and the connection torqued to the manufacturer's specification.
- 6) The conductor from the neutral terminal of the last receptacle in the series was routed back using the white wire in the NM-B cable, through the wire-splicing devices and terminated at a terminal bar mounted to the support board for connection back to the power supply.

- 7) All connections were tightened as follows. Torquing tools were calibrated and calibration documented:
 - a) The wire-splicing devices were torqued to the manufacturer's specification in the instructions. If there was no specification, then the 14 AWG copper-clad aluminum conductors were torqued to 2.47 lbf-in and the 14 AWG copper conductors were torqued to 4.11 lbf-in [Specification from UL 486C – 9.1.9.4]
 - b) The terminals of the receptacles and of the attachment plugs were torqued to the manufacturer's specification in the installation instructions. If there was no torque specification provided, then the terminals were torqued to 9 lbf-in.
- 8) Thermocouples were connected as shown in the diagram, Figure 1 and as shown in photos 2 through 8 in Appendix F.
 - a) Thermocouples were installed on device terminals so that it did not interfere with the terminal.

For the wire-splicing devices, the thermocouples were attached into the wire bundle within the wire-splicing devices.
 - b) The thermocouples that measured center wire temperatures had a flap of the NM-B jacket and the conductor insulation peeled back to expose the conductor. The thermocouple was attached with thermo-cement to the conductor and the conductor insulation and jacket flap folded back to the original position with two wraps of black electrical tape wrapped to hold the flap in place.
 - c) A thermocouple was positioned midway in elevation to the test setup for each circuit and recorded the ambient temperature as testing was completed.
- 10) The power supply was a programable constant current power supply. The current was monitored and recorded by the data logger along with the temperature recordings. The power supply was connected to a terminal bus on the board, and to the neutral terminal bar where the return white conductor from the NM-B cable was terminated.

3.0 Materials for Testing

The generous support with the supplying of materials for the thermocycling testing by Copperweld, Eaton, Hubbell, Legrand, and Leviton, are acknowledged and appreciated. The following materials were used to complete the setups for thermocycling testing as described above.

- 1) The yellow wire-splicing devices were as follows:
 - a) Gardner-Bender ULTRA WingGard™
 - b) Ideal WingTwist®
 - c) 3M™ Performance Plus™ Red/Yellow+
 - d) Commercial Electric WT4
- 2) The receptacles for both the copper-clad aluminum and copper testing were:
 - a) Eaton (Cooper) model TR6250W, NEMA 5-15R single receptacle with wire binding screw and pressure plate terminals (back and side wired)
 - b) Hubbell model HBL 5261, NEMA 5-15R single receptacle with both wire binding screw and pressure plate terminals (back and side wired)
 - c) Legrand (Pass & Seymour) model TR 5251, NEMA 5-15R single receptacle with both wire binding screw and pressure plate terminals (back and side wired)
 - d) Leviton model T 5015, NEMA 5-15R single receptacle with both wire binding screw and pressure plate terminals (back and side wired)
- 3) Thermocouples, UL calibrated, model UL 3055, with sufficient length to connect and route to datalogger recording device.
- 4) Datalogger recording device and laptop or another required device for the datalogger.
- 5) Programable power supplies from Eaton laboratory. Maximum current for the copper was 30 Amps and for the copper-clad aluminum was 20 amps.
- 6) Approximately 50 feet each of 14-2 w/ground copper-clad aluminum NM-B cable and of 14-2 w/ground copper NM-B cable.
- 7) Approximately 50 feet each of 14 AWG solid THHN copper-clad aluminum and 14 AWG solid THHN copper single conductors.

4.0 Test Procedures

4.1 Conductor Material Testing

A sample of each the 14-2 NM-B and 14 AWG THHN copper-clad aluminum conductors used for the testing was returned to the Copperweld factory laboratory for analysis. The testing was performed to confirm the conductors that were used for the testing at Eaton were in fact 14 AWG and met the requirements for copper-clad aluminum as specified in UL 83 Annex E and ASTM B566. The packaging was photo documented from the Eaton laboratory and the opening of the package at the Copperweld laboratory photo documented.

The Copperweld laboratory technician, who routinely performs the full ASTM B566 and UL follow-up battery of testing, completed all the testing and documented it on a Copperweld laboratory test data sheet.

Standard materials testing was completed by Copperweld laboratory technician including:

- DC resistance
- Copper thickness
- Copper Volume
- Tensile strength
- Elongation
- Adhesion
- Cohesion

The following tests, as completed by the Copperweld laboratory technician, were witnessed and documented by the UL Field Representative that normally completes follow-up inspections of copper-clad aluminum conductors as part of the recognized component program, under UL category DVVU2 and UL standard *UL 3566*:

- DC resistance
- Copper thickness
- Tensile strength
- Elongation

4.2 Terminal Temperature Testing

The following test procedures, except the flexing test, used references from parts of UL 486A-486B; UL 486C; UL 489; UL 20; and UL 498.

The test results were recorded with twelve (12) thermocouples for each of the four (4) test circuits as shown in the figure 1 drawing above. The first circuit using copper conductors had the thermocouple locations identified as follows:

- 1a – Receptacle (manufacturer 1 ID) terminated with wire binding screw
- 2a – Receptacle (manufacturer 1 ID) with a single conductor terminated into one of the side back terminal (entry hole) of the pressure plate terminal
- 3a – Receptacle (manufacturer 1 ID) with two conductors terminated into each side back terminal (entry hole) of the pressure plate terminal

- 4a – Receptacle (manufacturer 2 ID) terminated with wire binding screw
- 5a – Receptacle (manufacturer 2 ID) with a single conductor terminated into one of the side back terminal (entry hole) of the pressure plate terminal
- 6a Receptacle (manufacturer 2 ID) with two conductors terminated into each side back terminal (entry hole) of the pressure plate terminal
- 7a not used (was circuit breaker thermocouple in static heating testing)
- 8a Line conductor
- 9a Line side (black conductor) wire splicing device
- 10a Load conductor
- 11a Load side (white conductor) wire splicing device
- 12a Room ambient temperature
- 13a Current in circuit

The second setup with copper conductors, with using manufacturer 3 and 4 receptacles, used the same point identifications but has the point identification use a “b” in place of the “a”.

The third and fourth setups were assembled with copper-clad aluminum conductors duplicating the devices and assembly used for the copper conductors. The point identification for the copper-clad aluminum conductors used the letters “c” and “d” in place of “a” for the points as identified above.

Test #1 – Rated Current Temperature

The terminal temperature testing was completed in August 2020 and the results (Appendix C1) are provided in the Part I report of this project. Please see the Part I report for complete details of test procedure and results.

Test #2 – Circuit Breaker Overload Temperature

The terminal temperature testing was completed in August 2020 and the results provided in the Part I report of this project. Please see the Part I report for complete details of test procedure and results.

Test #3 – Wiring Device Overload Temperature

The terminal temperature testing was completed in August 2020 and the results (Appendices C2 to C4) are provided in the Part I report of this project. Please see the Part I report for complete details of test procedure and results.

Test #4 – Circuit Breaker Overload Temperature

The terminal temperature testing was completed in August 2020 and the results (Appendices C2 to C4) are provided in the Part I report of this project. Please see the Part I report for complete details of test procedure and results.

Test #5 – Wiring Device Thermal Cycling

Testing of all four circuits without a circuit breaker in the circuit was completed simultaneously. Two circuits were for 14 AWG copper conductors and two circuits were for 14 AWG copper-clad aluminum conductors. For each of conductor material assemblies, the top row black supply conductor was connected to a terminal directly connected to the programmable power supply. The return white conductor from the top row was connected to the black supply conductor in the second row for a series circuit. The return white conductor from the second row was connected to the neutral terminal block.

Each circuit was operated at the indicated currents for 500 cycles of 1½ hours on and then 1/2 hour off. The current on and off cycle was controlled using the programmable power supply. The test currents are as follows:

- a) Copper tested at 40 Amps (266 percent of the 15-amp ampacity at 60°C)
- b) Copper-clad aluminum tested at 26.67 Amps (266 percent of the proposed 10-amp ampacity at 60°C)

Device terminal temperatures, ambient temperature, and current were recorded by the datalogger every 30 minutes starting at time zero.

The testing data results at eleven (11) cycle intervals. These were recorded at the cycle intervals of 25, 50, 75, 100, 125, 170, 215, 260, 340, 420, 500 cycles in accordance with UL 498 section 169.2.4 and UL 486C section 7.2.3. The temperature results recorded at these cycle intervals was used to calculate the thermal stability in accordance with UL 498 section 169.4.1 and UL 486C section 7.2.4. The difference in the recorded ambient temperature and the average ambient temperature for the individual test setup was calculated to show ambient temperature stability.

For the receptacle terminal temperature recorded data, the temperature rise above the recorded ambient for each interval was calculated and documented on the data sheets. The average temperature rise was then calculated for the eleven recorded cycles. The temperature stability factor was calculated by subtracting the calculated temperature rise for each data entry from the average for that device. The deviation of any calculated temperature rise from the average is not to exceed 10°C.

For the thermal cycling test, the terminal temperature rise above ambient should not exceed:

- a. wire-splicing devices – 125°C [UL 486C, 7.2.2]
- b. receptacle terminal (at rated current) – 100°C [UL 498, 169.1.1(b)]

For the wire splicing device terminal temperature recorded data, the temperature difference the reference conductor temperature for each interval was calculated and documented on the data sheets. This is different than the procedure for the wiring devices. The reference conductor temperature used was the line conductor recorded temperature. The average temperature differential was then

calculated for the eleven recorded cycles. The temperature stability factor was calculated by subtracting the calculated temperature differential for each data entry from the average for that device. The deviation of any calculated temperature rise from the average is not to exceed 10°C

At the conclusion of the thermal cycling each receptacle was removed and a pull-out test with 20 lbs. force applied to the conductors connected to the line and the neutral terminals. The pull test was completed with the pulling direction perpendicular to the plane of the back of the receptacle for one (1) minute. The test for each side of the receptacle was done separately.

Test # 6 – Conductor Flexing Test

The conductor flexing tests were completed in August 2020 and the results (Appendix D) are provided in the Part I report of this project. Please see the Part I report for complete details of test procedure and results.

5.0 Test Results

5.1 Copper-Clad Aluminum Conductor Material Testing

After the static heating testing was completed, Eaton laboratory technicians packed and shipped samples of the copper-clad aluminum conductor, NM-B cable and THHN single conductor, that had been used for the testing to Copperweld's laboratory for verification testing. Photos 11 to 13 in Appendix F show the samples the Eaton laboratory technicians packaged into the bag and shipped to the Copperweld laboratory. Note the date on these photos as August 24, 2020. Appendix G pages G1 and G2 show photos of the received package and opening of that package with these samples for the testing.

The samples of the 14 AWG copper-clad aluminum NM-B cable and the 14 AWG copper-clad aluminum THHN single conductors were tested in the Copperweld factory laboratory on August 27, 2020. The Copperweld laboratory testing data is provided in Appendix G page G3 and the calibration of the test equipment on pages G4 through G6.

The UL field engineer who routinely completes the quarterly follow-up inspections for the copper-clad aluminum conductor witnessed the testing required under the UL standard UL 3566 follow-up program; that testing was completed on August 27, 2020. As shown in Appendix G, page G1 and Appendix G, page G7, the UL field engineer confirmed that *"the 14 Awg from the NMB and THHN samples passed the UL tests for DVVUs, including Tensile, Elongation, copper thickness and DC resistance"*

The test results for the copper-clad aluminum confirm that the conductors used for this testing were 14 AWG and that the material tested met the requirements in ASTM B566.

5.2 Static Heating Tests 1 Through 4

The static heating testing was completed in August 2020 and the results (Appendix C1 to C4) are provided in the Part I report of this project. Please see the Part I report for complete details of test procedure and results.

5.3 Flexing Test 6

The conductor flexing tests were completed in August 2020 and the results (Appendix D) are provided in the Part I report of this project. Please see the Part I report for complete details of test procedure and results.

5.4 Test Setup and Torquing

The test setups were as described in Section 2.0 of this report and shown in photos 1 through 8 in Appendix F. The terminations were tightened to the applicable torque value with a calibrated torque wrench. For the thermocycling testing table 1 below shows the torque values applied for each setup and device terminal.

Table 1

Item being torqued	in/lbs.	mfr. spec	default
3M wire splicing device (on CU clad AL wire)	2.47	no	yes
Commercial Electric wire splicing device (on CU clad AL wire)	2.47	no	yes
Gardner-Bender wire splicing device (on CU clad AL wire)	2.47	no	yes
Ideal wire splicing device (on CU clad AL wire)	2.47	no	yes
3M wire splicing device (on copper wire)	4.11	no	yes
Commercial Electric wire splicing device (on copper wire)	4.11	no	yes
Gardner-Bender wire splicing device (on copper wire)	4.11	no	yes
Ideal wire splicing device (on copper wire)	4.11	no	yes
Legrand receptacle	9	no	yes
Leviton receptacle	9	no	yes
Cooper receptacle	9	no	yes
Hubbell receptacle	12	yes	no

5.5 Thermocycling Test 5 Results.

5.5.1 Data Sheet Layout

The recorded data for the 11 specified intervals, the calculated temperature differential, and the calculated temperature stability factors are found in Appendix H. For each of the test setups, there are three (3) sequential pages (e. g. Appendix H pages H1, H2, H3). For each set of pages, the first page is the recorded data (salmon color header). On this page, the last row shows the difference from the recorded ambient temperature for that interval from the average ambient temperature shown in the last column. The second page (violet color header) is the calculated temperature rise, or temperature differential. The third page (green color header) is the calculated stability factor.

On the second and third page of each set, the rows for line and load conductor temperatures do not have any calculated temperature rise or differential values since temperature rise or differential does not apply to conductor temperatures. Similarly, there is no calculated values for ambient temperature rise or current as these are strictly recorded values and no calculations are applicable.

5.5.2 Missing Data Points

The continuous duration for this test is 500 cycles, at 2-hours each, which is 1000 hours (approximately 42 days) of laboratory time. A review of the data sheets in Appendix H note that two columns have recorded “no data” for the 100 and 125 cycle columns. During the 3-day Labor Day weekend, a computer system failure for the data logger stopped recording the data. The separate system operating the power supply that cycled power on and off as programmed did continue to operate. Due to the datalogger recording being off, the 100-cycle interval and 125-cycle intervals did not have data to enter onto the data sheet. This situation was caught at the 130-cycle point Tuesday morning. It was decided to use the 130-cycle data for the 125-cycle interval. To make up the one missed interval of 25 cycles, an additional 25 cycles were added to the end point making the overall testing 525 cycles. The final data recording provided the 11 entry points needed for calculations.

5.5.3 Specific Device Data Comparison

Since the method of termination on each the three receptacles from one manufacturer was different (wire binding screw, back wired with pressure plate with one conductor and back wired with pressure plate with two conductors) exact data comparison of terminal temperature needs to be done line by line. For example, from appendix pages H1 through H3, the line 1a for manufacturer no. 10 with copper needs to be compared with line 1c on Appendix pages H7 through H9 for manufacturer no. 10 with copper-clad aluminum.

Similarly, for the wire splicing device setups the four (4) devices were from the four (4) different manufacturers. Therefore, the line 9a for copper would be the same wire splicing device as line 9c for copper-clad aluminum.

5.5.4 Temperature Rise

One of the limits for this testing was in a maximum allowed temperature rise above ambient throughout the testing. A review of the calculated temperature rise values found that none of the calculated results exceeded the maximum allowed 125°C for wire splicing devices or 100°C for the receptacles. The maximum temperature rise for the receptacles was 87.48°C for copper and 64.85°C for copper-clad aluminum. The maximum temperature rise above ambient for the wire splicing devices was 102.62°C for copper and 69.4°C for copper-clad aluminum.

5.5.5 Conductor Temperatures

A review of the conductor temperatures subjected to this elevated current for 500 cycles, found the 14 AWG copper-clad aluminum conductor temperatures to operate on average lower than the copper conductors. Table 2 below extracts the average line and load conductor temperatures to show the comparison.

Table 2

Conductor Material	Line Wire (°C)	Load Wire (°C)
Copper (circuit no. 1)	114.86	106.77
Copper (circuit no. 2)	96.57	93.00
Copper-clad aluminum (circuit no. 1)	95.10	77.19
Copper-clad aluminum (circuit no. 2)	82.41	77.36

5.5.6 Receptacle Terminal Temperatures and Stability Factor

A line by line or general review of the recorded temperature rise on the receptacle terminals found the terminals with copper-clad aluminum to have a temperature rise above ambient less than the related copper connected terminals. A line by line or general review of the calculated temperature rise values also found the temperature rise values to be stable for each device. Table 3 below is the average calculated temperature rise for the receptacles.

Table 3

Data sheet Device ID No.	Copper Circuit 1	Copper Circuit 2	Copper-clad aluminum Circuit 1	Copper-clad aluminum Circuit 2
	(a)	(b)	(c)	(d)
1	79.33	63.76	47.00	38.18
2	85.74	62.53	47.72	41.22
3	65.67	52.56	43.00	34.12
4	77.34	66.43	41.26	39.88
5	81.27	71.32	46.86	40.09
6	70.57	65.07	43.02	39.37

The stability factor is calculated separately for each receptacle terminal based on the formula in UL 498 section 169.4.1. The procedure to complete this calculation is to determine the temperature rise from ambient for each of the eleven (11) recorded data points. The average of these eleven (11) calculated temperature rise values is determined. These results are shown in Appendix H, pages H2, H5, H8 and H11.

The stability factor is then calculated by taking the calculated temperature rise and subtracting the average for that row. A positive result means the temperature rise value was higher than the average and a negative result means the temperature rise value is less than the average. The evaluation of the calculated stability factors found in all cases that the stability factor was less than the allow 10°C. These results are found in Appendix H pages H3, H6, H9 and H12.

5.5.7 Wire Splicing Device Temperatures and Stability Factor

A line by line or general review of the recorded temperatures on the wire splicing devices found the terminals with copper-clad aluminum to operate at a temperature below the related copper connected terminals.

The stability factor is calculated separately for each receptacle terminal based on the formula in UL 486C section 7.2.4. The procedure to complete this calculation is to determine the temperature difference between the reference conductor (line wire) and the recorded temperature of the wire splicing device. This is accomplished by subtracting the recorded wire splicing device temperature from the recorded line wire temperature for the eleven (11) recorded data points. The average of these eleven (11) calculated temperature difference values is determined. These results are shown in Appendix H, pages H2, H5, H8 and H11 on rows 9 and 11.

The stability factor is then calculated by taking the calculated temperature difference and subtracting the average for that row. A positive result means the temperature difference value was higher than the average and a negative result means the temperature difference value is less than the average. The evaluation of the calculated stability factors found in all cases that the stability factor was less than the allow 10°C. These results are found in Appendix H pages H3, H6, H9 and H12 on rows 9 and 11.

5.5.8 Receptacle Pull Out Test

After completing the 525 cycles and the receptacles at ambient temperature, the conductors connected to the line and neutral sides were cut so that as much length as possible remained for the pullout test. A calibrated weight of 20 pounds was attached to the conductor and gently lowered until the receptacle terminal was supporting the weight for a period of one (1) minute, see photos 9 and 10 in Appendix F. As shown in Appendix J all terminals passed the test and no conductors separated from the terminal.

6.0 Conclusions

The results from the thermocycling testing conducted for this part of the project found the 14 AWG copper-clad aluminum to have terminal and conductor temperatures generally less than copper when tested on the basis of the respective 60°C ampacity values. In all cases, the temperature recorded, the calculated temperature rise (differential), and the calculated stability factor were within the limits provided in the referenced UL standards. The pull testing found that after 525 cycles of current, the terminations did not loosen such that a 20-pound pulling force could pull the conductor out of or off the terminal.

As stated in the introduction, this testing project was to answer specific questions raised by the Bimetallics Task Group regarding temperature performance of 14 AWG copper-clad aluminum compared with 14 AWG copper in typical applications. These questions have been addressed and data provided with both the Part I and Part II reports submitted to the task group.

While testing conducted followed parts of several UL standards, it is to be understood the more extreme testing was conducted solely to provide specific performance data and information as requested by the task group. The testing does not provide performance evaluation methodology or data normally conducted for certification of any of the components used for this testing.

7.0 Test Equipment and Calibration

The following test and measurement equipment was used for the testing. The certificates of calibration for each of the above items is provided in Appendix K.

Description	manufacturer	Eaton Asset #	Cal Date	Cal Due
Thermocouples	Pacific Test and Measurement	N/A	7/10/2020	N/A
DACQ datalogger	Agilent (HP)	EM7054	7/16/2020	7/16/2021
DVM	Fluke	EM4437	7/16/2020	7/16/2021
DVM	Fluke	EM7014	7/16/2020	7/16/2021
DVM	Fluke	EM7024	7/16/2020	7/16/2021
CT	AEMC	EM6996	7/16/2020	7/16/2021
CT	AEMC	EM6997	7/16/2020	7/16/2021
CT	AEMC	EM8032	7/16/2020	7/16/2021
Torque wrench	CDI	EM8363	7/14/2020	7/14/2021
Tape measure	Stanley	EM6927	7/16/2020	7/16/2021
10 Pound weight	Standard Weight	EM3031-8	10/09/2020	10/09/2021
5 Pound weight	Standard Weight	EM3932-7	10/09/2020	10/09/2021
2 Pound weight	Standard Weight	EM6402	10/09/2020	10/09/2021
2 Pound weight	Standard Weight	EM3931-2	10/09/2020	10/09/2021
1 Pound weight	Standard Weight	EM3930-4	10/09/2020	10/09/2021
Stop watch	Sportline	EM8101	10/07/2020	10/07/2021

Appendix F - Photos



Photo 1 – Laboratory View



Photo 2 – Thermocycling Overall Test Arrangement

Appendix F - Photos



Photo 3 – Power Supply and Datalogger Arrangement

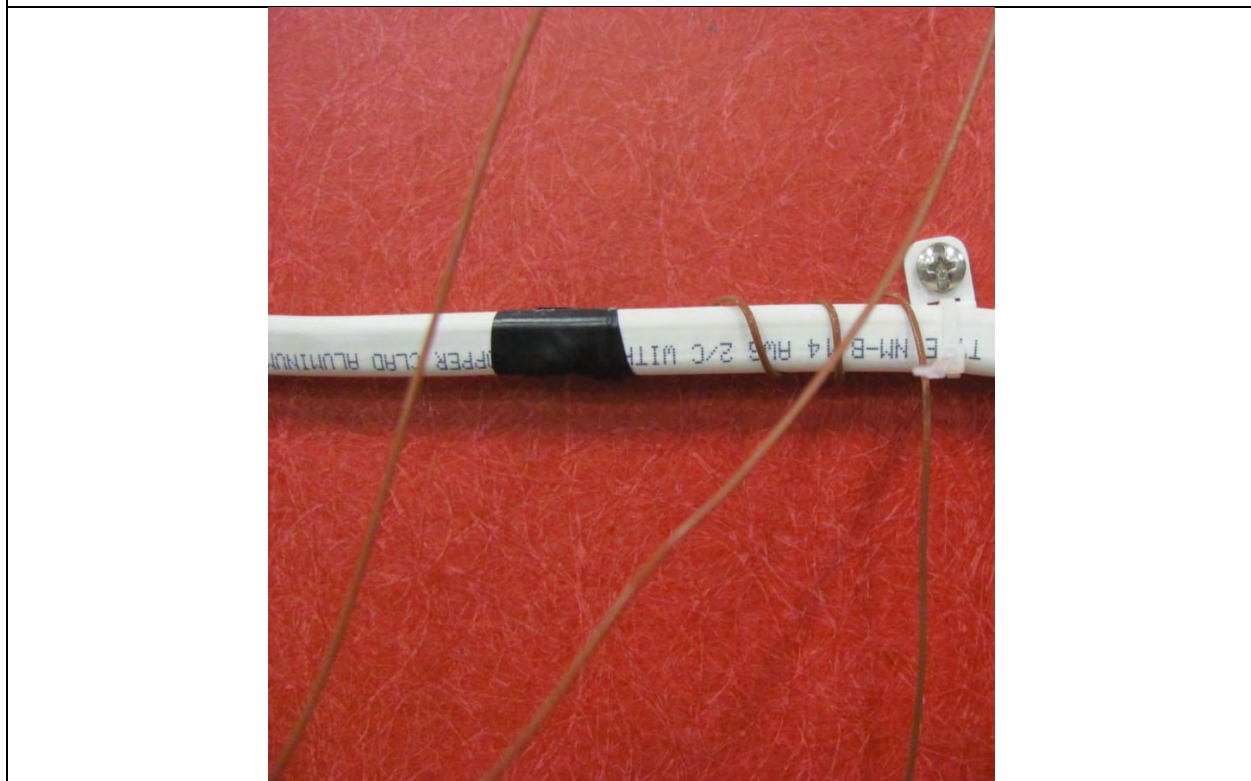


Photo 4– Copper-Clad Aluminum NM-B Cable with Thermocouple on Black Conductor

Appendix F - Photos

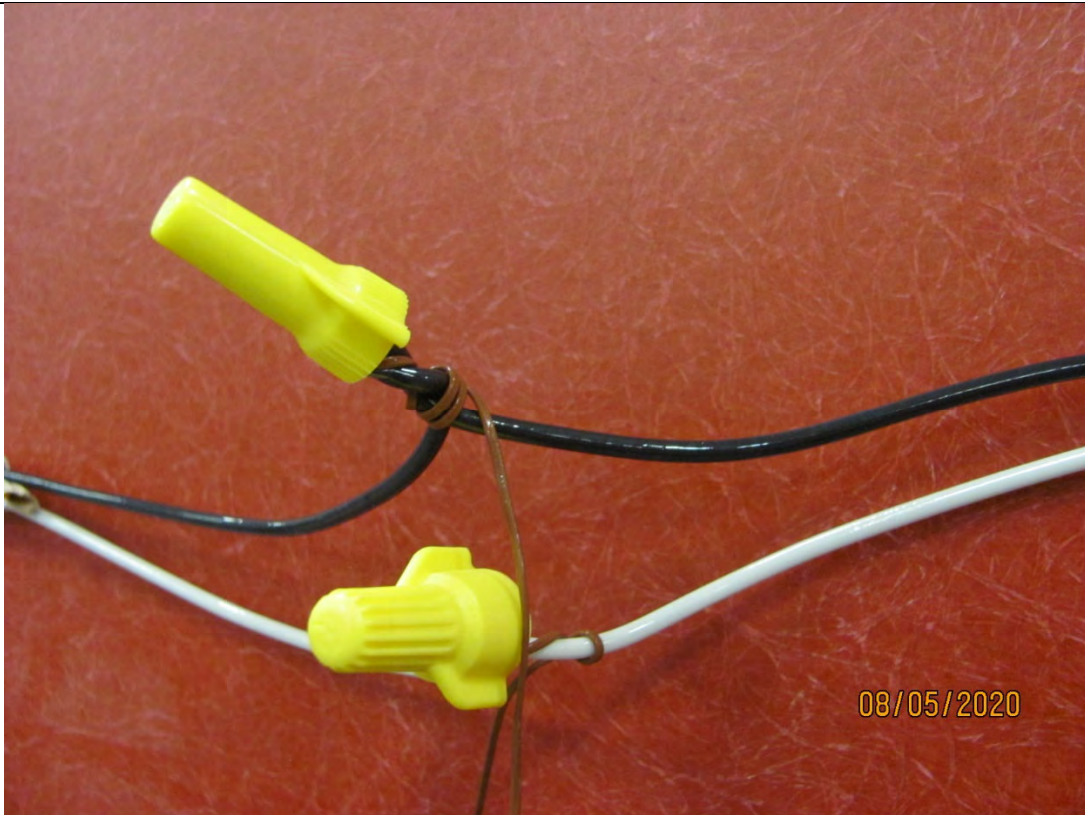


Photo 5 – Typical Installation of Wire Splicing Devices with Thermocouple



Photo 6 – Typical Installation of Receptacle using Wire Binding Screw

Appendix F - Photos

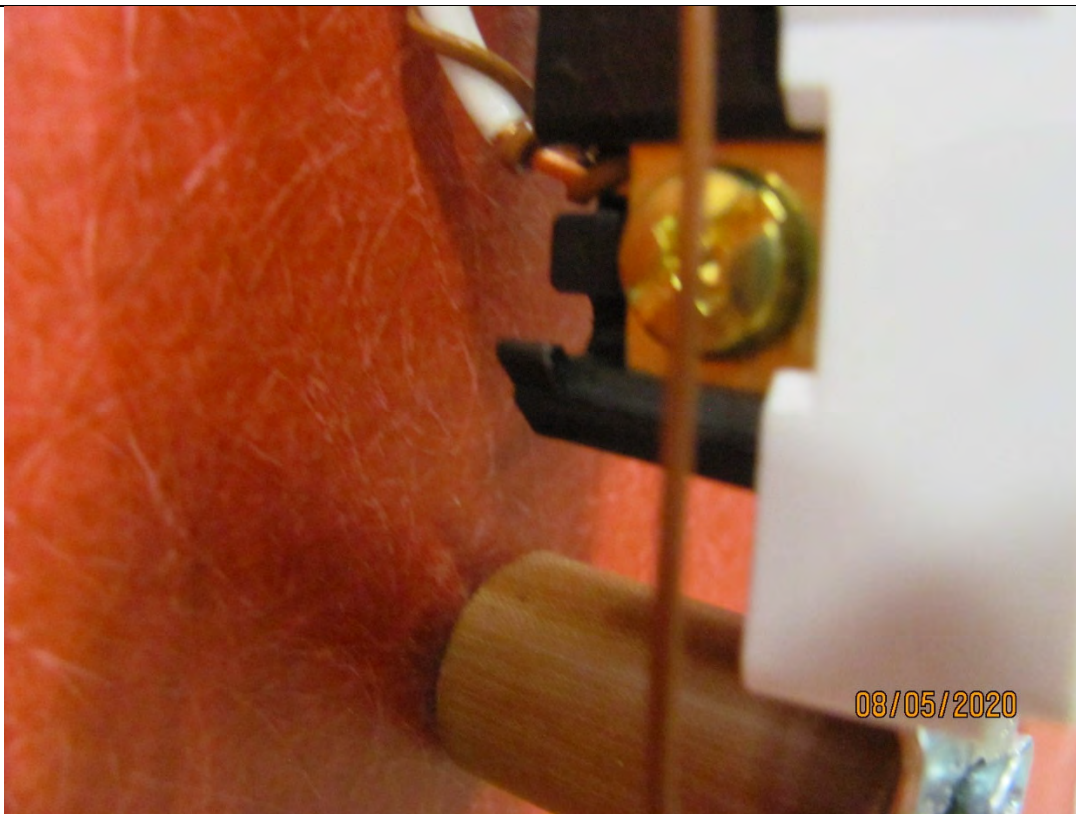


Photo 7 – Typical Installation of Receptacle Since Conductor Back Wired



Photo 8 – Typical Installation of Receptacle Two Conductors Back Wired

Appendix F - Photos



Photo 9 – Pull Out Test Setup



Photo 10 – Pull Out Test Suspended Weight

Appendix F - Photos

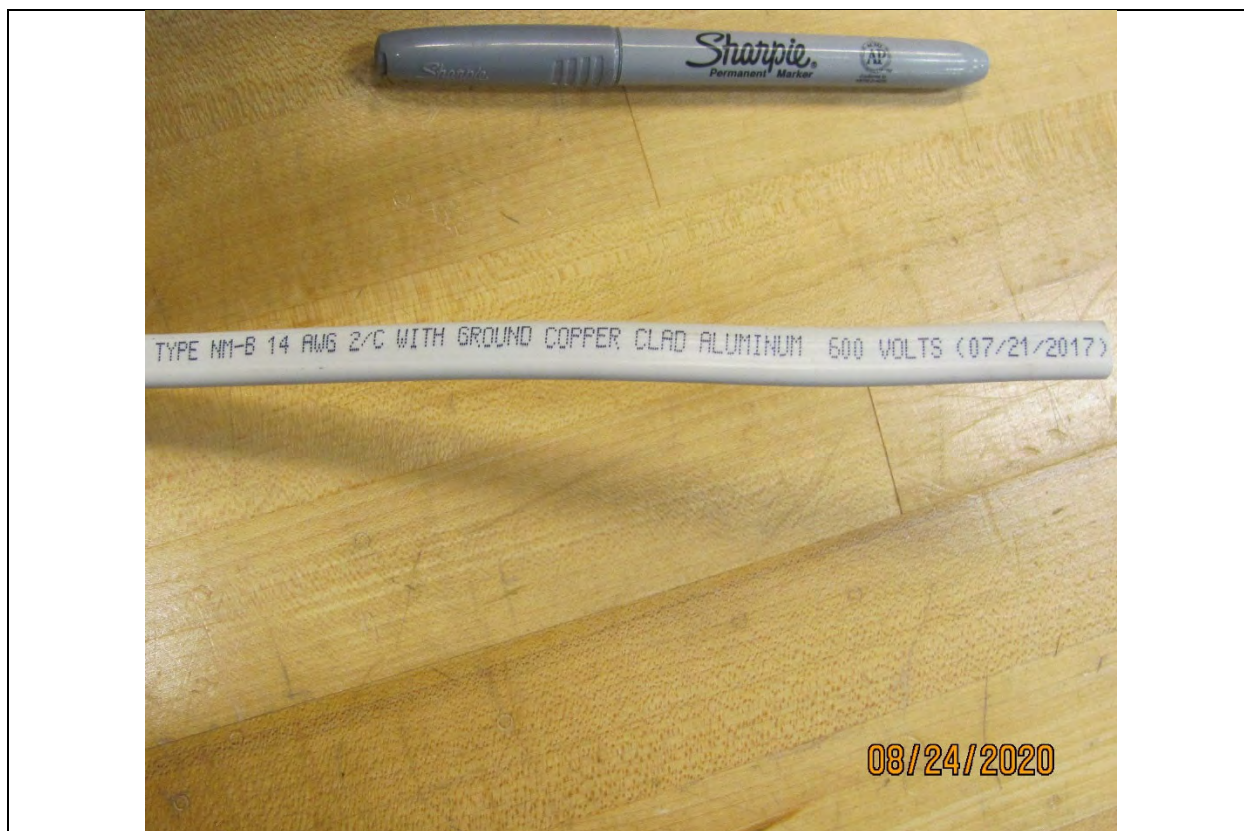


Photo 11 – Copper-Clad Aluminum NM-B Sample Packaging at Eaton



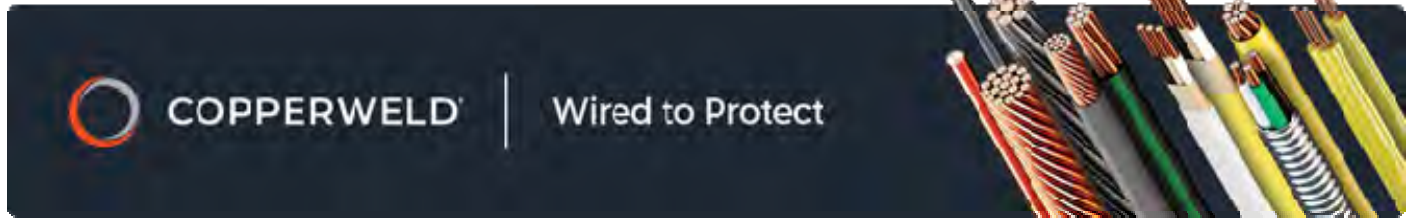
Photo 12 – Copper-Clad Aluminum THHN Sample Packaging at Eaton

Appendix F - Photos



Photo 13 – Copper-Clad Aluminum Sample Packaging at Eaton

Appendix G - Copper-Clad Aluminum Lab Report
(Appendix G same as Part I report, Appendix B)



The power of two

Metallurgical Laboratory Report

Customer:	NEC Bimetals Task Group		
Subject:	14 AWG Building Wire—NMB and THHN		
Date:	8-27-2020	Report No:	456

Analysis By:	Sammy Hampton --Metallographer
Authored By:	Sammy Hampton --Metallographer
Approved By:	Bill Lewey-- QA Manager

Tested to ASTM Designation: B 566-- 04a

The NM and THHN class samples in this report were sent to Copperweld via a sealed package by Eaton Menomonee Falls test lab. The chain of custody was not broken. The testing was witnessed by a third party as part of routine auditing service. The witnessing session was recorded. The copper clad aluminum conductor material from these samples that was tested on August 27, 2020 by the Copperweld Metallurgical Lab was manufactured by Copperweld Bimetals to ASTM B566 standards.



Package as received from Eaton

**Appendix G - Copper-Clad Aluminum Lab Report
(Appendix G same as Part I report, Appendix B)**



Opening the Package



Package Contents

**Appendix G - Copper-Clad Aluminum Lab Report
(Appendix G same as Part I report, Appendix B)**

The wire consists of a core of aluminum with a continuous outer cladding of copper metallurgically bonded to the core throughout and meets the requirements of this specification (5.1).

Test required	Test result	ASTM B 566 requirement	Result
Diameter	0.0641"	± 0.0001 0.0640" minimum 0.0642" maximum	Pass
Break load (lbs.)	55 pounds	64.4 pounds maximum	Pass
Tensile strength (psi)	17195 psi	20000 (psi) maximum	Pass
% elongation	22.78%	15.0% minimum	Pass
Copper thickness (minimum)	0.00148" = 4.6% of wire radius	minimum copper thickness= 3.5% of wire radius	Pass
Copper volume	10.05%	8% minimum 12% maximum	Pass
Adhesion test	No separation (see attached image 1)	The wire shall be repeatedly reverse bent to fracture by any convenient means. The copper clad aluminum wire shall be free from cladding delamination.	Pass
Cohesion test	No seams or splits (see attached images 2 and 3)	The copper clad aluminum wire shall be free from seams or splits	Pass

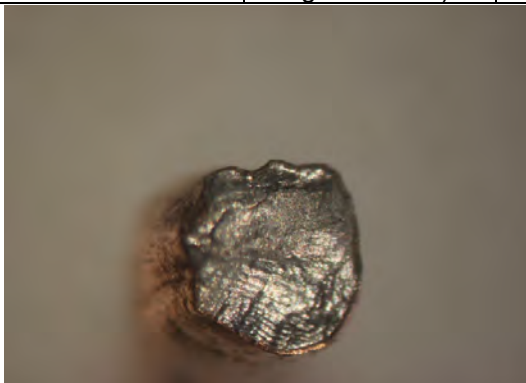


Image 1: adhesion test

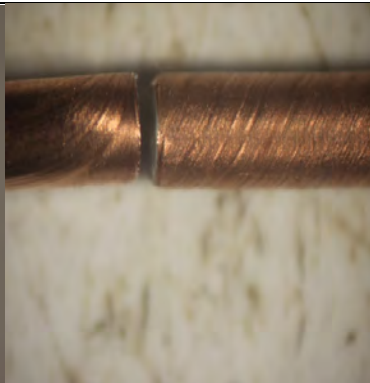


Image 2: cohesion test
(torsion)



image 3: cohesion test
(reverse torsion)

Test and measurement equipment

Equipment	Gauge ID	In calibration	Next due calibration
Micrometer	CP-01	Yes	April 2021
Tensile tester	1755-2000	Yes	January 2022
Ohmmeter	62-1625	Yes	December 2020
Calibration Certificates Attached below			

Appendix G - Copper-Clad Aluminum Lab Report (Appendix G same as Part I report, Appendix B)



PRECISION
CALIBRATION
SYSTEMS

107 N Porter St
Winchester, TN 37398
E-mail: info@pcslcm.com
Phone: 866-521-3823
Website: www.pcslcm.com

INSTRUMENT CALIBRATION REPORT



Copperweld

Instrument ID CP-01

Description Micrometer

Calibrated 8/3/2020

Performed At Customer Location

Manufacturer Mitutoyo

Model Number 293-344-30

Location Main

Building 254 Cotton Mill Rd.

Fayetteville, TN 37334

Frequency Semi-Annual

Certificate # CO080320JM-03

Serial Number 66936496

Cal Procedure QS0003JB2010

Department Quality

Status In Service

Temp 73°F

Humidity 59%

Calibration Specifications

Group # 1		Group Name OD							
Nom In Val / In Val	In Type	Std Accy	Acc %	+/-	Out Val	Out Type	End As	Lft As	In Tol
0.25000 / 0.25000	Inch	Plus / Minus	0.000000	±0.00010	0.25000	Inch	0.25000	0.25000	Yes
0.50000 / 0.50000	Inch	Plus / Minus	0.000000	±0.00010	0.50000	Inch	0.50000	0.50000	Yes
1.00000 / 1.00000	Inch	Plus / Minus	0.000000	±0.00010	1.00000	Inch	1.00000	1.00000	Yes

Test Instruments Used During the Calibration

Test Instrument ID	Description	Manufacturer	Model Number	Serial Number	(As Of Cal Entry Date)	
					Last Cal Date	Next Cal Date
Z-GA-010 GAGE	Gage Block 81pc Set Standard	China	Rectangular Steel	E1599	4/8/2016	4/30/2021
BLCK SET STD SHOP						

Notes about this calibration

Uncertainty = ± (64.9+5.2L) μin (95%CL; K=2)

Calibration Result Calibration Successful

Who Calibrated James Meadows

Finalized By James Meadows

Date Finalized 8/3/2020 9:19:05AM

Total expanded measurement uncertainties expressed are based on a confidence level of 95%, coverage factor of (k=2). Decision Rule: The statement of compliance in this certificate was issued without taking the uncertainty of measurement into consideration. The customer shall assess the results and uncertainty when determining if the results meet their needs. This is considered "shared responsibility." This calibration was conducted using standards traceable to the SI through NIST. The results on this certificate of accuracy apply only to the item described above.

Accredited to ISO IEC 17025: 2017.

This document may not be reproduced except in full.

Laboratory Authorized Signature

James Meadows

Revision Date: 05/08/2020
Rev: 04

Page 1 of 1

QF0016

Appendix G - Copper-Clad Aluminum Lab Report (Appendix G same as Part I report, Appendix B)

INSTRUMENT CALIBRATION REPORT



Copperweld

Instrument ID 1755-2000

Description Tensile Tester (2 Load cells)

Calibrated 8/4/2020

Performed At Customer Location

Manufacturer Thwing-Albert Instruments
Model Number EJA

Location Main
Building 254 Cotton Mill Rd.
Fayetteville, TN 37334

Frequency Semi-Annual
Certificate # CO080420JM-13

Serial Number 1755-2000
Cal Procedure QS0033BG2013

Department Quality
Status In Service

Temp 70°F
Humidity 57%

Calibration Specifications

Group # 1									
Group Name 0-11lb Load Cell 627022									
Nom In Val / In Val	In Type	Std Accy	Acc %	±/-	Out Val	Out Type	End As	Lft As	In Tol
1 / 1	lbf	Pct of Range	0.500000	0.00	1.00	lbf	1.01	1.01	Yes
2 / 2	lbf	Pct of Range	0.500000	0.00	2.00	lbf	2.01	2.01	Yes
3 / 3	lbf	Pct of Range	0.500000	0.00	3.00	lbf	3.01	3.01	Yes
5 / 5	lbf	Pct of Range	0.500000	0.00	5.00	lbf	5.02	5.02	Yes
7 / 7	lbf	Pct of Range	0.500000	0.00	7.00	lbf	7.03	7.03	Yes
10 / 10	lbf	Pct of Range	0.500000	0.00	10.00	lbf	10.04	10.04	Yes
Group # 2									
Group Name 0-225 lb Load cell 608236									
Nom In Val / In Val	In Type	Std Accy	Acc %	±/-	Out Val	Out Type	End As	Lft As	In Tol
5 / 5	lbf	Pct of Range	0.500000	0.00	5.00	lbf	5.00	5.00	Yes
20.446 / 20.446	lbf	Pct of Range	0.500000	0.00	20.45	lbf	20.48	20.48	Yes
50.414 / 50.414	lbf	Pct of Range	0.500000	0.00	50.41	lbf	50.48	50.48	Yes
88.532 / 88.532	lbf	Pct of Range	0.500000	0.00	88.53	lbf	88.64	88.64	Yes
99.044 / 99.044	lbf	Pct of Range	0.500000	0.00	99.04	lbf	99.15	99.15	Yes
117.60 / 117.60	lbf	Pct of Range	0.500000	0.00	117.60	lbf	117.73	117.73	Yes
131.71 / 131.71	lbf	Pct of Range	0.500000	0.00	131.71	lbf	131.83	131.83	Yes
151.04 / 151.04	lbf	Pct of Range	0.500000	0.00	151.04	lbf	151.22	151.22	Yes
161.19 / 161.19	lbf	Pct of Range	0.500000	0.00	161.19	lbf	161.38	161.38	Yes
207.76 / 207.76	lbf	Pct of Range	0.500000	0.00	207.76	lbf	207.99	207.99	Yes

Revision Date 05/08/2020
Rev: 04

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INSTRUMENT CALIBRATION REPORT



Copperweld

Instrument ID 1755-2000

Description Tensile Tester (2 Load cells)

Calibrated 8/4/2020

Performed At Customer Location

Test Instruments Used During the Calibration

Test Instrument ID	Description	Manufacturer	Model Number	Serial Number	(As Of Cal Entry Date)	
					Last Cal Date	Next Cal Date
Z-LO-005 5K LOAD CELL	Load Cell, 5000lb, Tension & Compression	Futek	LSB453	575093	1/7/2020	1/31/2022
Z-WE-003 HANGING WEIGHTS	Weight Set, 1-20lbs, Cast Iron	Rice Lake	ASTM Class 6	D7-D10 (20), D1-D4 (10), D1-D2 (2), 8MB8 (1), 8MB4 (2), 8MB5 (5)	3/26/2019	3/31/2021

Notes about this calibration

Uncertainty = ± 0.23% of Reading (95%CL; K=2)

Calibration Result Calibration Successful

Who Calibrated James Meadows

Finalized By James Meadows

Date Finalized 8/4/2020 1:12:08PM

Total expanded measurement uncertainties expressed are based on a confidence level of 95%, coverage factor of (k=2). Decision Rule: The statement of compliance in this certificate was issued without taking the uncertainty of measurement into consideration. The customer shall assess the results and uncertainty when determining if the results meet their needs. This is considered "shared responsibility." This calibration was conducted using standards traceable to the SI through NIST. The results on this certificate of accuracy apply only to the items described above. Accredited to ISO/IEC 17025:2017.

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Laboratory Authorized Signature

James Meadows

Revision Date 05/08/2020
Rev: 04

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Confidential

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9/2/2020

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Appendix G - Copper-Clad Aluminum Lab Report (Appendix G same as Part I report, Appendix B)



PRECISION
CALIBRATION
SYSTEMS

107 N Porter St
Winchester, TN 37398
E-mail: info@pcslcm.com
Phone: 866-521-3823
Website: www.pcslcm.com

INSTRUMENT CALIBRATION REPORT



Copperweld

Instrument ID 62-1625

Description Micro Ohm Meter

Calibrated 8/4/2020

Performed At Customer Location

Manufacturer Valhalla Scientific
Model Number 4176

Location Main
Building 254 Cotton Mill Rd.
Fayetteville, TN 37334

Frequency Semi-Annual
Certificate # CO080420JM-03

Serial Number 62-1625

Cal Procedure QS0011JB2010

Department Quality
Status In Service

Temp 70°F
Humidity 57%

Calibration Specifications

Group # 1									
Group Name Ohm - Source									
Nom In Val / In Val	In Type	Std Accy	Acc %	±/-	Out Val	Out Type	End As	Lft As	In Tol
1.000 / 1.000	Ohm	Pct of Reading	0.040000	0.0000	1.0000	Ohm	0.9998	0.9998	Yes
10.000 / 10.000	Ohm	Pct of Reading	0.040000	0.000	10.000	Ohm	9.999	9.999	Yes
100.000 / 100.000	Ohm	Pct of Reading	0.040000	0.00	100.00	Ohm	99.99	99.99	Yes

Test Instruments Used During the Calibration

Test Instrument ID	Description	Manufacturer	Model Number	Serial Number	(As Of Cal Entry Date)	
					Last Cal Date	Next Cal Date
Z-EL-020 DECADE RESISTANCE BOX	General Radio Small Decade Resistance Box	General Radio	1433-U	2545	12/18/2018	12/31/2020

Notes about this calibration

Uncertainty = ± 2 mOhm (95%CL; K=2)

Calibration Result Calibration Successful

Who Calibrated James Meadows

Finalized By James Meadows

Date Finalized 8/4/2020 12:47:33PM

Total expanded measurement uncertainties expressed are based on a confidence level of 95%, coverage factor of (k=2). Decision Rule: The statement of compliance in this certificate was issued without taking the uncertainty of measurement into consideration. The customer shall assess the results and uncertainty when determining if the results meet their needs. This is considered "shared responsibility." This calibration was conducted using standards traceable to the SI through NIST. The results on this certificate of accuracy apply only to the item described above.
Accredited to ISO/IEC 17025:2017.

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Laboratory Authorized Signature *James Meadows*

Revision Date: 05/09/2020
Rev: 04

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**Follow-up Service Inspection Report
E4911851200827165202**

INSPECTION DETAILS			
Date:	2020-08-27	File Number.:	E491185
Responsible Office:	Melville	Volume:	1
Inspection Center:	232	CCN:	DVVU2
Product Type:	CCA Conductor	UL Rep Name:	Gregory Cornett
Deliverable Type:	Recognized	UL Rep ID:	20708
Party Site Number:	1626131	Subscriber Factory No.:	
Manufacturer Name:	Copperweld Bimetallics LLC	Factory Rep Name	Mr. Sammy Hampton
Manufacturer Address:	254 Cotton Mill Rd Fayetteville, TN 37334	Factory Rep Phone:	931-433-0495
		Factory Rep Email:	shampton@copperweld.com
Nature of visit:	Regular Inspection	Sample Status:	Sample requirements fulfilled for sample period
UL Marks Used?	Yes	UL Marks Removed?	No
Variation Notice Issued?	No	Inspection Conducted Remotely?	Yes
Comments After Submission:			

PRODUCT DOCUMENTS/PRODUCTION READY VISIT			
Model	Product	Section	Multiple Listed
14 Awg Class 10A	Copper Clad Aluminum	1	No

SAMPLE DOCUMENTS			
If samples are required to be sent to UL, indicate below. If required samples are not sent, explain in the Comments area.			
No Samples			
Additional Comments	14 Awg conductors from the NMB and THHN samples passed the UL tests for DVVU2, including Tensile, Elongation, copper thickness and DC Resistance.		

In addition to the requirements specified in the applicable UL Services agreement and Follow-Up Service Procedure, UL further defines responsibilities, duties and requirements for both manufacturers and UL representatives in the document titled "UL Mark Surveillance Requirements" that can be located at www.ul.com/fus, and in accordance with the applicable terms and conditions of the document at www.ul.com/responsibilities. Manufacturers without Internet access may obtain the current versions of these documents from their local UL customer service representative or UL field representative.

Appendix H – Thermocycling Recorded Test Data and Calculated Results

Test #5; Wiring Device Thermal Cycling tests with Copper 14awg wire with Mfg. 10 and Mfg. 9 receptacles at 40A:

data logger CH #	Location	Recorded Temperature (°C)													average
cycle #		25	50	75	100	125	130	170	215	260	340	420	500	525	
1a	Mfg. 10 - 1	101.71	101.64	103.31	no data	no data	99.60	99.29	99.78	101.04	101.26	98.88	99.63	100.47	100.60
2a	Mfg. 10 - 2	106.08	108.49	108.38	no data	no data	108.20	106.11	106.46	103.40	106.82	107.87	107.04	108.32	107.02
3a	Mfg. 10 - 3	86.84	88.70	88.32	no data	no data	89.04	86.73	86.92	82.52	85.29	88.23	86.42	87.37	86.94
4a	Mfg. 9 - 1	98.51	101.13	100.59	no data	no data	99.49	97.48	98.09	98.18	98.71	97.88	96.98	97.73	98.62
5a	Mfg. 9 - 2	105.21	105.04	105.10	no data	no data	101.65	102.00	102.41	101.82	103.30	99.02	100.81	101.59	102.54
6a	Mfg. 9 - 3	90.81	91.88	92.16	no data	no data	89.66	90.26	92.91	91.22	91.29	87.43	91.67	101.00	91.84
8a	line wire	118.77	115.34	116.50	no data	no data	116.03	112.96	114.17	117.50	111.59	110.94	115.59	114.04	114.86
9a	line wire splicing device	113.83	120.93	121.41	no data	no data	123.77	119.19	118.41	116.56	119.75	120.32	121.05	120.91	119.65
10a	load wire	106.81	109.20	109.94	no data	no data	106.41	105.53	106.38	109.85	107.26	102.73	105.44	104.96	106.77
11a	load wire splicing device	102.27	111.17	111.60	no data	no data	104.05	97.47	98.51	109.16	97.41	95.49	104.82	104.52	103.32
12a	room ambient (°C)	22.19	21.52	21.86	no data	no data	21.15	20.87	21.16	22.02	20.98	20.63	20.81	20.84	21.28
13a	current (amps)	40.06	40.06	40.11	no data	no data	40.11	40.30	40.19	40.00	40.21	40.20	40.05	40.05	40.12
	Ambient Temp. Difference from Average	0.91	0.24	0.58	no data	no data	-0.13	-0.41	-0.12	0.74	-0.30	-0.65	-0.47	-0.44	

(See 5.5.2 for explanation of yellow highlighted “no data” entries.)

Appendix H – Thermocycling Recorded Test Data and Calculated Results

Test #5; Wiring Device Thermal Cycling tests with Copper 14awg wire with Mfg. 10 and Mfg. 9 receptacles at 40A:

data logger CH #	Location	Receptacles Calc Temp Rise from Ambient (°C) / Wire Splicing Devices Calc Temp Differential from Line Conductor													average
cycle #		25	50	75	100	125	130	170	215	260	340	420	500	525	
1a	Mfg. 10 - 1	79.52	80.12	81.45	no data	no data	78.45	78.42	78.62	79.02	80.28	78.25	78.82	79.63	79.33
2a	Mfg. 10 - 2	83.89	86.97	86.52	no data	no data	87.05	85.24	85.30	81.38	85.84	87.24	86.23	87.48	85.74
3a	Mfg. 10 - 3	64.65	67.18	66.46	no data	no data	67.89	65.86	65.76	60.50	64.31	67.60	65.61	66.53	65.67
4a	Mfg. 9 - 1	76.32	79.61	78.73	no data	no data	78.34	76.61	76.93	76.16	77.73	77.25	76.17	76.89	77.34
5a	Mfg. 9 - 2	83.02	83.52	83.24	no data	no data	80.50	81.13	81.25	79.80	82.32	78.39	80.00	80.75	81.27
6a	Mfg. 9 - 3	68.62	70.36	70.30	no data	no data	68.51	69.39	71.75	69.20	70.31	66.80	70.86	80.16	70.57
8a	line wire														
9a	line wire splicing device	-4.94	5.59	4.91	no data	no data	7.74	6.23	4.24	-0.94	8.16	9.38	5.46	6.87	4.79
10a	load wire														
11a	load wire splicing device	-16.50	-4.17	-4.90	no data	no data	-11.98	-15.49	-15.66	-8.34	-14.18	-15.45	-10.77	-9.52	-11.54

(See 5.5.2 for explanation of yellow highlighted “no data” entries.)

Appendix H – Thermocycling Recorded Test Data and Calculated Results

Test #5; Wiring Device Thermal Cycling tests with Copper 14awg wire with Mfg. 10 and Mfg. 9 receptacles at 40A:

data logger CH #	Location	Stability Factor												
		25	50	75	100	125	130	170	215	260	340	420	500	525
Cycle #														
1a	Mfg. 10 - 1	0.19	0.79	2.12	no data	no data	-0.88	-0.91	-0.71	-0.31	0.95	-1.08	-0.51	0.30
2a	Mfg. 10 - 2	-1.85	1.23	0.78	no data	no data	1.31	-0.50	-0.44	-4.36	0.10	1.50	0.49	1.74
3a	Mfg. 10 - 3	-1.02	1.51	0.79	no data	no data	2.22	0.19	0.09	-5.17	-1.36	1.93	-0.06	0.86
4a	Mfg. 9 - 1	-1.02	2.27	1.39	no data	no data	1.00	-0.73	-0.41	-1.18	0.39	-0.09	-1.17	-0.45
5a	Mfg. 9 - 2	1.75	2.25	1.97	no data	no data	-0.77	-0.14	-0.02	-1.47	1.05	-2.88	-1.27	-0.52
6a	Mfg. 9 - 3	-1.95	-0.21	-0.27	no data	no data	-2.06	-1.18	1.18	-1.37	-0.26	-3.77	0.29	9.59
8a	line wire													
9a	line wire splicing device	-9.73	0.80	0.12	no data	no data	2.95	1.44	-0.55	-5.73	3.37	4.59	0.67	2.08
10a	load wire													
11a	load wire splicing device	-4.96	7.37	6.64	no data	no data	-0.44	-3.95	-4.12	3.20	-2.64	-3.91	0.77	2.02

(See 5.5.2 for explanation of yellow highlighted “no data” entries.)

Appendix H – Thermocycling Recorded Test Data and Calculated Results

Test #5; Wiring Device Thermal Cycling tests with Copper 14awg wire with Mfg. 11 and Mfg. 8 receptacles at 40A:

data logger CH #	Location	Recorded Temperature (°C)													average
cycle #		25	50	75	100	125	130	170	215	260	340	420	500	525	
1b	Mfg. 11 - 1	86.23	86.35	86.84	no data	no data	85.53	84.24	84.41	85.17	84.16	84.22	84.25	84.49	85.08
2b	Mfg. 11 - 2	84.34	84.59	85.28	no data	no data	85.22	82.92	83.34	83.12	82.63	83.99	83.38	83.52	83.85
3b	Mfg. 11 - 3	73.84	74.56	74.44	no data	no data	75.93	73.25	73.57	72.27	71.86	75.29	73.44	74.26	73.88
4b	Mfg. 8 - 1	87.65	88.67	88.73	no data	no data	88.79	87.11	87.48	86.41	87.02	87.59	87.70	88.16	87.76
5b	Mfg. 8 - 2	93.60	93.20	94.10	no data	no data	92.96	92.04	92.31	92.40	92.15	92.74	91.52	92.07	92.64
6b	Mfg. 8 - 3	84.90	87.27	86.43	no data	no data	88.34	86.47	86.56	83.25	84.84	88.38	86.11	87.73	86.39
8b	line wire	103.03	100.21	100.67	no data	no data	97.02	94.39	95.31	100.77	93.25	92.30	92.84	92.50	96.57
9b	line wire splicing device	79.15	81.25	81.87	no data	no data	79.51	78.76	79.50	81.80	79.66	78.36	79.94	78.86	79.88
10b	load wire	95.24	95.06	96.18	no data	no data	92.55	91.91	92.21	94.43	92.09	90.55	91.62	91.13	93.00
11b	load wire splicing device	95.02	99.85	99.32	no data	no data	95.89	92.86	94.22	100.13	94.08	94.04	97.19	96.97	96.32
12b	room ambient	22.21	21.53	21.90	no data	no data	21.09	20.91	21.32	21.94	21.08	20.63	20.80	21.14	21.32
13a	current (amps)	40.06	40.06	40.11	no data	no data	40.11	40.30	40.19	40.00	40.21	40.20	40.05	40.05	40.12
	Ambient Difference from Average	0.89	0.21	0.58	no data	no data	-0.23	-0.41	0.00	0.62	-0.24	-0.69	-0.52	-0.18	

(See 5.5.2 for explanation of yellow highlighted “no data” entries.)

Appendix H – Thermocycling Recorded Test Data and Calculated Results

Test #5; Wiring Device Thermal Cycling tests with Copper 14awg wire with Mfg. 11 and Mfg. 8 receptacles at 40A:

data logger CH #	Location	Receptacles Calc Temp Rise from Ambient (°C) / Wire Splicing Devices Calc Temp Differential from Line Conductor													average
cycle #		25	50	75	100	125	130	170	215	260	340	420	500	525	
1b	Mfg. 11 - 1	64.02	64.82	64.94	no data	no data	64.44	63.33	63.09	63.23	63.08	63.59	63.45	63.35	63.76
2b	Mfg. 11 - 2	62.13	63.06	63.38	no data	no data	64.13	62.01	62.02	61.18	61.55	63.36	62.58	62.38	62.53
3b	Mfg. 11 - 3	51.63	53.03	52.54	no data	no data	54.84	52.34	52.25	50.33	50.78	54.66	52.64	53.12	52.56
4b	Mfg. 8 - 1	65.44	67.14	66.83	no data	no data	67.70	66.20	66.16	64.47	65.94	66.96	66.90	67.02	66.43
5b	Mfg. 8 - 2	71.39	71.67	72.20	no data	no data	71.87	71.13	70.99	70.46	71.07	72.11	70.72	70.93	71.32
6b	Mfg. 8 - 3	62.69	65.74	64.53	no data	no data	67.25	65.56	65.24	61.31	63.76	67.75	65.31	66.59	65.07
8b	line wire														
9b	line wire splicing device	-23.88	-18.96	-18.80	no data	no data	-17.51	-15.63	-15.81	-18.97	-13.59	-13.94	-12.90	-13.64	-16.69
10b	load wire														
11b	load wire splicing device	-8.01	-0.36	-1.35	no data	no data	-1.13	-1.53	-1.09	-0.64	0.83	1.74	4.35	4.47	-0.25

(See 5.5.2 for explanation of yellow highlighted “no data” entries.)

Appendix H – Thermocycling Recorded Test Data and Calculated Results

Test #5; Wiring Device Thermal Cycling tests with Copper 14awg wire with Mfg. 11 and Mfg. 8 receptacles at 40A:

data logger CH #	Location	Stability Factor												
		25	50	75	100	125	130	170	215	260	340	420	500	525
cycle #														
1b	Mfg. 11 - 1	0.26	1.06	1.18	no data	no data	0.68	-0.43	-0.67	-0.53	-0.68	-0.17	-0.31	-0.41
2b	Mfg. 11 - 2	-0.40	0.53	0.85	no data	no data	1.60	-0.52	-0.51	-1.35	-0.98	0.83	0.05	-0.15
3b	Mfg. 11 - 3	-0.93	0.47	-0.02	no data	no data	2.28	-0.22	-0.31	-2.23	-1.78	2.10	0.08	0.56
4b	Mfg. 8 - 1	-0.99	0.71	0.40	no data	no data	1.27	-0.23	-0.27	-1.96	-0.49	0.53	0.47	0.59
5b	Mfg. 8 - 2	0.07	0.35	0.88	no data	no data	0.55	-0.19	-0.33	-0.86	-0.25	0.79	-0.60	-0.39
6b	Mfg. 8 - 3	-2.38	0.67	-0.54	no data	no data	2.18	0.49	0.17	-3.76	-1.31	2.68	0.24	1.52
8b	line wire				no data	no data								
9b	line wire splicing device	-7.19	-2.27	-2.11	no data	no data	-0.82	1.06	0.88	-2.28	3.10	2.75	3.79	3.05
10b	load wire				no data	no data								
11b	load wire splicing device	-7.76	-0.11	-1.10	no data	no data	-0.88	-1.28	-0.84	-0.39	1.08	1.99	4.60	4.72

(See 5.5.2 for explanation of yellow highlighted “no data” entries.)

Appendix H – Thermocycling Recorded Test Data and Calculated Results

Test #5; Wiring Device Thermal Cycling tests with Copper-clad 14awg wire with Mfg. 10 and Mfg. 9 receptacles at 26.67A:

data logger CH #	Location	Recorded Temperature (°C)													average
		25	50	75	100	125	130	170	215	260	340	420	500	525	
cycle #															
1c	Mfg. 10 - 1	69.16	68.03	69.28	no data	no data	67.96	67.50	67.44	68.59	67.59	68.68	67.91	67.72	68.17
2c	Mfg. 10 - 2	70.05	68.90	70.64	no data	no data	68.79	68.52	68.33	68.83	68.34	69.13	67.56	68.74	68.89
3c	Mfg. 10 - 3	65.24	64.21	65.83	no data	no data	63.32	63.64	63.72	64.27	63.44	64.83	63.53	63.85	64.17
4c	Mfg. 9 - 1	63.58	62.02	63.64	no data	no data	62.23	61.77	61.91	62.69	61.93	62.95	61.81	62.23	62.43
5c	Mfg. 9 - 2	68.66	68.04	68.35	no data	no data	68.31	67.48	67.32	68.53	67.80	68.39	67.80	67.63	68.03
6c	Mfg. 9 - 3	64.53	62.76	64.56	no data	no data	63.17	62.50	62.76	64.08	63.04	63.70	67.42	67.58	64.19
8c	line wire	95.90	95.18	96.89	no data	no data	94.12	95.12	95.44	93.96	95.78	95.00	93.58	95.15	95.10
9c	line wire splicing device	76.51	75.45	76.02	no data	no data	75.24	74.49	74.15	76.82	75.21	77.42	75.64	73.31	75.48
10c	load wire	77.76	77.59	77.43	no data	no data	77.15	75.91	75.93	79.65	76.52	78.82	77.30	75.05	77.19
11c	load wire splicing device	88.90	88.39	88.45	no data	no data	87.92	86.72	86.15	90.73	87.13	89.96	88.69	86.02	88.10
12c	room ambient	22.13	21.37	21.77	no data	no data	20.98	20.75	21.04	21.88	20.86	20.56	20.78	20.74	21.17
13c	current (amps)	26.61	26.74	26.73	no data	no data	26.69	26.77	26.73	26.57	26.72	26.71	26.63	26.69	26.69
	Ambient Difference from Average	0.96	0.20	0.60	no data	no data	-0.19	-0.42	-0.13	0.71	-0.31	-0.61	-0.39	-0.43	

(See 5.5.2 for explanation of yellow highlighted “no data” entries.)

Appendix H – Thermocycling Recorded Test Data and Calculated Results

Test #5; Wiring Device Thermal Cycling tests with Copper-clad 14awg wire with Mfg. 10 and Mfg. 9 receptacles at 26.67A:

data logger CH #	Location	Receptacles Calc Temp Rise from Ambient (°C) / Wire Splicing Devices Calc Temp Differential from Line Conductor													average
cycle #		25	50	75	100	125	130	170	215	260	340	420	500	525	
1c	Mfg. 10 - 1	47.03	46.66	47.51	no data	no data	46.98	46.75	46.40	46.71	46.73	48.12	47.13	46.98	47.00
2c	Mfg. 10 - 2	47.92	47.53	48.87	no data	no data	47.81	47.77	47.29	46.95	47.48	48.57	46.78	48.00	47.72
3c	Mfg. 10 - 3	43.11	42.84	44.06	no data	no data	42.34	42.89	42.68	42.39	42.58	44.27	42.75	43.11	43.00
4c	Mfg. 9 - 1	41.45	40.65	41.87	no data	no data	41.25	41.02	40.87	40.81	41.07	42.39	41.03	41.49	41.26
5c	Mfg. 9 - 2	46.53	46.67	46.58	no data	no data	47.33	46.73	46.28	46.65	46.94	47.83	47.02	46.89	46.86
6c	Mfg. 9 - 3	42.40	41.39	42.79	no data	no data	42.19	41.75	41.72	42.20	42.18	43.14	46.64	46.84	43.02
8c	line wire														
9c	line wire splicing device	-19.39	-19.73	-20.87	no data	no data	-18.88	-20.63	-21.29	-17.14	-20.57	-17.58	-17.94	-21.84	-19.62
10c	load wire														
11c	load wire splicing device	-7.00	-6.79	-8.44	no data	no data	-6.20	-8.40	-9.29	-3.23	-8.65	-5.04	-4.89	-9.13	-7.01

(See 5.5.2 for explanation of yellow highlighted “no data” entries.)

Appendix H – Thermocycling Recorded Test Data and Calculated Results

Test #5; Wiring Device Thermal Cycling tests with Copper-clad 14awg wire with Mfg. 10 and Mfg. 9 receptacles at 26.67A:

data logger CH #	Location	Stability Factor												
		25	50	75	100	125	130	170	215	260	340	420	500	525
cycle #														
1c	Mfg. 10 - 1	0.03	-0.34	0.51	no data	no data	-0.02	-0.25	-0.60	-0.29	-0.27	1.12	0.13	-0.02
2c	Mfg. 10 - 2	0.20	-0.19	1.15	no data	no data	0.09	0.05	-0.43	-0.77	-0.24	0.85	-0.94	0.28
3c	Mfg. 10 - 3	0.11	-0.16	1.06	no data	no data	-0.66	-0.11	-0.32	-0.61	-0.42	1.27	-0.25	0.11
4c	Mfg. 9 - 1	0.19	-0.61	0.61	no data	no data	-0.01	-0.24	-0.39	-0.45	-0.19	1.13	-0.23	0.23
5c	Mfg. 9 - 2	-0.33	-0.19	-0.28	no data	no data	0.47	-0.13	-0.58	-0.21	0.08	0.97	0.16	0.03
6c	Mfg. 9 - 3	-0.62	-1.63	-0.23	no data	no data	-0.83	-1.27	-1.30	-0.82	-0.84	0.12	3.62	3.82
8c	line wire													
9c	line wire splicing device	0.23	-0.11	-1.25	no data	no data	0.74	-1.01	-1.67	2.48	-0.95	2.04	1.68	-2.22
10c	load wire													
11c	load wire splicing device	0.01	0.22	-1.43	no data	no data	0.81	-1.39	-2.28	3.78	-1.64	1.97	2.12	-2.12

(See 5.5.2 for explanation of yellow highlighted “no data” entries.)

Appendix H – Thermocycling Recorded Test Data and Calculated Results

Test #5; Wiring Device Thermal Cycling tests with Copper-clad 14awg wire with Mfg. 11 and Mfg. 8 receptacles at 26.67A:

data logger CH #	Location	Recorded Temperature (°C)													average
cycle #		25	50	75	100	125	130	170	215	260	340	420	500	525	
1d	Mfg. 11 - 1	60.89	60.43	61.16	no data	no data	59.33	59.49	59.60	60.16	59.12	59.72	59.35	58.20	59.77
2d	Mfg. 11 - 2	64.73	63.33	64.85	no data	no data	61.72	62.07	62.22	62.60	61.57	62.85	62.56	62.36	62.81
3d	Mfg. 11 - 3	57.50	55.44	57.81	no data	no data	54.73	54.94	56.12	55.18	54.41	55.93	55.01	55.69	55.71
4d	Mfg. 8 - 1	62.66	61.45	62.87	no data	no data	61.20	61.09	61.01	62.08	60.69	61.28	60.61	61.14	61.46
5d	Mfg. 8 - 2	62.72	62.13	62.84	no data	no data	60.91	61.20	61.28	62.18	60.90	62.00	61.28	60.95	61.67
6d	Mfg. 8 - 3	62.55	61.25	62.88	no data	no data	59.57	60.16	60.25	61.54	60.06	61.11	60.58	60.60	60.96
8d	line wire	83.80	83.00	83.71	no data	no data	82.14	82.00	82.02	82.71	81.99	83.16	81.44	80.54	82.41
9d	line wire splicing device	74.75	75.04	75.10	no data	no data	73.26	72.71	72.37	77.18	73.34	75.18	76.06	72.67	74.33
10d	load wire	78.44	77.66	79.26	no data	no data	77.09	76.83	76.65	77.79	76.48	77.82	77.01	75.92	77.36
11d	load wire splicing device	73.94	74.81	74.46	no data	no data	72.78	71.48	71.57	75.43	71.68	73.53	74.32	70.95	73.18
12d	room ambient	22.70	21.79	22.27	no data	no data	21.28	21.21	21.53	22.24	21.23	20.88	21.09	21.23	21.59
13c	current (amps)	26.61	26.74	26.73	no data	no data	26.69	26.77	26.73	26.57	26.72	26.71	26.63	26.69	26.69
	Ambient Difference from Average	1.11	0.20	0.68	no data	no data	-0.31	-0.38	-0.06	0.65	-0.36	-0.71	-0.50	-0.36	

(See 5.5.2 for explanation of yellow highlighted “no data” entries.)

Appendix H – Thermocycling Recorded Test Data and Calculated Results

Test #5; Wiring Device Thermal Cycling tests with Copper-clad 14awg wire with Mfg. 11 and Mfg. 8 receptacles at 26.67A:

data logger CH #	Location	Receptacles Calc Temp Rise from Ambient (°C) / Wire Splicing Devices Calc Temp Differential from Line Conductor													average
cycle #		25	50	75	100	125	130	170	215	260	340	420	500	525	
1d	Mfg. 11 - 1	38.19	38.64	38.89	no data	no data	38.05	38.28	38.07	37.92	37.89	38.84	38.26	36.97	38.18
2d	Mfg. 11 - 2	42.03	41.54	42.58	no data	no data	40.44	40.86	40.69	40.36	40.34	41.97	41.47	41.13	41.22
3d	Mfg. 11 - 3	34.80	33.65	35.54	no data	no data	33.45	33.73	34.59	32.94	33.18	35.05	33.92	34.46	34.12
4d	Mfg. 8 - 1	39.96	39.66	40.60	no data	no data	39.92	39.88	39.48	39.84	39.46	40.40	39.52	39.91	39.88
5d	Mfg. 8 - 2	40.02	40.34	40.57	no data	no data	39.63	39.99	39.75	39.94	39.67	41.12	40.19	39.72	40.09
6d	Mfg. 8 - 3	39.85	39.46	40.61	no data	no data	38.29	38.95	38.72	39.30	38.83	40.23	39.49	39.37	39.37
8d	line wire														
9d	line wire splicing device	-9.05	-7.96	-8.61	no data	no data	-8.88	-9.29	-9.65	-5.53	-8.65	-7.98	-5.38	-7.87	-8.08
10d	load wire														
11d	load wire splicing device	-9.86	-8.19	-9.25	no data	no data	-9.36	-10.52	-10.45	-7.28	-10.31	-9.63	-7.12	-9.59	-9.23

(See 5.5.2 for explanation of yellow highlighted “no data” entries.)

Appendix H – Thermocycling Recorded Test Data and Calculated Results

Test #5; Wiring Device Thermal Cycling tests with Copper-clad 14awg wire with Mfg. 11 and Mfg. 8 receptacles at 26.67A:

data logger CH #	Location	Stability Factor												
cycle #		25	50	75	100	125	130	170	215	260	340	420	500	525
1d	Mfg. 11 - 1	0.01	0.46	0.71	no data	no data	-0.13	0.10	-0.11	-0.26	-0.29	0.66	0.08	-1.21
2d	Mfg. 11 - 2	0.81	0.32	1.36	no data	no data	-0.78	-0.36	-0.53	-0.86	-0.88	0.75	0.25	-0.09
3d	Mfg. 11 - 3	0.68	-0.47	1.42	no data	no data	-0.67	-0.39	0.47	-1.18	-0.94	0.93	-0.20	0.34
4d	Mfg. 8 - 1	0.08	-0.22	0.72	no data	no data	0.04	0.00	-0.40	-0.04	-0.42	0.52	-0.36	0.03
5d	Mfg. 8 - 2	-0.07	0.25	0.48	no data	no data	-0.46	-0.10	-0.34	-0.15	-0.42	1.03	0.10	-0.37
6d	Mfg. 8 - 3	0.48	0.09	1.24	no data	no data	-1.08	-0.42	-0.65	-0.07	-0.54	0.86	0.12	0.00
8d	line wire													
9d	line wire splicing device	-0.97	0.12	-0.53	no data	no data	-0.80	-1.21	-1.57	2.55	-0.57	0.10	2.70	0.21
10d	load wire													
11d	load wire splicing device	-0.63	1.04	-0.02	no data	no data	-0.13	-1.29	-1.22	1.95	-1.08	-0.40	2.11	-0.36

(See 5.5.2 for explanation of yellow highlighted “no data” entries.)

Appendix J – Pull Out Test Results

Test #5; Post Thermal Cycling tests - 20 pound pull-out test on receptacle terminal wire for 1 minute duration:

type of 14awg wire being tested	receptacle ID	thermocouple ID #	Test group #	pull-out test on hot wire	pull-out test on neutral
Copper	Mfg. 10 -	1	A	passed	passed
Copper	Mfg. 10 -	2	A	passed	passed
Copper	Mfg. 10 -	3	A	passed	passed
Copper	Mfg. 9 -	4	A	passed	passed
Copper	Mfg. 9 -	5	A	passed	passed
Copper	Mfg. 9 -	6	A	passed	passed
Copper	Mfg. 11 -	1	B	passed	passed
Copper	Mfg. 11 -	2	B	passed	passed
Copper	Mfg. 11 -	3	B	passed	passed
Copper	Mfg. 8 -	4	B	passed	passed
Copper	Mfg. 8 -	5	B	passed	passed
Copper	Mfg. 8 -	6	B	passed	passed
Copper-clad	Mfg. 10 -	1	C	passed	passed
Copper-clad	Mfg. 10 -	2	C	passed	passed
Copper-clad	Mfg. 10 -	3	C	passed	passed
Copper-clad	Mfg. 9 -	4	C	passed	passed
Copper-clad	Mfg. 9 -	5	C	passed	passed
Copper-clad	Mfg. 9 -	6	C	passed	passed
Copper-clad	Mfg. 11 -	1	D	passed	passed
Copper-clad	Mfg. 11 -	2	D	passed	passed
Copper-clad	Mfg. 11 -	3	D	passed	passed
Copper-clad	Mfg. 8 -	4	D	passed	passed
Copper-clad	Mfg. 8 -	5	D	passed	passed
Copper-clad	Mfg. 8 -	6	D	passed	passed



PO Box 2363, Clackamas, OR 97015
15648 114th Ave. Suite 109, Clackamas OR 97015
Phone: 503-406-4373 Fax: 503 905 0457
www.pacifictestandmeasurement.com

Certificate of Conformance

Issued to:	CDCMello Consulting LLC PO Box 872317 Vancouver, WA 98687
Customer PO:	Verbal Chuck Mello
Model:	UL3055
Lot Number:	952103-019
Report:	JK202006300-003
Description:	Type J, 30 Gauge FEP/FEP Teflon, Special Limits of Error Tolerance, 15 feet length, Thermocouple

Pacific Test and Measurement Inc certifies that the order of thermocouples meets all applicable instructions, specifications, and in accordance with DAP UL 00-OP-C0037 version 10.0. The preferred method of welding to produce a single point weld or bead using ThermX model 258B welder has been used to assemble the thermocouple junction which has been proven as reliable and repeatable through validation. The finish products were assembled from UL4047, a spool of described wire calibrated to accredited standards as described in the calibration report.

Certified by: _____

(Quality Department)

Date: 7-10-2020

Appendix K - Certificates of Calibration

(Appendix pages K1 to K26 identical to pages E1 to E26)



Report of Calibration

Eustis Co., Inc./Pyrocom Calibration lab
12407-B Mukilteo Speedway #200
Lynnwood, wa 98087

Report No: JK202006300-003

Page 1 of 2

Model: UL4047 Serial: 952103-019 Description: TYPE J, 30AWG, FEP/FEP	Customer:
Calibration Range: Limited Received Condition: New Current: N/A Procedure: ECP 339/341	CDCMello Consulting LLC PO Box 872317 Vancouver, WA 98687

The unit under test (UUT) on this certificate has been calibrated by comparison method as covered by ASTM E220-13, and calibrated against standards traceable to the National Institute of Standards and Technology (NIST). Eustis Co., Inc./Pyrocom Calibration Lab meets the requirements of ANSI/NCCL Z540-1-1994 and ISO/IEC 17025 and is accredited by A2LA via Certificate Number 2496.01 for calibrations within the scope to which it applies. The uncertainty represents an expanded uncertainty expressed at approximately the 95% confidence level using a coverage factor of $k=2$. All results contained within this certificate relate only to the item calibrated. Any number of factors may cause the calibrated item to drift out of calibration.

Nominal Value (Set-point) (C)	Actual Value (Reference) (C)	UUT (Test Sensor) (C)	Error (C)	Measurement Uncertainty (C)	Method of Realization
21.00	21.41	21.38	-0.03	+/- 0.31	COMP
40.00	40.08	40.02	-0.06	+/- 0.40	COMP
95.00	95.02	94.97	-0.05	+/- 0.40	COMP
150.00	150.02	150.10	0.08	+/- 0.50	COMP
200.00	200.01	200.23	0.22	+/- 0.50	COMP

Test Equipment

Manufacturer	Model	Description	Serial Number	Recall Date
Hart Scientific	1560	"Black Stack" Base Unit	96539	NCR
Hart Scientific	2560	SPRT Module	A25631	3/24/2021
Fluke	5628	4 Wire SPRT	4303	3/26/2021
Fluke	2566	Thermocouple Scanner	B7A380	3/24/2021
Fluke	9173	Metrology Well, 700 C	B47975	NCR
Fluke	7380	Bath, Ultra Low-Temperature	B2A527	NCR

Calibration Date: 6/18/2020
Temperature: 23.0 C
Humidity: 47%
Customer Order: 74523

Technician:

Julia Kalin

Approved By:

Walter Paulson
QA Manager

Appendix K - Certificates of Calibration
(Appendix pages K1 to K26 identical to pages E1 to E26)
Report of Calibration

Report No: JK202006300-003
Page 2 of 2

Notes: The thermocouple wire meets or exceeds the criteria established for type "J" SPECIAL LIMITS OF ERROR per ASTM E230/E230M-17 table 1 & ISA-MC96.1-1982 Par. 2.5 Table 8 $\pm 1.1^{\circ}\text{C}$ OR $\pm .4\%$ whichever is greater. Lot calibration data supplied for your reference.

Calibrated item meets special limits of error for all results given according to the comparison of "error" reading to the specifications found in ASTM E230/E230M-17 table 1 & MC96.1-1982 table 8; acceptance determination is ultimately the responsibility of the customer, taking into account all uncertainties and other factors. The closer the results are to the specification limits, the greater the risk that the unit under test will be out of tolerance.

Report issue date: JUN 19 2020

Appendix K - Certificates of Calibration

(Appendix pages K1 to K26 identical to pages E1 to E26)

Fox Valley Metrology

3114 Medalist Drive
Oshkosh, WI 54902
(920) 426-5894 • Fax (920) 426-8120
<http://www.FoxValleyMetrology.com>

CERTIFICATE OF CALIBRATION



Certificate No. ACT-1272

Certification Number CK198-33105-466 For Eaton Corporation - ICD W126 N7250 Flint Drive Menomonee Falls, WI 53051 Purchase Order # 4044-671109 Test Instrument Data Acquisition Unit Make Keysight Model 34972A Serial Number MY49002695 Identification EM7054 Customer Location ICD Condition Received In Tolerance Condition Returned In Tolerance Calibrated By Alex Paulsen Technical Review By Tim Bending Calibration Location FVM Calibration Conditions 67.8°F, 19.9°C, 57.3%RH Calibration Date 07/16/2020 Recalibration Due 07/16/2021		Procedures Followed FVE-000 rev. 2 FVE-006 rev. 2 Standards Used <table style="width: 100%; border-collapse: collapse;"> <thead> <tr> <th style="text-align: left;">Instrument</th> <th style="text-align: left;">Serial Number</th> <th style="text-align: left;">Trace Number</th> <th style="text-align: left;">Next Cal</th> </tr> </thead> <tbody> <tr> <td>FVS-275A</td> <td>RY11838</td> <td>CJ191-70508-513</td> <td>07/28/2020</td> </tr> <tr> <td>FVS-737</td> <td>4542903</td> <td>CK041-57440-531</td> <td>02/28/2021</td> </tr> </tbody> </table>		Instrument	Serial Number	Trace Number	Next Cal	FVS-275A	RY11838	CJ191-70508-513	07/28/2020	FVS-737	4542903	CK041-57440-531	02/28/2021
Instrument	Serial Number	Trace Number	Next Cal												
FVS-275A	RY11838	CJ191-70508-513	07/28/2020												
FVS-737	4542903	CK041-57440-531	02/28/2021												

This certificate shall not be altered in any form or reproduced, except in full, without prior written approval from originating lab. These results relate only to the item(s) calibrated. Form Revision 6: 02/04/2012

Total expanded measurement uncertainties expressed are based on a confidence level of 95%; coverage factor of (k=2). The statement of compliance in this certificate was issued without taking the uncertainty of measurement into consideration. The customer shall assess the results and uncertainty when determining if the results meet their needs. (This is considered "shared responsibility.") Uncertainties expressed in nominal units.

All instruments have been calibrated against standards traceable to NIST. Calibration was completed in accordance with ISO/IEC 17025:2017, ANSI/NCSL Z540-1-1994 and ANSI/NCSL Z540.3-2006. Other standards listed upon request.

Calibration Results

* denotes "Out of Tolerance"

Feature	Nominal	Lower Limit	Upper Limit	As Found	As Left	Uncertainty
Root Difference Square guardbanding method used.						
UUT IDENTIFICATION						
Serial Number: MY49002695						
Firmware Level: 1.11-1.12-02-01						
INPUT MODULE CHARACTERISTICS						
Model: 34901A						
Firmware Level: 2.3						
SELF TEST				Pass	Pass	

Appendix K - Certificates of Calibration

(Appendix pages K1 to K26 identical to pages E1 to E26)

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CERTIFICATE OF CALIBRATION



Certificate No. ACT-1272

Feature	Nominal	Lower Limit	Upper Limit	As Found	As Left	Uncertainty
INTERNAL DMM VERIFICATION						
ZERO OFFSET VERIFICATION						
DC CURRENT						
10 mA Range 0.00000 mA	0.00000	-0.00200	0.00200	0.00003	0.00003	0.000007
100 mA Range 0.0000 mA	0.0000	-0.0050	0.0050	0.0000	0.0000	0.00006
1 A Range 0.000000 A	0.000000	-0.000100	0.000100	0.000001	0.000001	0.0000006
DC VOLTS						
100 mV Range 0.0000 mV	0.0000	-0.0040	0.0040	0.0004	0.0004	0.00007
1 V Range 0.000000 V	0.000000	-0.000007	0.000007	0.000001	0.000001	0.0000007
10 V Range 0.00000 V	0.00000	-0.00005	0.00005	0.00000	0.00000	0.000007
100 V Range 0.0000 V	0.0000	-0.0006	0.0006	0.0000	0.0000	0.00006
300 V Range 0.000 V	0.000	-0.009	0.009	0.000	0.000	0.0006
2 WIRE $\square$						
100 $\square$ Range 0.0000 Ohm	0.0000	-4.0040	4.0040	0.0626	0.0626	0.00007
1 k $\square$ Range 0.000000 kOhm	0.000000	-0.004010	0.004010	0.000065	0.000065	0.0000006
10 k $\square$ Range 0.00000 kOhm	0.00000	-0.00410	0.00410	0.00008	0.00008	0.000006
100 k $\square$ Range 0.0000 kOhm	0.0000	-0.0050	0.0050	0.0002	0.0002	0.00007
1 M $\square$ Range 0.000000 MOhm	0.000000	-0.000014	0.000014	0.000000	0.000000	0.0000007
10 M $\square$ Range						

Appendix K - Certificates of Calibration

(Appendix pages K1 to K26 identical to pages E1 to E26)

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CERTIFICATE OF CALIBRATION



CALIBRATION AND TESTING
LABORATORY
Certificate No. ACT-1272

Feature	Nominal	Lower Limit	Upper Limit	As Found	As Left	Uncertainty
0.00000 MOhm	0.00000	-0.00010	0.00010	0.00000	0.00000	0.000007
100 M Ω Range						
0.0000 MOhm	0.0000	-0.0100	0.0100	0.0000	0.0000	0.00006
4 WIRE $\square$						
100 $\square$ Range						
0.0000 Ohm	0.0000	-0.0040	0.0040	-0.0023	-0.0023	0.00006
1 k $\square$ Range						
0.000000 kOhm	0.000000	-0.000010	0.000010	0.000000	0.000000	0.0000006
10 k $\square$ Range						
0.00000 kOhm	0.00000	-0.00010	0.00010	0.00000	0.00000	0.000007
100 k $\square$ Range						
0.0000 kOhm	0.0000	-0.0010	0.0010	0.0000	0.0000	0.00007
1 M $\square$ Range						
0.000000 MOhm	0.000000	-0.000010	0.000010	0.000000	0.000000	0.0000006
10 M $\square$ Range						
0.00000 MOhm	0.00000	-0.00010	0.00010	0.00000	0.00000	0.000006
100 M $\square$ Range						
0.0000 MOhm	0.0000	-0.0100	0.0100	0.0000	0.0000	0.00007
GAIN VERIFICATION						
DC VOLTS						
100 mV Range						
100.0000 mV	100.0000	99.9910	100.0090	100.0000	100.0000	0.00006
-100.0000 mV	-100.0000	-100.0090	-99.9910	-99.9987	-99.9987	0.00007
1 V Range						
1.000000 V	1.000000	0.999953	1.000047	0.999993	0.999993	0.0000007
-1.000000 V	-1.000000	-1.000047	-0.999953	-0.999989	-0.999989	0.0000007
10 V Range						
10.00000 V	10.00000	9.99960	10.00040	9.99994	9.99994	0.000006
-10.00000 V	-10.00000	-10.00040	-9.99960	-9.99992	-9.99992	0.000006
100 V Range						
100.0000 V	100.0000	99.9949	100.0051	99.9996	99.9996	0.00007
-100.0000 V	-100.0000	-100.0051	-99.9949	-99.9993	-99.9993	0.00007
300 V Range						
300.000 V	300.000	299.978	300.022	299.998	299.998	0.0006

Appendix K - Certificates of Calibration

(Appendix pages K1 to K26 identical to pages E1 to E26)

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CERTIFICATE OF CALIBRATION



Certificate No. ACT-1272

Feature	Nominal	Lower Limit	Upper Limit	As Found	As Left	Uncertainty
2 WIRE □						
100 □ Range						
100.0000 Ohm	100.0000	95.9860	104.0140	100.0067	100.0067	0.00007
1 k□ Range						
1.000000 kOhm	1.000000	0.995890	1.004110	1.000032	1.000032	0.0000006
10 k□ Range						
10.00000 kOhm	10.00000	9.99490	10.00510	10.00035	10.00035	0.000007
100 k□ Range						
100.0000 kOhm	100.0000	99.9850	100.0150	100.0029	100.0029	0.00006
1 M□ Range						
1.000000 MOhm	1.000000	0.999886	1.000114	1.000016	1.000016	0.0000006
10 M□ Range						
10.00000 MOhm	10.00000	9.99590	10.00410	9.99768	9.99768	0.000006
100 M□ Range						
100.0000 MOhm	100.0000	99.1900	100.8100	100.3688	100.3688	0.00007
4 WIRE □						
100 □ Range						
100.0000 Ohm	100.0000	99.9860	100.0140	100.0039	100.0039	0.00006
1 k□ Range						
1.000000 kOhm	1.000000	0.999890	1.000110	1.000030	1.000030	0.0000007
10 k□ Range						
10.00000 kOhm	10.00000	9.99890	10.00110	10.00032	10.00032	0.000006
100 k□ Range						
100.0000 kOhm	100.0000	99.9890	100.0110	100.0021	100.0021	0.00007
1 M□ Range						
1.000000 MOhm	1.000000	0.999890	1.000110	0.999970	0.999970	0.0000007
10 M□ Range						
10.00000 MOhm	10.00000	9.99590	10.00410	9.99595	9.99595	0.000006
100 M□ Range						
100.0000 MOhm	100.0000	99.1900	100.8100	99.8275	99.8275	0.00006
DC CURRENT						
10 mA Range						
10.00000 mA	10.00000	9.99300	10.00700	9.99898	9.99898	0.000007
-10.00000 mA	-10.00000	-10.00700	-9.99300	-9.99887	-9.99887	0.000007

Appendix K - Certificates of Calibration

(Appendix pages K1 to K26 identical to pages E1 to E26)

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CERTIFICATE OF CALIBRATION



ISO/IEC 17025
CALIBRATION AND TESTING
LABORATORY

Certificate No. ACT-1272

Feature	Nominal	Lower Limit	Upper Limit	As Found	As Left	Uncertainty
100 mA Range						
100.0000 mA	100.0000	99.9450	100.0550	99.9882	99.9882	0.00006
-100.0000 mA	-100.0000	-100.0550	-99.9450	-99.9879	-99.9879	0.00006
1 A Range						
1.000000 A	1.000000	0.998900	1.001100	0.999534	0.999534	0.0000006
-1.000000 A	-1.000000	-1.001100	-0.998900	-0.999537	-0.999537	0.0000006
AC VOLTS						
100 mV Range						
10.0000 mV @ 1 kHz	10.0000	9.9540	10.0460	9.9997	9.9997	0.00006
100.0000 mV @ 1 kHz	100.0000	99.9000	100.1000	99.9912	99.9912	0.00006
100.0000 mV @ 50 kHz	100.0000	99.8300	100.1700	99.9383	99.9383	0.00006
1 V Range						
1.000000 V @ 20 Hz	1.000000	0.999000	1.001000	0.999803	0.999803	0.0000006
1.000000 V @ 1 kHz	1.000000	0.999000	1.001000	0.999950	0.999950	0.0000006
1.000000 V @ 20 kHz	1.000000	0.999000	1.001000	0.999888	0.999888	0.0000006
1.000000 V @ 50 kHz	1.000000	0.998300	1.001700	0.999504	0.999504	0.0000007
1.000000 V @ 100 kHz	1.000000	0.993200	1.006800	0.998811	0.998811	0.0000006
1.000000 V @ 200 kHz	1.000000	0.955000	1.045000	0.999068	0.999068	0.0000006
1.000000 V @ 250 kHz	1.000000	0.955000	1.045000	0.999202	0.999202	0.0000007
1.000000 V @ 300 kHz	1.000000	0.955000	1.045000	0.998797	0.998797	0.0000006
10 V Range						
0.10000 V @ 1 kHz	0.10000	0.08594	0.11406	0.10086	0.10086	0.000006
1.00000 V @ 1 kHz	1.00000	0.99540	1.00460	0.99992	0.99992	0.000006
10.00000 V @ 10 Hz	10.00000	9.99000	10.01000	9.99743	9.99743	0.000007
10.00000 V @ 1 kHz	10.00000	9.99000	10.01000	9.99855	9.99855	0.000006
10.00000 V @ 50 kHz	10.00000	9.98300	10.01700	9.99499	9.99499	0.000006
100 V Range						
100.0000 V @ 1 kHz	100.0000	99.9000	100.1000	99.9653	99.9653	0.00006
100.0000 V @ 50 kHz	100.0000	99.8300	100.1700	99.8943	99.8943	0.00006

Appendix K - Certificates of Calibration

(Appendix pages K1 to K26 identical to pages E1 to E26)

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Certificate No. ACT-1272

Feature	Nominal	Lower Limit	Upper Limit	As Found	As Left	Uncertainty
300 V Range						
300.000 V @ 1 kHz	300.000	299.580	300.420	299.884	299.884	0.0006
200.000 V @ 50 kHz	200.000	199.400	200.600	199.750	199.750	0.0007
AC CURRENT						
10 mA Range						
10.00000 mA @ 1 kHz	10.00000	9.98600	10.01400	9.99766	9.99766	0.000007
100 mA Range						
100.0000 mA @ 1 kHz	100.0000	99.4000	100.6000	99.9484	99.9484	0.00007
1 A Range						
0.010000 A @ 1 kHz	0.010000	0.008590	0.011410	0.009960	0.009960	0.0000007
1.000000 A @ 1 kHz	1.000000	0.998600	1.001400	0.999502	0.999502	0.0000006
FREQUENCY						
100 Hz Range						
100.0000 Hz	100.0000	99.9000	100.1000	100.0056	100.0056	0.00007
100 kHz Range						
100.0000 kHz	100.0000	99.9900	100.0100	100.0001	100.0001	0.00007

Appendix K - Certificates of Calibration

(Appendix pages K1 to K26 identical to pages E1 to E26)

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CERTIFICATE OF CALIBRATION



Certificate No. ACT-1272

Certification Number CK198-39504-466 For Eaton Corporation - ICD W126 N7250 Flint Drive Menomonee Falls, WI 53051 Purchase Order # 4044-671109 Test Instrument Multimeter Digital Multimeter Make Fluke Model 179 Serial Number 77840008 Identification EM4437 Customer Location ICD Condition Received In Tolerance Condition Returned In Tolerance Calibrated By Alex Paulsen Technical Review By Tim Bending Calibration Location FVM Calibration Conditions 68.3°F, 20.2°C, 56.2%RH Calibration Date 07/16/2020 Recalibration Due 07/16/2021		Procedures Followed FVE-000 rev. 2 FVE-001 rev. 2 Standards Used <table style="width: 100%; border-collapse: collapse;"> <tr> <th style="text-align: left;">Instrument</th> <th style="text-align: left;">Serial Number</th> <th style="text-align: left;">Trace Number</th> <th style="text-align: left;">Next Cal</th> </tr> <tr> <td>FVS-275A</td> <td>RY11838</td> <td>CJ191-70508-513</td> <td>07/28/2020</td> </tr> <tr> <td>FVS-737</td> <td>4542903</td> <td>CK041-57440-531</td> <td>02/28/2021</td> </tr> </table>		Instrument	Serial Number	Trace Number	Next Cal	FVS-275A	RY11838	CJ191-70508-513	07/28/2020	FVS-737	4542903	CK041-57440-531	02/28/2021	This certificate shall not be altered in any form or reproduced, except in full, without prior written approval from originating lab. These results relate only to the item(s) calibrated. Form Revision 6: 02/04/2012
Instrument	Serial Number	Trace Number	Next Cal													
FVS-275A	RY11838	CJ191-70508-513	07/28/2020													
FVS-737	4542903	CK041-57440-531	02/28/2021													

Total expanded measurement uncertainties expressed are based on a confidence level of 95%; coverage factor of (k=2). The statement of compliance in this certificate was issued without taking the uncertainty of measurement into consideration. The customer shall assess the results and uncertainty when determining if the results meet their needs. (This is considered "shared responsibility.") Uncertainties expressed in base units.

All instruments have been calibrated against standards traceable to NIST. Calibration was completed in accordance with ISO/IEC 17025:2017, ANSI/NCSL Z540-1-1994 and ANSI/NCSL Z540.3-2006. Other standards listed upon request.

Calibration Results

* denotes "Out of Tolerance"

Feature	Nominal	Lower Limit	Upper Limit	As Found	As Left	Uncertainty
AC VOLTS						
600 mV Range						
300.0 mV @ 45 Hz	300.0	296.7	303.3	299.2	299.2	0.07
6 V Range						
5.000 V @ 500 Hz	5.000	4.947	5.053	4.987	4.987	0.0007
5.000 V @ 1 kHz	5.000	4.897	5.103	4.949	4.949	0.0007
60 V Range						
50.00 V @ 45 Hz	50.00	49.47	50.53	49.98	49.98	0.007
50.00 V @ 1 kHz	50.00	48.97	51.03	50.02	50.02	0.007
600 V Range						
300.0 V @ 45 Hz	300.0	296.7	303.3	299.9	299.9	0.07
500.0 V @ 500 Hz	500.0	494.7	505.3	500.5	500.5	0.06
500.0 V @ 1 kHz	500.0	489.7	510.3	500.5	500.5	0.06
1000 V Range						
1000 V @ 45 Hz	1000	987	1013	1002	1002	0.7

Appendix K - Certificates of Calibration

(Appendix pages K1 to K26 identical to pages E1 to E26)

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CERTIFICATE OF CALIBRATION



Certificate No. ACT-1272

Feature	Nominal	Lower Limit	Upper Limit	As Found	As Left	Uncertainty
AC VOLTS FREQUENCY						
45.00 Hz @ 1 V	45.00	44.95	45.06	45.01	45.01	0.007
50.00 kHz @ 5 V	50.00	49.94	50.06	50.00	50.00	0.006
DC VOLTAGE						
6 V Range						
5.000 V	5.000	4.994	5.007	4.997	4.997	0.0006
600 V Range						
300.0 V	300.0	299.5	300.5	299.8	299.8	0.06
1000 V Range						
1000 V	1000	997	1004	999	999	0.6
-1000 V	-1000	-1004	-997	-1000	-1000	0.7
DC VOLTS FREQUENCY						
45.00 Hz @ 3 V	45.00	44.95	45.06	45.01	45.01	0.007
50.00 kHz @ 30 V	50.00	49.94	50.06	50.00	50.00	0.007
DC MILLIVOLTS						
30.0 mV	30.0	29.8	30.2	30.0	30.0	0.06
-300.0 mV	-300.0	-300.5	-299.5	-299.9	-299.9	0.06
600.0 mV	600.0	599.3	600.7	599.7	599.7	0.07
TEMPERATURE						
0.0 °C	0.0	-1.0	1.0	1.0	1.0	0.06
-40.0 °C	-40.0	-41.4	-38.6	-39.0	-39.0	0.07
400.0 °C	400.0	395.0	405.0	400.9	400.9	0.06
OHMS						
600 Ohm Range						
19.0 Ohm	19.0	18.6	19.4	19.3	19.3	0.07
50 MOhm Range						
19.00 MOhm	19.00	18.68	19.32	19.00	19.00	0.006
CAPACITANCE						
1000 nF Range						
900 nF	900	887	913	899	899	0.6
CONTINUITY						
0 Ohms: Beeper On				Pass	Pass	
190 Ohms: Beeper Off				Pass	Pass	
DIODE TEST						

Appendix K - Certificates of Calibration

(Appendix pages K1 to K26 identical to pages E1 to E26)

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CERTIFICATE OF CALIBRATION



Certificate No. ACT-1272

Feature	Nominal	Lower Limit	Upper Limit	As Found	As Left	Uncertainty
2.000 V	2.000	1.978	2.022	2.000	2.000	0.0007
AC MILLIAMPS						
60 mA Range						
3.00 mA @ 45 Hz	3.00	2.92	3.08	3.00	3.00	0.007
50.00 mA @ 1 kHz	50.00	49.22	50.78	50.06	50.06	0.006
400 mA Range						
400.0 mA @ 1 kHz	400.0	393.7	406.3	400.4	400.4	0.07
AC AMPS						
6 A Range						
4.000 A @ 45 Hz	4.000	3.937	4.063	4.005	4.005	0.0007
10A Range						
9.00 A @ 1 kHz	9.00	8.84	9.16	9.04	9.04	0.007
DC MILLIAMPS						
60 mA Range						
3.00 mA	3.00	2.94	3.06	3.00	3.00	0.006
50.00 mA	50.00	49.47	50.53	49.92	49.92	0.007
400 mA Range						
-400.0 mA	-400.0	-404.3	-395.7	-399.8	-399.8	0.07
DC AMPS						
6 A Range						
4.000 A	4.000	3.957	4.043	3.999	3.999	0.0007
10 A Range						
-9.00 A	-9.00	-9.12	-8.88	-9.01	-9.01	0.006

Appendix K - Certificates of Calibration

(Appendix pages K1 to K26 identical to pages E1 to E26)

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CERTIFICATE OF CALIBRATION



Certificate No. ACT-1272

Certification Number CK198-38060-466 For Eaton Corporation - ICD W126 N7250 Flint Drive Menomonee Falls, WI 53051 Purchase Order # 4044-671109 Test Instrument Multimeter Digital Multimeter Make Fluke Model 175 Serial Number 13700492 Identification EM7014 Customer Location ICD Condition Received In Tolerance Condition Returned In Tolerance Calibrated By Alex Paulsen Technical Review By Tim Bending Calibration Location FVM Calibration Conditions 68.2°F, 20.1°C, 56.6%RH Calibration Date 07/16/2020 Recalibration Due 07/16/2021		Procedures Followed FVE-000 rev. 2 FVE-001 rev. 2 Standards Used <table style="width: 100%; border-collapse: collapse;"> <tr> <th style="text-align: left;">Instrument</th> <th style="text-align: left;">Serial Number</th> <th style="text-align: left;">Trace Number</th> <th style="text-align: left;">Next Cal</th> </tr> <tr> <td>FVS-275A</td> <td>RY11838</td> <td>CJ191-70508-513</td> <td>07/28/2020</td> </tr> <tr> <td>FVS-737</td> <td>4542903</td> <td>CK041-57440-531</td> <td>02/28/2021</td> </tr> </table>		Instrument	Serial Number	Trace Number	Next Cal	FVS-275A	RY11838	CJ191-70508-513	07/28/2020	FVS-737	4542903	CK041-57440-531	02/28/2021
Instrument	Serial Number	Trace Number	Next Cal												
FVS-275A	RY11838	CJ191-70508-513	07/28/2020												
FVS-737	4542903	CK041-57440-531	02/28/2021												

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Total expanded measurement uncertainties expressed are based on a confidence level of 95%; coverage factor of (k=2). The statement of compliance in this certificate was issued without taking the uncertainty of measurement into consideration. The customer shall assess the results and uncertainty when determining if the results meet their needs. (This is considered "shared responsibility.") Uncertainties expressed in base units.

All instruments have been calibrated against standards traceable to NIST. Calibration was completed in accordance with ISO/IEC 17025:2017, ANSI/NCSL Z540-1-1994 and ANSI/NCSL Z540.3-2006. Other standards listed upon request.

Calibration Results

* denotes "Out of Tolerance"

Feature	Nominal	Lower Limit	Upper Limit	As Found	As Left	Uncertainty
AC VOLTS						
600 mV Range						
300.0 mV @ 45 Hz	300.0	296.7	303.3	299.9	299.9	0.07
6 V Range						
5.000 V @ 500 Hz	5.000	4.947	5.053	4.994	4.994	0.0007
5.000 V @ 1 kHz	5.000	4.897	5.103	4.955	4.955	0.0006
60 V Range						
50.00 V @ 45 Hz	50.00	49.47	50.53	49.94	49.94	0.007
50.00 V @ 1 kHz	50.00	48.97	51.03	50.06	50.06	0.006
600 V Range						
300.0 V @ 45 Hz	300.0	296.7	303.3	299.8	299.8	0.07
500.0 V @ 500 Hz	500.0	494.7	505.3	500.4	500.4	0.07
500.0 V @ 1 kHz	500.0	489.7	510.3	500.4	500.4	0.06
1000 V Range						
1000 V @ 45 Hz	1000	987	1013	996	996	0.6

Appendix K - Certificates of Calibration

(Appendix pages K1 to K26 identical to pages E1 to E26)

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Certificate No. ACT-1272

Feature	Nominal	Lower Limit	Upper Limit	As Found	As Left	Uncertainty
AC VOLTS FREQUENCY						
45.00 Hz @ 1 V	45.00	44.95	45.06	45.00	45.00	0.007
50.00 kHz @ 5 V	50.00	49.94	50.06	50.00	50.00	0.007
DC VOLTAGE						
6 V Range						
5.000 V	5.000	4.990	5.010	5.000	5.000	0.0007
600 V Range						
300.0 V	300.0	299.4	300.6	300.0	300.0	0.06
1000 V Range						
1000 V	1000	997	1004	1000	1000	0.7
-1000 V	-1000	-1004	-997	-1000	-1000	0.7
DC VOLTS FREQUENCY						
45.00 Hz @ 3 V	45.00	44.95	45.06	45.00	45.00	0.007
50.00 kHz @ 30 V	50.00	49.94	50.06	50.00	50.00	0.007
DC MILLIVOLTS						
30.0 mV	30.0	29.8	30.2	30.0	30.0	0.07
-300.0 mV	-300.0	-300.6	-299.4	-299.9	-299.9	0.06
600.0 mV	600.0	598.9	601.1	599.9	599.9	0.06
OHMS						
600 Ohm Range						
19.0 Ohm	19.0	18.6	19.4	19.0	19.0	0.07
50 MOhm Range						
19.00 MOhm	19.00	18.68	19.32	18.99	18.99	0.006
CAPACITANCE						
1000 nF Range						
900 nF	900	887	913	900	900	0.7
CONTINUITY						
0 Ohms: Beeper On				Pass	Pass	
190 Ohms: Beeper Off				Pass	Pass	
DIODE TEST						
2.000 V	2.000	1.978	2.022	2.001	2.001	0.0006
AC MILLIAMPS						
60 mA Range						

Appendix K - Certificates of Calibration

(Appendix pages K1 to K26 identical to pages E1 to E26)

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CERTIFICATE OF CALIBRATION



Certificate No. ACT-1272

Feature	Nominal	Lower Limit	Upper Limit	As Found	As Left	Uncertainty
3.00 mA @ 45 Hz	3.00	2.92	3.08	3.01	3.01	0.007
50.00 mA @ 1 kHz	50.00	49.22	50.78	49.96	49.96	0.007
400 mA Range						
400.0 mA @ 1 kHz	400.0	393.7	406.3	399.4	399.4	0.06
AC AMPS						
6 A Range						
4.000 A @ 45 Hz	4.000	3.937	4.063	3.997	3.997	0.0007
10A Range						
9.00 A @ 1 kHz	9.00	8.84	9.16	9.00	9.00	0.007
DC MILLIAMPS						
60 mA Range						
3.00 mA	3.00	2.94	3.06	3.02	3.02	0.006
50.00 mA	50.00	49.47	50.53	49.99	49.99	0.006
400 mA Range						
-400.0 mA	-400.0	-404.3	-395.7	-400.0	-400.0	0.07
DC AMPS						
6 A Range						
4.000 A	4.000	3.957	4.043	3.999	3.999	0.0007
10 A Range						
-9.00 A	-9.00	-9.12	-8.88	-9.00	-9.00	0.007

Appendix K - Certificates of Calibration

(Appendix pages K1 to K26 identical to pages E1 to E26)

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CERTIFICATE OF CALIBRATION



Certificate No. ACT-1272

Certification Number CK198-38779-466 For Eaton Corporation - ICD W126 N7250 Flint Drive Menomonee Falls, WI 53051 Purchase Order # 4044-671109 Test Instrument Multimeter Digital Multimeter Make Fluke Model 179 Serial Number 14370601 Identification EM7024 Customer Location ICD Condition Received In Tolerance Condition Returned In Tolerance Calibrated By Alex Paulsen Technical Review By Tim Bending Calibration Location FVM Calibration Conditions 68.2°F, 20.1°C, 56.6%RH Calibration Date 07/16/2020 Recalibration Due 07/16/2021		Procedures Followed FVE-000 rev. 2 FVE-001 rev. 2 Standards Used <table style="width: 100%; border-collapse: collapse;"> <tr> <th style="text-align: left;">Instrument</th> <th style="text-align: left;">Serial Number</th> <th style="text-align: left;">Trace Number</th> <th style="text-align: left;">Next Cal</th> </tr> <tr> <td>FVS-275A</td> <td>RY11838</td> <td>CJ191-70508-513</td> <td>07/28/2020</td> </tr> <tr> <td>FVS-737</td> <td>4542903</td> <td>CK041-57440-531</td> <td>02/28/2021</td> </tr> </table>	Instrument	Serial Number	Trace Number	Next Cal	FVS-275A	RY11838	CJ191-70508-513	07/28/2020	FVS-737	4542903	CK041-57440-531	02/28/2021	This certificate shall not be altered in any form or reproduced, except in full, without prior written approval from originating lab. These results relate only to the item(s) calibrated. Form Revision 6: 02/04/2012 Total expanded measurement uncertainties expressed are based on a confidence level of 95%; coverage factor of (k=2). The statement of compliance in this certificate was issued without taking the uncertainty of measurement into consideration. The customer shall assess the results and uncertainty when determining if the results meet their needs. (This is considered "shared responsibility.") Uncertainties expressed in nominal units. All instruments have been calibrated against standards traceable to NIST. Calibration was completed in accordance with ISO/IEC 17025:2017, ANSI/NCSL Z540-1-1994 and ANSI/NCSL Z540.3-2006. Other standards listed upon request.
Instrument	Serial Number	Trace Number	Next Cal												
FVS-275A	RY11838	CJ191-70508-513	07/28/2020												
FVS-737	4542903	CK041-57440-531	02/28/2021												

Calibration Results

* denotes "Out of Tolerance"

Feature	Nominal	Lower Limit	Upper Limit	As Found	As Left	Uncertainty
AC VOLTS						
600 mV Range						
300.0 mV @ 45 Hz	300.0	296.7	303.3	300.0	300.0	0.06
6 V Range						
5.000 V @ 500 Hz	5.000	4.947	5.053	4.997	4.997	0.0006
5.000 V @ 1 kHz	5.000	4.897	5.103	4.961	4.961	0.0006
60 V Range						
50.00 V @ 45 Hz	50.00	49.47	50.53	49.97	49.97	0.006
50.00 V @ 1 kHz	50.00	48.97	51.03	50.10	50.10	0.007
600 V Range						
300.0 V @ 45 Hz	300.0	296.7	303.3	300.0	300.0	0.07
500.0 V @ 500 Hz	500.0	494.7	505.3	500.9	500.9	0.06
500.0 V @ 1 kHz	500.0	489.7	510.3	500.8	500.8	0.06
1000 V Range						
1000 V @ 45 Hz	1000	987	1013	997	997	0.7

Appendix K - Certificates of Calibration

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CERTIFICATE OF CALIBRATION



Certificate No. ACT-1272

Feature	Nominal	Lower Limit	Upper Limit	As Found	As Left	Uncertainty
AC VOLTS FREQUENCY						
45.00 Hz @ 1 V	45.00	44.95	45.06	45.00	45.00	0.007
50.00 kHz @ 5 V	50.00	49.94	50.06	50.00	50.00	0.006
DC VOLTAGE						
6 V Range						
5.000 V	5.000	4.994	5.007	5.000	5.000	0.0006
600 V Range						
300.0 V	300.0	299.5	300.5	299.9	299.9	0.06
1000 V Range						
1000 V	1000	997	1004	1000	1000	0.7
-1000 V	-1000	-1004	-997	-1000	-1000	0.7
DC VOLTS FREQUENCY						
45.00 Hz @ 3 V	45.00	44.95	45.06	45.00	45.00	0.007
50.00 kHz @ 30 V	50.00	49.94	50.06	50.00	50.00	0.006
DC MILLIVOLTS						
30.0 mV	30.0	29.8	30.2	30.0	30.0	0.06
-300.0 mV	-300.0	-300.5	-299.5	-299.9	-299.9	0.06
600.0 mV	600.0	599.3	600.7	599.8	599.8	0.06
TEMPERATURE						
0.0 °C	0.0	-1.0	1.0	0.5	0.5	0.06
-40.0 °C	-40.0	-41.4	-38.6	-39.3	-39.3	0.06
400.0 °C	400.0	395.0	405.0	400.4	400.4	0.06
OHMS						
600 Ohm Range						
19.0 Ohm	19.0	18.6	19.4	19.0	19.0	0.06
50 MOhm Range						
19.00 MOhm	19.00	18.68	19.32	18.98	18.98	0.006
CAPACITANCE						
1000 nF Range						
900 nF	900	887	913	900	900	0.6
CONTINUITY						
0 Ohms: Beeper On				Pass	Pass	
190 Ohms: Beeper Off				Pass	Pass	
DIODE TEST						

Appendix K - Certificates of Calibration

(Appendix pages K1 to K26 identical to pages E1 to E26)

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Certificate No. ACT-1272

Feature	Nominal	Lower Limit	Upper Limit	As Found	As Left	Uncertainty
2.000 V	2.000	1.978	2.022	2.001	2.001	0.0007
AC MILLIAMPS						
60 mA Range						
3.00 mA @ 45 Hz	3.00	2.92	3.08	3.02	3.02	0.006
50.00 mA @ 1 kHz	50.00	49.22	50.78	50.03	50.03	0.006
400 mA Range						
400.0 mA @ 1 kHz	400.0	393.7	406.3	399.9	399.9	0.06
AC AMPS						
6 A Range						
4.000 A @ 45 Hz	4.000	3.937	4.063	4.004	4.004	0.0006
10A Range						
9.00 A @ 1 kHz	9.00	8.84	9.16	9.01	9.01	0.007
DC MILLIAMPS						
60 mA Range						
3.00 mA	3.00	2.94	3.06	3.01	3.01	0.007
50.00 mA	50.00	49.47	50.53	49.99	49.99	0.007
400 mA Range						
-400.0 mA	-400.0	-404.3	-395.7	-399.9	-399.9	0.06
DC AMPS						
6 A Range						
4.000 A	4.000	3.957	4.043	3.998	3.998	0.0006
10 A Range						
-9.00 A	-9.00	-9.12	-8.88	-9.00	-9.00	0.007

Appendix K - Certificates of Calibration

(Appendix pages K1 to K26 identical to pages E1 to E26)

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CERTIFICATE OF CALIBRATION



Certificate No. ACT-1272

Certification Number CK198-41226-466 For Eaton Corporation - ICD W126 N7250 Flint Drive Menomonee Falls, WI 53051 Purchase Order # 4044-671109 Test Instrument Clamp Meter Make AEMC Model SR759 Serial Number 224137GKDV Identification EM6996 Customer Location ICD Condition Received In Tolerance Condition Returned In Tolerance Calibrated By Alex Paulsen Technical Review By Tim Bending Calibration Location FVM Calibration Conditions 67.8°F, 19.9°C, 56.3%RH Calibration Date 07/16/2020 Recalibration Due 07/16/2021		Procedures Followed FVE-007 rev. 2 Standards Used <table style="width: 100%; border-collapse: collapse;"> <tr> <th style="text-align: left;">Instrument</th> <th style="text-align: left;">Serial Number</th> <th style="text-align: left;">Trace Number</th> <th style="text-align: left;">Next Cal</th> </tr> <tr> <td>FVS-275A</td> <td>RY11838</td> <td>CJ191-70508-513</td> <td>07/28/2020</td> </tr> <tr> <td>FVS-546</td> <td>24560221</td> <td>CK093-41519-573</td> <td>04/30/2021</td> </tr> <tr> <td>FVS-737</td> <td>4542903</td> <td>CK041-57440-531</td> <td>02/28/2021</td> </tr> </table>		Instrument	Serial Number	Trace Number	Next Cal	FVS-275A	RY11838	CJ191-70508-513	07/28/2020	FVS-546	24560221	CK093-41519-573	04/30/2021	FVS-737	4542903	CK041-57440-531	02/28/2021
Instrument	Serial Number	Trace Number	Next Cal																
FVS-275A	RY11838	CJ191-70508-513	07/28/2020																
FVS-546	24560221	CK093-41519-573	04/30/2021																
FVS-737	4542903	CK041-57440-531	02/28/2021																

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All instruments have been calibrated against standards traceable to NIST. Calibration was completed in accordance with ISO/IEC 17025:2017, ANSI/NCSL Z540-1-1994 and ANSI/NCSL Z540.3-2006. Other standards listed upon request.

Calibration Results

* denotes "Out of Tolerance"

Feature	Nominal	Lower Limit	Upper Limit	As Found	As Left	Uncertainty
1A Range; 1000mV/A @60 Hz	(mV AC)	(mV AC)	(mV AC)	(mV AC)	(mV AC)	(mV AC)
10 mA	10.0	8.7	11.3	10.1	10.1	0.07
100 mA	100.0	96.0	104.0	101.3	101.3	0.06
500 mA	500.0	495.5	504.5	504.5	504.5	0.06
	(V AC)	(V AC)	(V AC)	(V AC)	(V AC)	(V AC)
1 A	1.000	0.992	1.008	1.008	1.008	0.0006
10A Range; 100mV/A @60 Hz	(mV AC)	(mV AC)	(mV AC)	(mV AC)	(mV AC)	(mV AC)
100 mA	10.0	9.7	10.3	10.0	10.0	0.07
1 A	100.0	99.3	100.7	100.4	100.4	0.07
5 A	500.0	497.5	502.5	501.8	501.8	0.06
	(V AC)	(V AC)	(V AC)	(V AC)	(V AC)	(V AC)
10 A	1.000	0.995	1.005	1.004	1.004	0.0007
100A Range; 10mV/A @60 Hz	(mV AC)	(mV AC)	(mV AC)	(mV AC)	(mV AC)	(mV AC)
1 A	10.0	9.7	10.3	10.0	10.0	0.07
10 A	100.0	99.3	100.7	100.1	100.1	0.06

Appendix K - Certificates of Calibration

(Appendix pages K1 to K26 identical to pages E1 to E26)

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Certificate No. ACT-1272

Feature	Nominal	Lower Limit	Upper Limit	As Found	As Left	Uncertainty
50 A	500.0	498.5	501.5	500.3	500.3	0.06
	(V AC)	(V AC)	(V AC)	(V AC)	(V AC)	(V AC)
100 A	1.000	0.998	1.002	1.001	1.001	0.0006
1000A Range; 1mV/A @60 Hz	(mV AC)	(mV AC)	(mV AC)	(mV AC)	(mV AC)	(mV AC)
10 A	10.0	9.7	10.3	10.0	10.0	0.06
100 A	100.0	99.3	100.7	100.1	100.1	0.07
500 A	500.0	499.0	501.0	500.5	500.5	0.07
900 A	900.0	898.0	902.0	901.2	901.2	0.07

Appendix K - Certificates of Calibration

(Appendix pages K1 to K26 identical to pages E1 to E26)

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CERTIFICATE OF CALIBRATION



Certificate No. ACT-1272

Certification Number CK198-40179-466 For Eaton Corporation - ICD W126 N7250 Flint Drive Menomonee Falls, WI 53051 Purchase Order # 4044-671109 Test Instrument Clamp Meter Make AEMC Model SR759 Serial Number 224139GKDV Identification EM6997 Customer Location ICD Condition Received In Tolerance Condition Returned In Tolerance Calibrated By Alex Paulsen Technical Review By Tim Bending Calibration Location FVM Calibration Conditions 67.8°F, 19.9°C, 56.3%RH Calibration Date 07/16/2020 Recalibration Due 07/16/2021		Procedures Followed FVE-007 rev. 2 Standards Used <table style="width: 100%; border-collapse: collapse;"> <tr> <th style="text-align: left;">Instrument</th> <th style="text-align: left;">Serial Number</th> <th style="text-align: left;">Trace Number</th> <th style="text-align: left;">Next Cal</th> </tr> <tr> <td>FVS-275A</td> <td>RY11838</td> <td>CJ191-70508-513</td> <td>07/28/2020</td> </tr> <tr> <td>FVS-546</td> <td>24560221</td> <td>CK093-41519-573</td> <td>04/30/2021</td> </tr> <tr> <td>FVS-737</td> <td>4542903</td> <td>CK041-57440-531</td> <td>02/28/2021</td> </tr> </table>		Instrument	Serial Number	Trace Number	Next Cal	FVS-275A	RY11838	CJ191-70508-513	07/28/2020	FVS-546	24560221	CK093-41519-573	04/30/2021	FVS-737	4542903	CK041-57440-531	02/28/2021
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FVS-737	4542903	CK041-57440-531	02/28/2021																

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Calibration Results

* denotes "Out of Tolerance"

Feature	Nominal	Lower Limit	Upper Limit	As Found	As Left	Uncertainty
1A Range; 1000mV/A @60 Hz	(mV AC)	(mV AC)	(mV AC)	(mV AC)	(mV AC)	(mV AC)
10 mA	10.0	8.7	11.3	10.1	10.1	0.06
100 mA	100.0	96.0	104.0	101.1	101.1	0.06
500 mA	500.0	495.5	504.5	504.5	504.5	0.06
	(V AC)	(V AC)	(V AC)	(V AC)	(V AC)	(V AC)
1 A	1.000	0.992	1.008	1.008	1.008	0.0006
10A Range; 100mV/A @60 Hz	(mV AC)	(mV AC)	(mV AC)	(mV AC)	(mV AC)	(mV AC)
100 mA	10.0	9.7	10.3	10.0	10.0	0.07
1 A	100.0	99.3	100.7	100.2	100.2	0.06
5 A	500.0	497.5	502.5	500.9	500.9	0.06
	(V AC)	(V AC)	(V AC)	(V AC)	(V AC)	(V AC)
10 A	1.000	0.995	1.005	1.002	1.002	0.0006
100A Range; 10mV/A @60 Hz	(mV AC)	(mV AC)	(mV AC)	(mV AC)	(mV AC)	(mV AC)
1 A	10.0	9.7	10.3	10.0	10.0	0.06
10 A	100.0	99.3	100.7	100.1	100.1	0.07

Appendix K - Certificates of Calibration

(Appendix pages K1 to K26 identical to pages E1 to E26)

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Feature	Nominal	Lower Limit	Upper Limit	As Found	As Left	Uncertainty
50 A	500.0	498.5	501.5	500.1	500.1	0.06
	(V AC)	(V AC)	(V AC)	(V AC)	(V AC)	(V AC)
100 A	1.000	0.998	1.002	1.001	1.001	0.0006
1000A Range; 1mV/A @60 Hz	(mV AC)	(mV AC)	(mV AC)	(mV AC)	(mV AC)	(mV AC)
10 A	10.0	9.7	10.3	10.0	10.0	0.07
100 A	100.0	99.3	100.7	100.1	100.1	0.06
500 A	500.0	499.0	501.0	500.3	500.3	0.06
900 A	900.0	898.0	902.0	901.4	901.4	0.06

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CERTIFICATE OF CALIBRATION



Certificate No. ACT-1272

Certification Number CK198-41583-466 For Eaton Corporation - ICD W126 N7250 Flint Drive Menomonee Falls, WI 53051 Purchase Order # 4044-671109 Test Instrument Clamp Meter Make AEMC Model SR759 Serial Number 239584HKDV Identification EM8032 Customer Location ICD Condition Received In Tolerance Condition Returned In Tolerance Calibrated By Alex Paulsen Technical Review By Tim Bending Calibration Location FVM Calibration Conditions 67.8°F, 19.9°C, 56.3%RH Calibration Date 07/16/2020 Recalibration Due 07/16/2021		Procedures Followed FVE-007 rev. 2 Standards Used <table style="width: 100%; border-collapse: collapse;"> <tr> <th style="text-align: left;">Instrument</th> <th style="text-align: left;">Serial Number</th> <th style="text-align: left;">Trace Number</th> <th style="text-align: left;">Next Cal</th> </tr> <tr> <td>FVS-275A</td> <td>RY11838</td> <td>CJ191-70508-513</td> <td>07/28/2020</td> </tr> <tr> <td>FVS-546</td> <td>24560221</td> <td>CK093-41519-573</td> <td>04/30/2021</td> </tr> <tr> <td>FVS-737</td> <td>4542903</td> <td>CK041-57440-531</td> <td>02/28/2021</td> </tr> </table>		Instrument	Serial Number	Trace Number	Next Cal	FVS-275A	RY11838	CJ191-70508-513	07/28/2020	FVS-546	24560221	CK093-41519-573	04/30/2021	FVS-737	4542903	CK041-57440-531	02/28/2021
Instrument	Serial Number	Trace Number	Next Cal																
FVS-275A	RY11838	CJ191-70508-513	07/28/2020																
FVS-546	24560221	CK093-41519-573	04/30/2021																
FVS-737	4542903	CK041-57440-531	02/28/2021																

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Calibration Results

* denotes "Out of Tolerance"

Feature	Nominal	Lower Limit	Upper Limit	As Found	As Left	Uncertainty
1A Range; 1000mV/A @60 Hz	(mV AC)	(mV AC)	(mV AC)	(mV AC)	(mV AC)	(mV AC)
10 mA	10.0	8.7	11.3	10.2	10.2	0.07
100 mA	100.0	96.0	104.0	101.1	101.1	0.07
500 mA	500.0	495.5	504.5	504.3	504.3	0.06
	(V AC)	(V AC)	(V AC)	(V AC)	(V AC)	(V AC)
1 A	1.000	0.992	1.008	1.007	1.007	0.0007
10A Range; 100mV/A @60 Hz	(mV AC)	(mV AC)	(mV AC)	(mV AC)	(mV AC)	(mV AC)
100 mA	10.0	9.7	10.3	10.0	10.0	0.07
1 A	100.0	99.3	100.7	100.2	100.2	0.07
5 A	500.0	497.5	502.5	500.7	500.7	0.06
	(V AC)	(V AC)	(V AC)	(V AC)	(V AC)	(V AC)
10 A	1.000	0.995	1.005	1.002	1.002	0.0006
100A Range; 10mV/A @60 Hz	(mV AC)	(mV AC)	(mV AC)	(mV AC)	(mV AC)	(mV AC)
1 A	10.0	9.7	10.3	10.0	10.0	0.07
10 A	100.0	99.3	100.7	100.0	100.0	0.07

Appendix K - Certificates of Calibration

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Certificate No. ACT-1272

Feature	Nominal	Lower Limit	Upper Limit	As Found	As Left	Uncertainty
50 A	500.0	498.5	501.5	500.0	500.0	0.07
	(V AC)	(V AC)	(V AC)	(V AC)	(V AC)	(V AC)
100 A	1.000	0.998	1.002	1.000	1.000	0.0007
1000A Range; 1mV/A @60 Hz	(mV AC)	(mV AC)	(mV AC)	(mV AC)	(mV AC)	(mV AC)
10 A	10.0	9.7	10.3	10.0	10.0	0.07
100 A	100.0	99.3	100.7	100.0	100.0	0.06
500 A	500.0	499.0	501.0	500.3	500.3	0.07
900 A	900.0	898.0	902.0	900.6	900.6	0.07

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CERTIFICATE OF CALIBRATION



Certificate No. ACT-1272

Certification Number CK196-72143-379 For Eaton Corporation - ICD W126 N7250 Flint Drive Menomonee Falls, WI 53051 Purchase Order # 4044-671109 Test Instrument Torque Wrench Make CDI Model 1502LDIN (3%) Serial Number 0312910937 Identification EM8363 Customer Location ICD Condition Received In Tolerance Condition Returned In Tolerance Calibrated By Jim Peterson Technical Review By Kevin Dehne Calibration Location FVM Calibration Conditions 69.0°F, 20.6°C, 54.2%RH Calibration Date 07/14/2020 Recalibration Due 07/14/2021		Procedures Followed FVE-014 rev. 2 Standards Used <table style="width: 100%; border-collapse: collapse;"> <tr> <th style="text-align: left;">Instrument</th> <th style="text-align: left;">Serial Number</th> <th style="text-align: left;">Trace Number</th> <th style="text-align: left;">Next Cal</th> </tr> <tr> <td>FVS-093</td> <td>03111</td> <td>CK191-31886-628</td> <td>10/31/2020</td> </tr> <tr> <td>FVS-275A</td> <td>RY11838</td> <td>CJ191-70508-513</td> <td>07/28/2020</td> </tr> </table>	Instrument	Serial Number	Trace Number	Next Cal	FVS-093	03111	CK191-31886-628	10/31/2020	FVS-275A	RY11838	CJ191-70508-513	07/28/2020
Instrument	Serial Number	Trace Number	Next Cal											
FVS-093	03111	CK191-31886-628	10/31/2020											
FVS-275A	RY11838	CJ191-70508-513	07/28/2020											

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Calibration Results

* denotes "Out of Tolerance"

Feature	Nominal	Lower Limit	Upper Limit	As Found	As Left	Uncertainty
Clockwise	(in lb)	(in lb)	(in lb)	(in lb)	(in lb)	(in lb)
	30.00	29.10	30.90	29.89	29.89	0.091
	90.00	87.30	92.70	90.23	90.23	0.271
	150.00	145.50	154.50	152.00	152.00	0.450
Counter Clockwise	(in lb)	(in lb)	(in lb)	(in lb)	(in lb)	(in lb)
	30.00	29.10	30.90	30.31	30.31	0.091
	90.00	87.30	92.70	89.53	89.53	0.271
	150.00	145.50	154.50	148.58	148.58	0.450

Appendix K - Certificates of Calibration

(Appendix pages K1 to K26 identical to pages E1 to E26)

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CERTIFICATE OF CALIBRATION



Certificate No. ACT-1272

Certification Number CK198-49542-348 For Eaton Corporation - ICD W126 N7250 Flint Drive Menomonee Falls, WI 53051 Purchase Order # 4044-671109 Test Instrument Tape Measure Make Stanley Model 30-824 Serial Number Identification EM6927 Customer Location ICD Tony Condition Received In Tolerance Condition Returned In Tolerance Calibrated By Matthew Roughen Technical Review By Laura Fuhrmann Calibration Location FVM Calibration Conditions 69.5°F, 20.8°C, 34.8%RH Calibration Date 07/16/2020 Recalibration Due 07/16/2021		Procedures Followed FVM-042 rev. 1 Standards Used <table style="width: 100%; border-collapse: collapse;"> <tr> <th style="text-align: left;">Instrument</th> <th style="text-align: left;">Serial Number</th> <th style="text-align: left;">Trace Number</th> <th style="text-align: left;">Next Cal</th> </tr> <tr> <td>FVM-044</td> <td>C404R</td> <td>CH121-20770-384</td> <td>05/28/2022</td> </tr> <tr> <td>FVM-079A</td> <td>RY11924</td> <td>CJ191-72229-513</td> <td>07/28/2020</td> </tr> </table>		Instrument	Serial Number	Trace Number	Next Cal	FVM-044	C404R	CH121-20770-384	05/28/2022	FVM-079A	RY11924	CJ191-72229-513	07/28/2020
Instrument	Serial Number	Trace Number	Next Cal												
FVM-044	C404R	CH121-20770-384	05/28/2022												
FVM-079A	RY11924	CJ191-72229-513	07/28/2020												

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All instruments have been calibrated against standards traceable to NIST. Calibration was completed in accordance with ISO/IEC 17025:2017, ANSI/NCSL Z540-1-1994 and ANSI/NCSL Z540.3-2006. Other standards listed upon request.

Calibration Results

* denotes "Out of Tolerance"

Feature	Nominal	Lower Limit	Upper Limit	As Found	As Left	Uncertainty
Length	(in)	(in)	(in)	(in)	(in)	
	12.000	11.969	12.031	11.995	11.995	0.0006
	24.000	23.938	24.062	23.995	23.995	0.0007
	48.000	47.938	48.062	47.995	47.995	0.0007
	72.000	71.938	72.062	71.995	71.995	0.0007
	144.000	143.938	144.062	143.995	143.995	0.0006
	216.000	215.938	216.062	215.995	215.995	0.0006
	312.000	311.938	312.062	311.995	311.995	0.0007
Length	(cm)	(cm)	(cm)	(cm)	(cm)	(cm)
	500.00	499.00	501.00	499.87	499.87	0.007
	1000.00	999.00	1001.00	999.87	999.87	0.006
	5000.00	4999.00	5001.00	4999.87	4999.87	0.008
	8000.00	7999.00	8001.00	7999.87	7999.87	0.012

Appendix K - Certificates of Calibration

(Appendix pages K1 to K26 identical to pages E1 to E26)

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CERTIFICATE OF CALIBRATION



Certificate No. ACT-1272

Certification Number CK283-37262-427

For Eaton Corporation - ICD
W126 N7250 Flint Drive
Menomonee Falls, WI 53051

Purchase Order #

Test Instrument Weights

Make Standard Weight

Model Standard Weight

Serial Number 5070

Identification EM3031-8



Customer Location ICD

Condition Received In Tolerance

Condition Returned In Tolerance

Calibrated By Michael Frank

Technical Review By Tim Bending

Calibration Location FVM

Calibration Conditions 68.6°F, 20.3°C, 41.3%RH

Calibration Date 10/09/2020

Recalibration Due 10/09/2021

Procedures Followed

FVE-059 rev. 1

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Standards Used

Instrument	Serial Number	Trace Number	Next Cal
FVS-019P	N/A	CK188-74019-614	06/30/2021
FVS-275A	RY11838	CK202-61167-614	07/31/2021
FVS-792	14737316	CK100-21449-466	04/30/2021

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Calibration Results

* denotes "Out of Tolerance"

Feature	Nominal	Lower Limit	Upper Limit	As Found	As Left	Uncertainty
ASTM E617 Class 7						
Conventional Mass				FVS-792	FVS-792	
Correction	(g)	(g)	(g)	(g)	(g)	(g)
10 lb	0.0	-1.3	1.3	-0.4	-0.4	0.06

Comments

Test Weights Conventional Mass Correction Reference = C0000-WGHTS-FVM

Appendix K - Certificates of Calibration

(Appendix pages K1 to K26 identical to pages E1 to E26)

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CERTIFICATE OF CALIBRATION



Certificate No. ACT-1272

Certification Number CK283-36927-427 For Eaton Corporation - ICD W126 N7250 Flint Drive Menomonee Falls, WI 53051 Purchase Order # Test Instrument Weights Make Standard Weight Model Standard Weight Serial Number C1538 Identification EM3932-7 Customer Location Condition Received In Tolerance Condition Returned In Tolerance Calibrated By Michael Frank Technical Review By Tim Bending Calibration Location FVM Calibration Conditions 68.6°F, 20.3°C, 41.3%RH Calibration Date 10/09/2020 Recalibration Due 10/09/2021		Procedures Followed FVE-059 rev. 1 Standards Used <table style="width: 100%; border-collapse: collapse;"> <tr> <th style="text-align: left;">Instrument</th> <th style="text-align: left;">Serial Number</th> <th style="text-align: left;">Trace Number</th> <th style="text-align: left;">Next Cal</th> </tr> <tr> <td>FVS-019P</td> <td>N/A</td> <td>CK188-74019-614</td> <td>06/30/2021</td> </tr> <tr> <td>FVS-275A</td> <td>RY11838</td> <td>CK202-61167-614</td> <td>07/31/2021</td> </tr> <tr> <td>FVS-792</td> <td>14737316</td> <td>CK100-21449-466</td> <td>04/30/2021</td> </tr> </table>		Instrument	Serial Number	Trace Number	Next Cal	FVS-019P	N/A	CK188-74019-614	06/30/2021	FVS-275A	RY11838	CK202-61167-614	07/31/2021	FVS-792	14737316	CK100-21449-466	04/30/2021
Instrument	Serial Number	Trace Number	Next Cal																
FVS-019P	N/A	CK188-74019-614	06/30/2021																
FVS-275A	RY11838	CK202-61167-614	07/31/2021																
FVS-792	14737316	CK100-21449-466	04/30/2021																

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Calibration Results

* denotes "Out of Tolerance"

Feature	Nominal	Lower Limit	Upper Limit	As Found	As Left	Uncertainty
ASTM E617 Class 7						
Conventional Mass				FVS-792	FVS-792	
Correction	(g)	(g)	(g)	(g)	(g)	(g)
5 lb	0.0	-0.8	0.8	-0.1	-0.1	0.06

Comments

Test Weights Conventional Mass Correction Reference = C0000-WGHTS-FVM

Appendix K - Certificates of Calibration

(Appendix pages K1 to K26 identical to pages E1 to E26)

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CERTIFICATE OF CALIBRATION



Certificate No. ACT-1272

Certification Number CK283-36604-427 For Eaton Corporation - ICD W126 N7250 Flint Drive Menomonee Falls, WI 53051 Purchase Order # Test Instrument Weights Make Standard Weight Model Standard Weight Serial Number 62631 Identification EM6402 Customer Location ICD Condition Received In Tolerance Condition Returned In Tolerance Calibrated By Michael Frank Technical Review By Tim Bending Calibration Location FVM Calibration Conditions 68.6°F, 20.3°C, 41.3%RH Calibration Date 10/09/2020 Recalibration Due 10/09/2021		Procedures Followed FVE-059 rev. 1 Standards Used <table style="width: 100%; border-collapse: collapse;"> <tr> <th style="text-align: left;">Instrument</th> <th style="text-align: left;">Serial Number</th> <th style="text-align: left;">Trace Number</th> <th style="text-align: left;">Next Cal</th> </tr> <tr> <td>FVS-019P</td> <td>N/A</td> <td>CK188-74019-614</td> <td>06/30/2021</td> </tr> <tr> <td>FVS-275A</td> <td>RY11838</td> <td>CK202-61167-614</td> <td>07/31/2021</td> </tr> <tr> <td>FVS-792</td> <td>14737316</td> <td>CK100-21449-466</td> <td>04/30/2021</td> </tr> </table>	Instrument	Serial Number	Trace Number	Next Cal	FVS-019P	N/A	CK188-74019-614	06/30/2021	FVS-275A	RY11838	CK202-61167-614	07/31/2021	FVS-792	14737316	CK100-21449-466	04/30/2021
Instrument	Serial Number	Trace Number	Next Cal															
FVS-019P	N/A	CK188-74019-614	06/30/2021															
FVS-275A	RY11838	CK202-61167-614	07/31/2021															
FVS-792	14737316	CK100-21449-466	04/30/2021															

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Calibration Results

* denotes "Out of Tolerance"

Feature	Nominal	Lower Limit	Upper Limit	As Found	As Left	Uncertainty
ASTM E617 Class 7						
Conventional Mass				FVS-792	FVS-792	
Correction	(g)	(g)	(g)	(g)	(g)	(g)
2 lb	0.0	-0.4	0.4	-0.1	-0.1	0.07

Comments

Test Weights Conventional Mass Correction Reference = C0000-WGHTS-FVM

Appendix K - Certificates of Calibration

(Appendix pages K1 to K26 identical to pages E1 to E26)

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CERTIFICATE OF CALIBRATION



Certificate No. ACT-1272

Certification Number CK283-36818-427 For Eaton Corporation - ICD W126 N7250 Flint Drive Menomonee Falls, WI 53051 Purchase Order # Test Instrument Weights Make Standard Weight Model Standard Weight Serial Number C2194 Identification EM3931-2 Customer Location ICD Condition Received In Tolerance Condition Returned In Tolerance Calibrated By Michael Frank Technical Review By Tim Bending Calibration Location FVM Calibration Conditions 68.6°F, 20.3°C, 41.3%RH Calibration Date 10/09/2020 Recalibration Due 10/09/2021		Procedures Followed FVE-059 rev. 1 Standards Used <table style="width: 100%; border-collapse: collapse;"> <tr> <th style="text-align: left;">Instrument</th> <th style="text-align: left;">Serial Number</th> <th style="text-align: left;">Trace Number</th> <th style="text-align: left;">Next Cal</th> </tr> <tr> <td>FVS-019P</td> <td>N/A</td> <td>CK188-74019-614</td> <td>06/30/2021</td> </tr> <tr> <td>FVS-275A</td> <td>RY11838</td> <td>CK202-61167-614</td> <td>07/31/2021</td> </tr> <tr> <td>FVS-792</td> <td>14737316</td> <td>CK100-21449-466</td> <td>04/30/2021</td> </tr> </table>		Instrument	Serial Number	Trace Number	Next Cal	FVS-019P	N/A	CK188-74019-614	06/30/2021	FVS-275A	RY11838	CK202-61167-614	07/31/2021	FVS-792	14737316	CK100-21449-466	04/30/2021
Instrument	Serial Number	Trace Number	Next Cal																
FVS-019P	N/A	CK188-74019-614	06/30/2021																
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FVS-792	14737316	CK100-21449-466	04/30/2021																

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Calibration Results

* denotes "Out of Tolerance"

Feature	Nominal	Lower Limit	Upper Limit	As Found	As Left	Uncertainty
ASTM E617 Class 7						
Conventional Mass				FVS-792	FVS-792	
Correction	(g)	(g)	(g)	(g)	(g)	(g)
2 lb	0.0	-0.4	0.4	-0.1	-0.1	0.06

Comments

Test Weights Conventional Mass Correction Reference = C0000-WGHTS-FVM

Appendix K - Certificates of Calibration

(Appendix pages K1 to K26 identical to pages E1 to E26)

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CERTIFICATE OF CALIBRATION



Certificate No. ACT-1272

Certification Number CK283-37082-427 For Eaton Corporation - ICD W126 N7250 Flint Drive Menomonee Falls, WI 53051 Purchase Order # Test Instrument Weights Make Standard Weight Model Standard Weight Serial Number C1701 Identification EM3930-4 Customer Location ICD Condition Received In Tolerance Condition Returned In Tolerance Calibrated By Michael Frank Technical Review By Tim Bending Calibration Location FVM Calibration Conditions 68.6°F, 20.3°C, 41.3%RH Calibration Date 10/09/2020 Recalibration Due 10/09/2021		Procedures Followed FVE-059 rev. 1 Standards Used <table style="width: 100%; border-collapse: collapse;"> <tr> <th style="text-align: left;">Instrument</th> <th style="text-align: left;">Serial Number</th> <th style="text-align: left;">Trace Number</th> <th style="text-align: left;">Next Cal</th> </tr> <tr> <td>FVS-019P</td> <td>N/A</td> <td>CK188-74019-614</td> <td>06/30/2021</td> </tr> <tr> <td>FVS-114</td> <td>13209856</td> <td>CK129-29540-466</td> <td>11/30/2020</td> </tr> <tr> <td>FVS-275A</td> <td>RY11838</td> <td>CK202-61167-614</td> <td>07/31/2021</td> </tr> </table>		Instrument	Serial Number	Trace Number	Next Cal	FVS-019P	N/A	CK188-74019-614	06/30/2021	FVS-114	13209856	CK129-29540-466	11/30/2020	FVS-275A	RY11838	CK202-61167-614	07/31/2021
Instrument	Serial Number	Trace Number	Next Cal																
FVS-019P	N/A	CK188-74019-614	06/30/2021																
FVS-114	13209856	CK129-29540-466	11/30/2020																
FVS-275A	RY11838	CK202-61167-614	07/31/2021																

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Calibration Results

* denotes "Out of Tolerance"

Feature	Nominal	Lower Limit	Upper Limit	As Found	As Left	Uncertainty
ASTM E617 Class 7						
Conventional Mass				FVS-114	FVS-114	
Correction	(g)	(g)	(g)	(g)	(g)	(g)
1 lb	0.00	-0.27	0.27	0.06	0.06	0.006

Comments

Test Weights Conventional Mass Correction Reference = C0000-WGHTS-FVM

Appendix K - Certificates of Calibration

(Appendix pages K1 to K26 identical to pages E1 to E26)

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CERTIFICATE OF CALIBRATION



Certificate No. ACT-1272

Certification Number CK281-48208-541 For Eaton Corporation - ICD W126 N7250 Flint Drive Menomonee Falls, WI 53051 Purchase Order # Test Instrument Stopwatch Make Sportline Model 220 Serial Number Identification EM8101 Customer Location ICD Condition Received In Tolerance Condition Returned In Tolerance Calibrated By Trevor Benish Technical Review By Kevin Dehne Calibration Location FVM Calibration Conditions 69.5°F, 20.8°C, 41.4%RH Calibration Date 10/07/2020 Recalibration Due 10/07/2021		Procedures Followed FVE-033 rev. 1 Standards Used <table style="width: 100%; border-collapse: collapse;"> <tr> <th style="text-align: left;">Instrument</th> <th style="text-align: left;">Serial Number</th> <th style="text-align: left;">Trace Number</th> <th style="text-align: left;">Next Cal</th> </tr> <tr> <td>FVS-275A</td> <td>RY11838</td> <td>CK202-61167-614</td> <td>07/31/2021</td> </tr> <tr> <td>FVS-393</td> <td>N/A</td> <td>CK147-37289-397</td> <td>05/31/2021</td> </tr> </table>		Instrument	Serial Number	Trace Number	Next Cal	FVS-275A	RY11838	CK202-61167-614	07/31/2021	FVS-393	N/A	CK147-37289-397	05/31/2021
Instrument	Serial Number	Trace Number	Next Cal												
FVS-275A	RY11838	CK202-61167-614	07/31/2021												
FVS-393	N/A	CK147-37289-397	05/31/2021												

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Calibration Results

* denotes "Out of Tolerance"

Feature	Nominal	Lower Limit	Upper Limit	As Found	As Left	Uncertainty
Chronograph	(sec)	(sec)	(sec)	(sec)	(sec)	(sec)
	60.00	59.50	60.50	60.01	60.01	0.007
	60.00	59.50	60.50	60.01	60.01	0.007
	(sec)	(sec)	(sec)	(sec)	(sec)	(sec)
	300.00	299.50	300.50	300.02	300.02	0.006
	300.00	299.50	300.50	300.02	300.02	0.007

Terminal and Conductor Temperature Testing of 14 AWG Copper-Clad Aluminum and 14 AWG Copper Conductors

Part I – Static Heating and Flexing Tests

For

Bimetallics Task Group

Conducted at

Eaton Laboratories
Menomonee Falls, Wisconsin

Report by

Chuck Mello
on behalf of Bimetallics Task Group

Report Date

August 28, 2020

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1.0 Introduction and Purpose

At the direction of the NFPA Standards Council in their Decisions D#19-2 and D#19-23, a Bimetallics Task Group of balanced interest was appointed. The scope was to review the proposed changes to the 2020 edition of the *NEC*® that relate to copper-clad aluminum conductors and recommend changes through tentative interim amendment(s) and/or to provide public inputs for the next revision cycle.

As the task group conducted the work, it was determined that testing data had been provided substantiating the ampacity of 14 AWG copper-clad aluminum but a number of related questions about 14 AWG copper-clad aluminum applications arose regarding terminal temperatures when applied to circuit breakers, wire splicing devices and device terminals. A testing plan was developed, reviewed over several task group meetings, and accepted by the task group to address the terminal temperature questions. This testing was completed at the Eaton Corporation laboratory facilities in Menomonee Falls, Wisconsin. The helpful assistance of Mr. Tom Domitrovich, Mr. Kevin Arnold, Mr. James Parrett, and Mr. Steve Averbek with Eaton Corporation is greatly appreciated in arranging for and executing the testing.

This test report provides the testing arrangement, testing procedures and results for the static heating and the flexing tests. The Part I testing detailed in this report commenced July 30, 2020 and completed on August 26, 2020. Thermocycling testing is presently being conducted and those test results will be provided in a separate report. The separation of the reports is necessary to meet the NFPA deadline of September 10, 2020 to submit public inputs and any supporting data.

The purpose of this testing is to provide data, as requested by the Bimetallics Task Group, to understand certain installation and operating conditions when considering the application of 14 AWG copper-clad aluminum conductors at the proposed ampacity for branch circuits. The testing being completed also includes 14 AWG copper conductors at its *NEC*® ampacity for comparison and performance. The basis for comparison is at the 60°C ampacity rating for copper (15 amps) and the proposed 60°C ampacity rating for copper-clad aluminum (10 amps). This testing is designed to represent a typical installation to determine the following:

- 1) The temperature (temperature rise) on the terminals and conductor immediately adjacent to a 10 Amp and 15 Amp molded case circuit breaker, under normal and identified abnormal conditions
- 2) The temperature (temperature rise) on wire-splicing devices (e.g., Ideal Wire Nuts® or similar), and conductor immediately adjacent, commonly used for splicing in junction or device boxes or attaching leads from utilization equipment, under normal and abnormal conditions
- 3) The temperature (temperature rise) on wiring devices (single receptacle as representative) and conductor immediately adjacent under normal and abnormal conditions
- 4) Conductor retention on wiring devices after abnormal thermal-cycling
- 5) The flexing durability of 14 AWG copper-clad aluminum when installed and removed from a single-gang device box

Since the various product standards do not presently have requirements, procedures or parameters for 14 AWG copper-clad aluminum, the testing being conducted is based on the 10-ampere branch circuit rating at 60°C and percentage multipliers taken from the applicable standards. Where the standard does not provide a percentage value, then the current for the testing was interpolated from the values for relative copper and/or aluminum conductors from the standard. The values for testing of 14 AWG copper are taken from the applicable product safety standards with an ampacity basis of 15 Amps at 60°C

It is to be understood this testing is only being conducted to provide specific performance data and information as requested by the task group. The testing does not provide performance or data for certification of any of the components used for the testing. If 14 AWG copper-clad aluminum is accepted into the 2023 *NEC*®, then numerous UL standards will need to be revised and testing completed under the requirements established in those standards. This testing for certification could be more extensive and take much more time to complete than what is provided here. The goal again is to provide information for a typical installation specific to terminal temperatures. The changes to UL standards will not begin to occur until 14 AWG copper-clad aluminum is recognized for installation in the *NEC*®.

To provide a basis to consider the test results for 14 AWG copper-clad aluminum, duplicate test set ups were constructed using 14 AWG copper conductors. The only difference in the setup for 14 AWG copper is the circuit breaker was rated 15 Amps and the testing values were based on the 15 Amp ampacity. This additional testing data provides a direct comparison in the same environment at the 60°C ampacity values for these two conductor types and assemblies.

2.0 Testing Arrangement and Setup

The test was conducted in a suitable facility with environmental controls and documented monitoring. The facility was free from extraneous changes in ambient temperature and from having random air flow (drafts) through the testing area. Ambient temperature was maintained between 20°C and 25°C and recorded with thermocouples positioned in the testing area while temperature testing was completed.

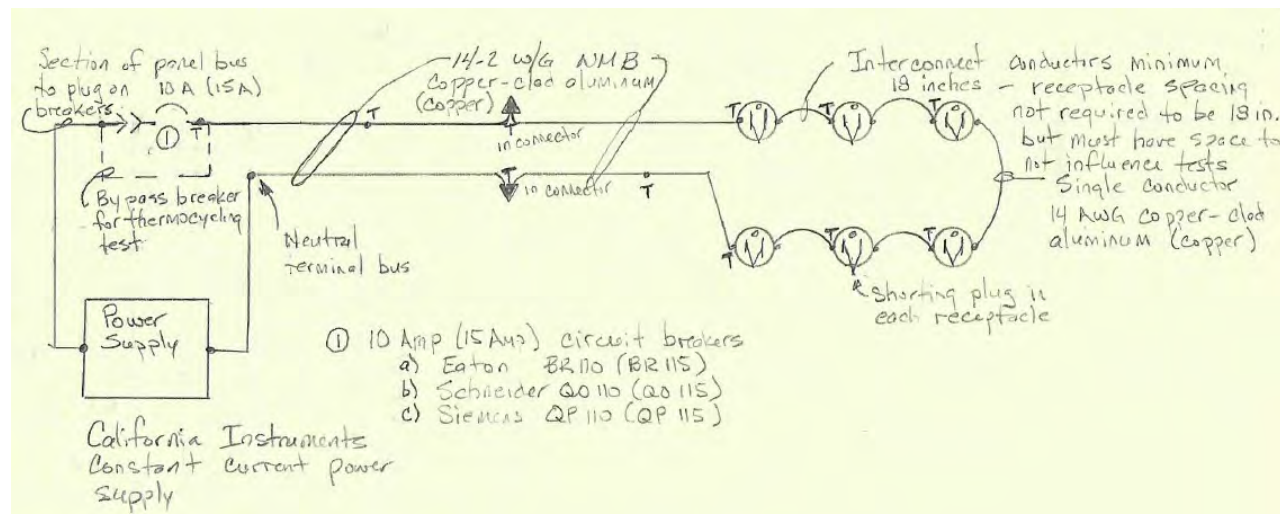


Figure 1 – Typical Test Circuit Diagram

The Eaton facility, being a division within a manufacturing company of wiring devices and circuit breakers, has laboratory technicians that are very familiar with testing of circuit components and equipment to UL standards.

The test circuit diagram shown in figure 1 above provides the basic layout of one (1) testing circuit consisting of one (1) circuit breaker, the conductor (14 AWG copper-clad aluminum or copper NM-B cable) two wire-splicing devices, and six (6) single receptacles. To complete tests 1 through 4 as described below, three (3) of these test circuits were assembled at a time. Photos 1 through 3 in Appendix A show the general test setup for completing the static heating testing. Each of the three (3) circuits have one of the manufacturer's (mfg. 1, mfg. 2, and mfg. 3) circuit breaker, the wire splicing devices on the black and white wire as described below, and three (3) each of receptacles from two of the manufacturers. Photos 4 through 7 show each of the setups with a sign indicating the circuit breaker, conductor material, wire splicing devices, and receptacles in that circuit.

For example, a setup had three (3) circuits with:

- Three different 10-amp circuit breakers (one each mfg. 1, mfg. 2, and mfg. 3)
- 14 AWG copper-clad aluminum NM-B conductors
- Mfg. 4 and mfg.5 wire splicing devices respectively, on the black and white conductors
- Three each of the mfg. 8 and mfg. 9 receptacles, and
- 14 AWG THHN copper-clad aluminum conductors for interconnection of the receptacles

These components were connected together to form a complete circuit. The second setup for 14 AWG copper-clad aluminum were same circuit breakers but with mfg.6 and mfg.7 wire splicing devices and with mfg. 10 and mfg.11 receptacles. The third and fourth setups were the same as 1 and 2 except using 15-amp circuit breakers and 14 AWG copper conductors.

Due to testing of several different circuit breakers, receptacles, and wire-splicing devices, the test arrangement was different than what may be used for certification testing of a single type of device. The test purpose was to approximate an actual installation under laboratory type conditions and not to establish certification type testing for any one device.

For tests 1 through 4 the three power supplies used were programmable constant current power supply sources. Each power supply was connected to one of the circuits and provided the current level specified for the tests being conducted.

For each of the four setups the following description is provided, see circuit diagram in figure 1 and Appendix A photos 1 through 7:

- 1) The three (3) circuits were mounted on an insulating sheet approximately 4 feet high and 8 feet wide. The partition had suitable framing to provide structural support for the partition to be in a vertical orientation to the floor.
- 2) During all testing, suitable barrier tape, safety cones, barriers, or other means was in place in accordance with the laboratory safety procedures to keep unauthorized persons out of the area and away from exposed live parts.
- 3) The individual conductors and devices were arranged horizontally with approximately 12 inches of vertical spacing between each horizontal assembly. Staples, or other fastening devices, such as cable ties, were used to keep the NM-B cable aligned with the respective test assembly.

- 4) For the circuit breaker testing the following was assembled:
- a) For the copper-clad aluminum conductors, three (3) 10-amp plug-on type panelboard circuit breakers were installed on sections of panelboard bus that are mounted onto the insulating board partition.
 - b) For the copper conductors, three (3) 15-amp plug-on type panelboard circuit breakers were installed on sections of panelboard bus that are mounted onto the insulating board partition. The panelboard bus had a terminal for connection of one conductor from the power supply.
- 5) From the circuit breaker approximately 4 feet of 14-2 NM-B cable was installed and supported as provided above. From this center junction another 2 feet of 14-2 NM-B cable (copper-clad aluminum or copper as applicable) was installed. The junction in the middle had approximately 6 inches of exposed conductor and a splice completed with yellow wire-splicing devices as provided for the black, white and equipment grounding conductors. The following was applied to the two setups for the copper-clad aluminum conductors respectfully and repeated for the copper conductor setups.
- a) The black wire for the first circuit set of three used a mfg. 4 yellow wire-splicing devices
 - b) The white wire for the first circuit set of three used an mfg. 5 yellow Wire Nuts®
 - c) The black wire of the second circuit set of three used a mfg. 6 yellow wire-splicing devices
 - d) The white wire of the second circuit set of three used a mfg. 7 yellow wire-splicing devices

The manufacturer and location of the wire-splicing devices used was recorded for each test setup.

- 6) Six (6) receptacles were installed at the end of each horizontal assembly.
- a) The first set of circuits of copper-clad aluminum or of copper had three (3) mfg. 11 receptacles and then three (3) receptacles from mfg. 8 all connected in series.
 - b) The second circuit of copper-clad aluminum or of copper had three (3) receptacles from mfg. 10 and then three (3) receptacles from mfg. 9 all connected in series.

The receptacles were spaced a minimum of six (6) inches apart horizontally and/or vertically and were interconnected with a minimum of eighteen (18) inches of 14 AWG solid THHN copper-clad aluminum or copper conductors respectfully.

The receptacles were mounted to the wall surface with screws, so that the face of the receptacle was approximately 1 1/2 inches from the insulating board partition surface.

For each manufacturer the receptacles were connected to terminals as follows:

- a) One receptacle had the conductors installed at each wire binding screw and the conductors were wrapped counter-clockwise around the screw shank under the screw head, for 2/3 to 3/4 of wire binding screw circumference.

- b) The second receptacle had the conductors installed into one side back terminal (entry hole) of the pressure plate terminal.
- c) The third receptacle had two conductors installed into each back-side pressure plate terminal as follows: one conductor of the test circuit into each side (hot and neutral) of the pressure plate terminal and one additional short conductor of equal diameter and material into the other side (entry hole) of the same pressure plate terminal. The second conductor was to fill the slot only and is not required for any other purpose than to balance the mechanical clamping forces applied.

Each receptacle had a shorting plug installed as follows:

- a) The ungrounded (BLACK) and grounded (WHITE) contacts of each receptacle being tested were connected together by a mated attachment plug having rigidly-attached solid blades.
 - b) The terminals of each attachment plug were short-circuited by the shortest feasible length of 14 AWG stranded copper conductor from type SJ flexible cord.
 - c) The flexible cord shorting conductor was mechanically terminated into the pressure plate terminals and the connection torqued to the manufacturer's specification.
- 7) The conductor from the neutral terminal of the last receptacle in the series was routed back using the white wire in the NM-B cable, through the wire-splicing devices and terminated at a terminal bar mounted to the support board for connection back to the power supply.
- 8) All connections were tightened as follows. Torquing tools were calibrated and calibration documented:
- a) The circuit breaker terminals were torqued as specified on the circuit breaker nameplate.
 - b) The wire-splicing devices were torqued to the manufacturer's specification in the instructions. If there was no specification, then the 14 AWG copper-clad aluminum conductors were torqued to 2.47 lbf-in and the 14 AWG copper conductors were torqued to 4.11 lbf-in [Specification from UL 486C – 9.1.9.4]
 - c) The terminals of the receptacles and of the attachment plugs were torqued to the manufacturer's specification in the installation instructions. If there was no torque specification provided, then the terminals were torqued to 9 lbf-in.
- 9) Thermocouples were connected as shown in the diagram, figure 1 and as shown in Appendix A photos 8 and 11 through 14.
- a) Thermocouples were installed on device terminals so that it did not interfere with the terminal.

For the wire-splicing devices, the thermocouples were attached into the wire bundle within the wire-splicing devices.

- b) The thermocouples that measured center wire temperatures had a flap of the NM-B jacket and the conductor insulation peeled back to expose the conductor. The thermocouple was attached with thermo-cement to the conductor and the conductor insulation and jacket flap folded back to the original position with two wraps of black electrical tape wrapped to hold the flap in place.
 - c) A thermocouple was positioned midway in elevation to the test setup for each circuit and recorded the ambient temperature as testing was completed.
- 10) The power supply was a programable constant current power supply. The current was monitored and recorded by the data logger along with the temperature recordings. The power supply was connected to the lug on the panelboard bus serving the circuit breaker and to the neutral terminal bar where the return white conductor from the NM-B cable was terminated.

3.0 Materials for Testing

The generous support with the supplying of materials by Copperweld, Eaton, Hubbell, Legrand, Leviton, and Siemens are acknowledged and appreciated. The following materials were used to complete the setups as described above.

- 1) The circuit breakers for the copper-clad aluminum testing were single pole 10 Amp 120/240 Volt, 10,000 interrupting rating with five (5) each of the following (two (2) breakers to be used and the others as backup):
 - a) Eaton BR110,
 - b) Schneider QO110, and
 - c) Siemens QP110.
- 2) The circuit breakers for the copper testing were single pole 15 Amp 120/240 Volt, 10,000 interrupting rating with five (5) each of the following (two (2) breakers to be used and the others as backup):
 - a) Eaton BR115,
 - b) Schneider QO115, and
 - c) Siemens QP115.
- 3) The yellow wire-splicing devices were as follows:
 - a) Gardner-Bender Ultra WingGard
 - b) Ideal Wing-Twist
 - c) 3M Performance Plus Red/Yellow+
 - d) Commercial Electric WT4

- 4) The receptacles for both the copper-clad aluminum and copper testing were:
 - a) Eaton (Cooper) model TR6250W, 5-15R single receptacle with wire binding screw and pressure plate terminals (back and side wired)
 - b) Hubbell model HBL 5261, 5-15R single receptacle with both wire binding screw and pressure plate terminals (back and side wired)
 - c) Legrand (Pass & Seymour) model TR 5251, 5-15R single receptacle with both wire binding screw and pressure plate terminals (back and side wired)
 - d) Leviton model T 5015, 5-15R single receptacle with both wire binding screw and pressure plate terminals (back and side wired)
- 5) Thermocouples, UL calibrated, model UL 3055, with sufficient length to connect and route to datalogger recording device.
- 6) Datalogger recording device and laptop or another required device for the datalogger.
- 7) Programable power supplies from Eaton laboratory. Maximum current for the copper was 30 Amps and for the copper-clad aluminum was 20 amps.
- 8) Approximately 50 feet each of 14-2 w/ground copper-clad aluminum NM-B cable and of 14-2 w/ground copper NM-B cable.
- 9) Approximately 50 feet each of 14 AWG solid THHN copper-clad aluminum and 14 AWG solid THHN copper single conductors.

4.0 Test Procedures

4.1 Conductor Material Testing

A sample of each the 14-2 NM-B and 14 AWG THHN copper-clad aluminum conductors used for the testing was returned to the Copperweld factory laboratory for analysis. The testing was performed to confirm the conductors that were used for the testing at Eaton were in fact 14 AWG and met the requirements for copper-clad aluminum as specified in UL 83 Annex E and ASTM B566. The packaging was photo documented from the Eaton laboratory and the opening of the package at the Copperweld laboratory photo documented.

The Copperweld laboratory technician, who routinely performs the full ASTM B566 battery of testing, completed all the testing and documented it on a Copperweld laboratory test data sheet.

Standard materials testing was completed by Copperweld laboratory technicians including:

- DC resistance
- Copper thickness
- Copper Volume
- Tensile strength
- Elongation
- Adhesion
- Cohesion

The following tests, as completed by the Copperweld laboratory technician, were witnessed and documented by the UL Field Representative that normally completes follow-up inspections of copper-clad aluminum conductors as part of the recognized component program, under category DVVU2:

- DC resistance
- Copper thickness
- Tensile strength
- Elongation

4.2 Terminal Temperature Testing

The following test procedures, except the flexing test, used references from parts of UL 486(A)(B); UL 486(C); UL 489; UL 20; and UL 498.

As stated, the tests 1 through 4 were completed with all three (3) manufacturer's circuit breakers in three circuits at one time. These tests are identified with the test number from below with an "a", "b" or "c" representing the representative circuit breaker used:

- a. mfg. 1 circuit breaker
- b. mfg. 2 circuit breaker
- c. mfg. 3 circuit breaker

This same nomenclature is used in the data sheets found in Appendix C. To minimize test setups, and the number of times terminations are completed or taken apart, all four (4) static heating tests were completed for the "a", "b", and "c" circuit setups. After these tests were completed, then the next setup was assembled by changing the wire splicing devices and receptacles or changing the conductors from copper-clad aluminum to copper as applicable.

All static heating tests, tests 1 through 4 commenced with all components at ambient temperature.

For all testing temperature equilibrium is three consecutive readings taken at no less than 5-minute intervals indicating no further rise in temperature above the ambient temperature. For tests where the circuit breaker trips, which may be before temperature equilibrium was attained, the last three recorded temperatures were recorded onto the data sheets.

Test #1 – Rated Current Temperature

Each circuit was operated at 100% of the branch circuit rating (CCA - 10 Amps or Cu - 15 Amps) until temperature equilibrium was achieved. The final temperatures were recorded. All terminations were inspected for evidence of thermal damage. Temperature measurements were recorded at one-minute intervals.

Test #2 – Circuit Breaker Overload Temperature

Each circuit was operated at 135% of the branch circuit rating (CCA - 13.5 Amps or CU - 20.25 Amps) until temperature equilibrium was achieved or the circuit breaker tripped whichever came first. The circuit breaker elapsed trip time was recorded. Table 1, in section 4.3 below, provides the expected circuit breaker trip times from the manufacturer's time current curves. If the circuit breaker tripped, the last three recorded temperatures of the conductor, wire-splicing devices and wiring device were recorded on the datasheet. All terminations were inspected for evidence of thermal damage. Temperature measurements were recorded at 20-second intervals.

Test #3 – Wiring Device Overload Temperature

Each circuit was operated at 150% of the branch circuit rating (CCA - 15 Amps, or CU - 22.5 Amps) until temperature equilibrium was achieved or the circuit breaker tripped whichever came first. The circuit breaker elapsed trip time was recorded. Expected circuit breaker trip times are in a table 1 below in section 4.3 of procedure. If the circuit breaker tripped, the last three recorded temperatures of the conductor, wire-splicing devices and wiring device were recorded on the datasheet. All terminations were inspected for evidence of thermal damage. Temperature measurements were recorded at 10 second intervals.

Test #4 – Circuit Breaker Overload Temperature

Each circuit was operated at 200% of the branch circuit rating (CCA - 20 Amps, or CU 30 Amps) until temperature equilibrium was achieved or the circuit breaker trip tripped whichever came first. The circuit breaker elapsed trip time was recorded. Expected circuit breaker trip times are in a table 1 below in section 4.3 of procedure. If the circuit breaker tripped, the last three recorded temperatures of the conductor, wire-splicing devices and wiring device were recorded on the datasheet. All terminations were inspected for evidence of thermal damage. Temperature measurements were recorded at 7 second intervals.

Test #5 – Wiring Device Thermal Cycling

The thermocycling testing is underway at the time this report is being written. In order to meet NFPA public input deadlines, this report is for all testing completed at this time. A subsequent report will be written for the thermocycling testing.

Test # 6 – Conductor Flexing Test

- a) A standard 2 x 3 device box was mounted to a wood stud fixed to a table for support. See Appendix A photo 15. The device box was mounted with screws through the back of the box.
- b) A length of 14-2 AWG copper-clad aluminum NM-B cable was installed into the device box using NM cable clamps. The NM-B had a minimum of 1/4 inch of cable jacket projecting into the box past the clamping device.
- c) The outside end of the NM-B cable was connected to a digital multimeter to indicate continuity of the circuit through the receptacle, see Appendix A photo 16.

- d) The NM-B cable jacket was stripped and cut to length so that 6 inches of conductor projected beyond the cable entry to the box and 3 inches beyond the front edge of the device box. A receptacle was terminated to the NM-B cable conductors and the conductors shaped to fit back in the box so the receptacle yoke mated with the box front edge.
- e) For the first test, the NM-B conductors were installed using the wire binding screw with the conductors wrapped counter-clockwise around the screw shank under the screw head, for 2/3 to 3/4 of wire binding screw circumference.
- f) A shorting plug was installed into the receptacle.
- g) The 6-32 screws were removed and approximately 4-inch-long 10-32 screws were fixed to the device box ears and through the yoke of the receptacle providing a guideway for repeated insertion and removal. The 10-32 screws had nuts installed in the inside and outside of the device box ears to make rigid to the box, see Appendix A photo 15.
- h) With the assembly complete, the receptacle was pushed into and retracted from the box for 10 cycles and the continuity monitored on the digital multimeter, see Appendix A photos 17 through 19.
- i) Steps 'b' through 'h' were repeated two more times with new lengths of 14-2 NM-B copper-clad aluminum cable.
 - For the second test the receptacle was assembled with the back-wiring pressure plate terminal and a single conductor.
 - For the third test the receptacle was assembled with the back-wiring pressure plate terminal and two conductors for mechanical balance on the wiring terminal.

4.3 Bimetallics Testing Circuit Breaker Trip Times

The below table provides the expected trip times based on the manufacturers time current curves at 40°C. The testing for this project was completed at about 22°C, based on the ambient temperatures recorded. Therefore, the trip times recorded from this testing may be somewhat higher but should not exceed the limits set in the UL Standard.

The UL standard specifies that calibration testing be completed at an ambient temperature of 25°C. The UL standard calibration testing at 25°C specifies that at:

- 135% of rating the maximum trip time for a 0 - 50-amp circuit breaker is 1 hour
- 200% of rating the maximum trip time for a breaker 0 – 30 amps is 2 minutes.

Table 1

Manufacturer	Catalog No.	Trip Time Range in Seconds @ 40°C			
		100% rated current	135% rated current	150% rated current	200% rated current
Eaton	BR110	No trip	35 - 3600	20 - 500	12 - 40
	BR115	No trip	35 - 3600	20 - 500	12 - 40
Schneider	QO110	No trip	40 - 500	26 - 240	10 - 60
	QO115	No trip	30 - 210	21 - 100	8 - 28
Siemens	QP110	No trip	60 - 800	40 - 450	19 - 150
	QP115	No trip	30 - 250	20 - 100	9 - 38

5.0 Test Results

5.1 Copper-Clad Aluminum Conductor Material Testing

After the static heating testing was completed, Eaton laboratory technicians packed and shipped samples of the copper-clad aluminum conductor, NM-B cable and THHN single conductor, that had been used for the testing to Copperweld's laboratory for verification testing. Appendix A photos 22 to 24 show the samples the Eaton laboratory technicians packaged into the bag and shipped to the Copperweld laboratory. Note the date on these photos as August 24, 2020. Appendix B pages B1 and B2 show photos of the received package and opening of that package with these samples for the testing.

The samples of the 14 AWG copper-clad aluminum NM-B cable and the 14 AWG copper-clad aluminum THHN single conductors were tested in the Copperweld factory laboratory on August 27, 2020. The Copperweld laboratory testing data is provided in Appendix B page B3 and the calibration of the test equipment on pages B4 through B6.

The UL field engineer that routinely completes the quarterly follow-up inspections for the copper-clad aluminum conductor witnessed the testing required under the UL standard follow-up program that was completed on August 27, 2020. As shown in Appendix B, page B7, the UL field engineer confirmed that *"the 14 Awg from the NMB and THHN samples passed the UL tests for DVVUs, including Tensile, Elongation, copper thickness and DC resistance"*

The test results for the copper-clad aluminum confirm that the conductors used for this testing were 14 AWG and that the material tested met the requirements in ASTM B566.

5.2 Test Setup and Torquing

The test setups were as described in Section 2.0 of this report and shown with photographs in Appendix A. The terminations were tightened to the applicable torque value with a calibrated torque wrench. For the static heating testing the following tables show the torque values applied for each setup and device terminal.

Copper-Clad Aluminum conductors with mfg. 11 and mfg. 8 Receptacles

Torques applied:

Item being torqued	in/lbs	mfr. spec	default
mfg. 1 brkr	20	yes	no
mfg. 2 brkr	36	yes	no
mfg. 3 brkr	25	yes	no
mfg. 4 wire splicing device	2.47	no	yes
mfg. 5 wire splicing device	2.47	no	yes
mfg. 11 receptacles	9	no	yes
mfg. 8 receptacles	12	yes	no

Copper-Clad Aluminum conductors with mfg. 10 and mfg. 9 Receptacles

Torques applied:

Item being torqued	in/lbs	mfr. spec	default
mfg. 1 brkr	20	yes	no
mfg. 2 brkr	36	yes	no
mfg. 3 brkr	25	yes	no
mfg. 6 wire splicing device	2.47	no	yes
mfg. 7 wire splicing device	2.47	no	yes
mfg. 10 receptacles	9	no	yes
mfg. 9 receptacles	9	no	yes

Copper conductors with mfg. 11 and mfg. 8 Receptacles

Torques applied:

Item being torqued	in/lbs	mfr. spec	default
mfg. 1 brkr	20	yes	no
mfg. 2 brkr	36	yes	no
mfg. 3 brkr	25	yes	no
mfg. 4 wire splicing device	4.11	no	yes
mfg. 5 wire splicing device	4.11	no	yes
mfg. 11 receptacle	9	no	yes
mfg. 8 receptacle	12	yes	no

Copper conductors with mfg. 10 and mfg. 9 Receptacles

Torques applied:

Item being torqued	in/lbs	mfr. spec	default
mfg. 1 brkr	20	yes	no
mfg. 2 brkr	36	yes	no
mfg. 3 brkr	25	yes	no
mfg. 6wire splicing device	4.11	no	yes
mfg. 7 wire splicing device	4.11	no	yes
mfg. 10 receptacle	9	no	yes
mfg. 9 receptacle	9	no	yes

5.3 Static Heating Test

The following are the results of the static heating testing, tests 1 through 4 with references to the applicable appendix pages. For all the testing data, the final three recorded temperature values are shown at either temperature equilibrium or the final three temperatures recorded before a circuit breaker tripped. All testing commenced with all test measurement points at ambient temperature. Also shown in the tables in the appendix are:

- The elapsed time from the start of the test,
- The ambient temperature recorded at the time of the recorded values, and
- The current at the time of the recorded values.

Since the UL standards reference temperature rise for most of the devices, those calculated values are shown immediately adjacent to the recorded values. The temperature rise was calculated by taking the recorded temperature and subtracting the ambient temperature recorded for that time.

Since the method of termination on each the three receptacles from one manufacturer was different (wire binding screw, back wired with pressure plate with one conductor and back wired with pressure plate with two conductors) exact data comparison of terminal temperature needs to be done line by line. For example, from appendix page C1 – 1, the line 1a for copper-clad aluminum, top table, needs to compare with line 1a for copper, bottom table.

Otherwise, data in general for terminal temperatures of specific devices, circuit breakers, wire splicing devices and receptacles as well as the conductor, can be compared in general. To facilitate ease of comparison, the pages in appendices C1 through C4 have been arranged so that each page has the copper-clad aluminum data in the top table and the related copper data in the bottom table.

5.3.1 Static Heating at 100% Rated Current

The data for the static heating testing at 100 percent of rated current are shown in Appendix C1. The recorded values are all after the temperatures being recorded had achieved temperature equilibrium. As can be seen in line by line or with general comparisons, the terminal and conductor temperatures for the copper-clad aluminum were less than those recorded for copper when operating at rated current. All temperatures recorded were less than the allowances in the applicable UL standards.

5.3.2 Static Heating at 135% Rated Current

The data for the static heating testing at 135 percent of rated current are shown in Appendix C2. The 135 percent current level is a calibration point for circuit breakers, rated up to 50 amps, where they are required to trip within 1 hour. The recorded values are the last three recorded temperatures before the circuit breaker tripped.

In doing analysis consideration must be given to the fact the temperatures recorded were still rising when the circuit breaker tripped. Therefore, when doing line by line or general comparisons, the circuit breaker trip time must be considered. It is noted the mfg. 1 10-amp circuit breaker tripped approximately twice as fast as the 15-amp circuit breaker, 8 vs. 19 seconds, and this resulted in higher recorded temperatures for copper. The test results with the mfg. 2 circuit breakers was reversed with the 15-amp breaker tripping in approximately half the time of the 10-amp circuit breaker, 3.5 vs. 5.5 seconds. Even with this time disparity the copper-clad aluminum with the longer time recorded lower temperatures than the copper. The trip times for the mfg. 3 circuit breakers had the 10-amp breaker tripping 3 times longer than the 15-amp breaker, but the copper-clad aluminum terminal temperatures still were less than or near to the copper terminal temperatures.

All temperatures recorded were less than the allowances in the applicable UL standards.

5.3.3 Static Heating at 150% Rated Current

The data for the static heating testing at 150 percent of rated current are shown in Appendix C3. The 150 percent current level is a static heating test current for wiring devices. The recorded values are the last three recorded temperatures before the circuit breaker tripped.

In doing analysis consideration must be given to the fact the temperatures recorded were still rising when the circuit breaker tripped. Therefore, when doing line by line or general comparisons, the circuit breaker trip time must be considered. The test data results shown in appendix C3 generally follow that same pattern as occurred with the 135 percent testing.

All temperatures recorded were less than the allowances in the applicable UL standards.

5.3.4 Static Heating at 200% Rated Current

The data for the static heating testing at 200 percent of rated current are shown in Appendix C4. The 200 percent current level is a calibration point for circuit breakers, rated up to 30 amps, where they are required to trip within 2 minutes. The recorded values are the last three recorded temperatures before the circuit breaker tripped.

In doing analysis consideration must be given to the fact the temperatures recorded were still rising when the circuit breaker tripped. Therefore, when doing line by line or general comparisons, the circuit breaker trip time must be considered. The test data results shown in appendix C4 generally follows the same pattern as occurred with the 135 percent and 150 percent testing.

All temperatures recorded were less than the allowances in the applicable UL standards.

5.3.5 Static Heating at 135% Rated Current – Circuit Breaker Did Not Trip

The first attempt at the 135 percent testing found the mfg. 2 10-amp circuit breaker not to trip within the required 1-hour time. The data for this static heating test at 100 percent and at 135 percent of rated current are shown in Appendix C5. The top table on this appendix page is the 100 percent test data and the bottom table is the 135 percent test data. As stated before, the 135 percent current level is a calibration point for circuit breakers, rated up to 50 amps, where they are required to trip within 1 hour.

Since the circuit breaker failed to trip the test was stopped shortly after the 1-hour time had elapsed. Analysis of the 135 percent data recorded found that after 1-hour at this current level, above the proposed rated current, none of the terminal or conductor temperatures had risen above UL standards allowances.

5.3.6 Flexing Tests

The data for the flexing testing is shown in Appendix D. There is no UL or other known industry standard for this specific test and the test process used was established and agreed to by the task group to represent an installation condition. Three tests were conducted, one with the receptacle terminated with the 14 AWG copper-clad aluminum wrapped around the wiring binding screw, the second with a single conductor back wired into the pressure plate and the third with two conductors back wired into the pressure plate.

The test results found that after 10 cycles of fully inserting and removing the receptacle to the full extended position, the copper-clad aluminum

conductors for the back wired assemblies did not break and therefore passed this test.

For the wire binding screw termination, the first test found the flexing for the 10 cycles passed where the conductors did not break. But when the conductors were being removed both the black and white conductors broke off near the end of the insulation, see Appendix A photo 20. A second test was conducted and the black conductor was found to break off near the end of the insulation on the eighth cycle. A third test was completed, using a 14 AWG NM-B sample from another coil, and this assembly passed the 10 cycles and removal of conductors with no breaking or signs of weakening in the stripped portion of the conductor, see Appendix A photo 21.

As stated, there is no industry standard for completing this flexing test and the test was conducted due to specific questions asked by members of the task group. The results demonstrate that there may be limits to the amount of flexing these conductors can withstand, but it should be noted that in normal installations the insertion and removal of a wiring device occurs far less than the eight to ten times as conducted in this test.

6.0 Conclusions

The results from the temperature testing conducted in this project found the 14 AWG copper-clad aluminum to have terminal and conductor temperatures generally less than copper when tested at the 60°C ampacity values. In all cases, the temperature and temperature rise recorded were below those provided in the referenced UL standards. The flexing testing found that there may be some limitations to the number of flexing operations a 14 AWG copper-clad aluminum conductor can withstand, but the number of flexing operations to breakage is above those normally encountered in any installation.

As stated in the introduction, this testing project was to answer specific questions raised by the Bimetallics Task Group regarding temperature performance of 14 AWG copper-clad aluminum compared with 14 AWG copper in typical applications. **While testing conducted followed parts of several UL standards, it is to be understood the testing was only conducted to provide specific performance data and information as requested by the task group. The testing does not provide performance or data for certification of any of the components used for the testing.**

7.0 Test Equipment and Calibration

The following test and measurement equipment was used for the testing. The certificates of calibration for each of the above items is provided in Appendix E.

Description	manufacturer	Eaton Asset #	Cal Date	Cal Due
Thermocouples	Pacific Test and Measurement	N/A	7/10/2020	N/A
DACQ datalogger	Agilent (HP)	EM7054	7/16/2020	7/16/2021
DVM	Fluke	EM4437	7/16/2020	7/16/2021
DVM	Fluke	EM7014	7/16/2020	7/16/2021
DVM	Fluke	EM7024	7/16/2020	7/16/2021
CT	AEMC	EM6996	7/16/2020	7/16/2021
CT	AEMC	EM6997	7/16/2020	7/16/2021
CT	AEMC	EM8032	7/16/2020	7/16/2021
Torque wrench	CDI	EM8363	7/14/2020	7/14/2021
Tape measure	Stanley	EM6927	7/16/2020	7/16/2021

Appendix A - Photos



Photo 1 – Laboratory View



Photo 2 – Test Board and Test Equipment Arrangement

Appendix A - Photos

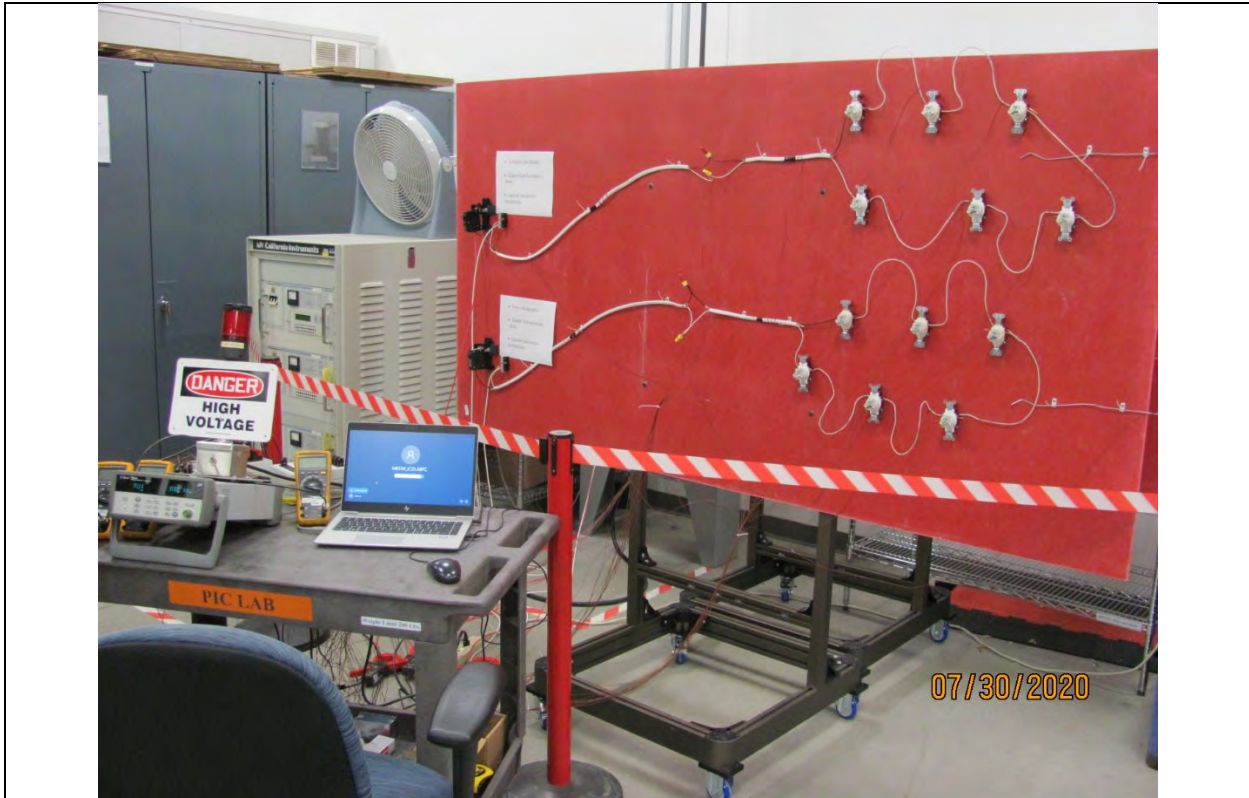


Photo 3 – Test Board and Test Equipment Arrangement



Photo 4 – Copper-Clad Aluminum with Eaton and Hubbell Receptacles

Appendix A - Photos

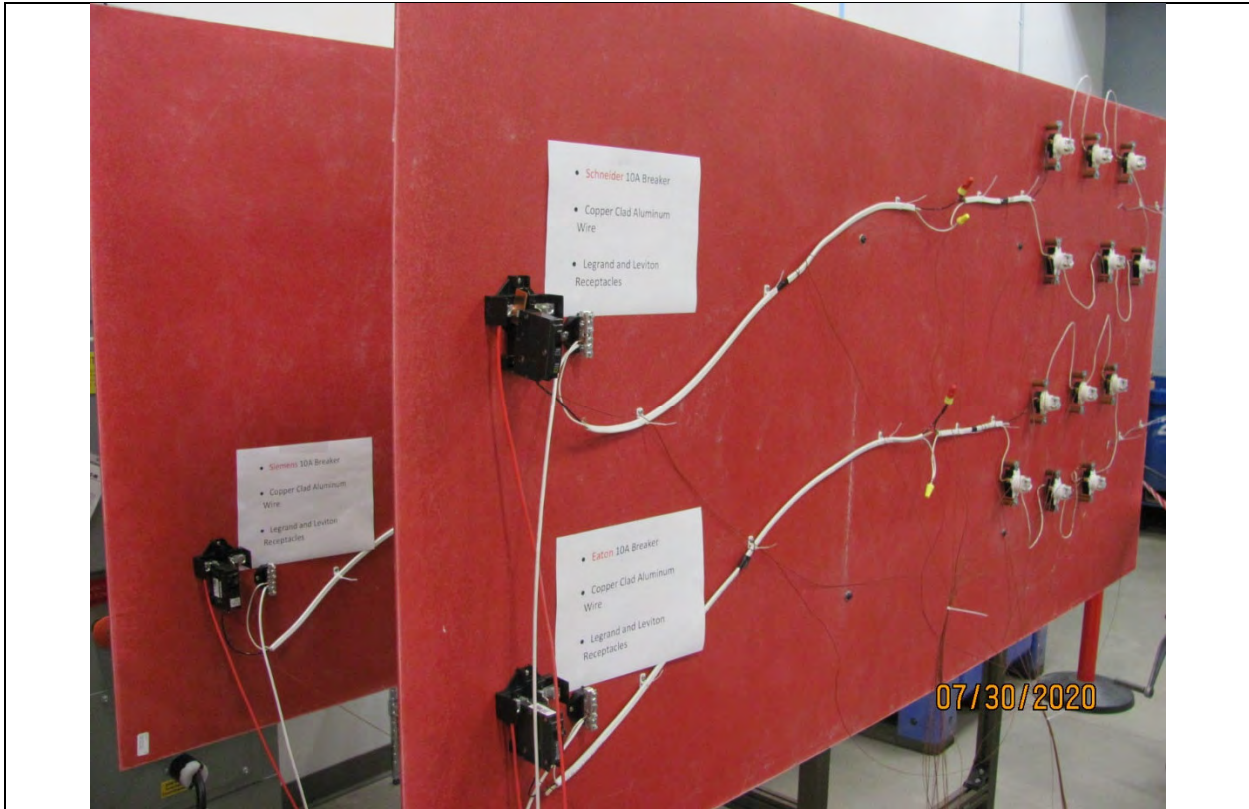


Photo 5 – Copper-Clad Aluminum with Legrand and Leviton Receptacles



Photo 6 – Copper with Eaton and Hubbell Receptacles

Appendix A - Photos



Photo 7 – Copper with Legrand and Leviton Receptacles

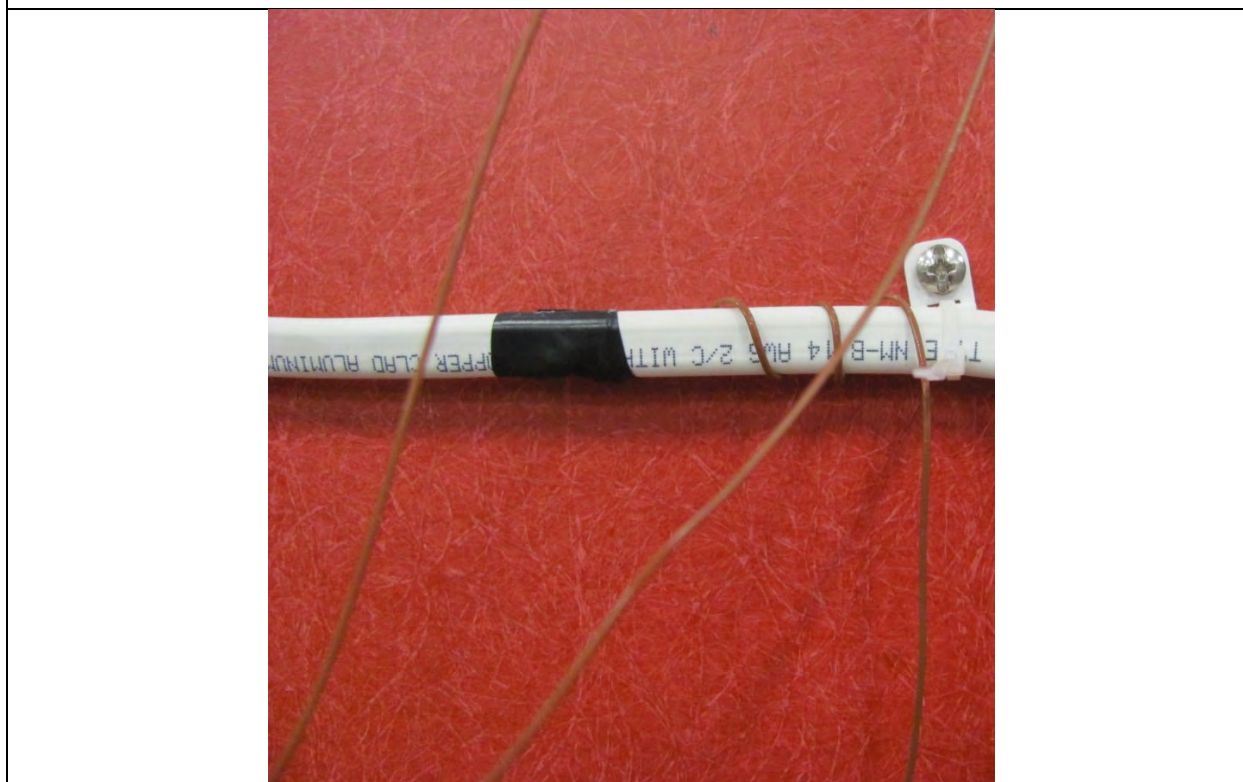


Photo 8 – Copper-Clad Aluminum NM-B Cable

Appendix A - Photos

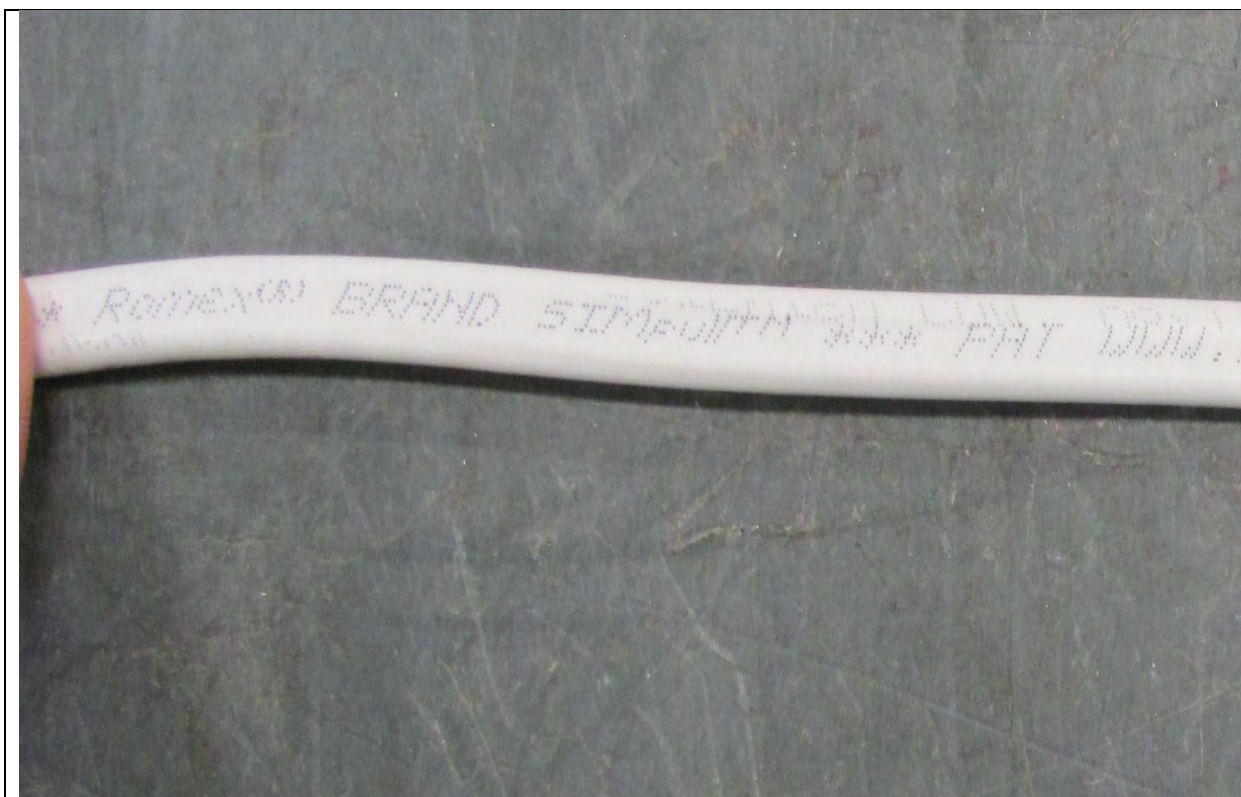


Photo 9 – Copper NM-B Cable



Photo 10 – Copper NM-B Cable Packaging

Appendix A - Photos

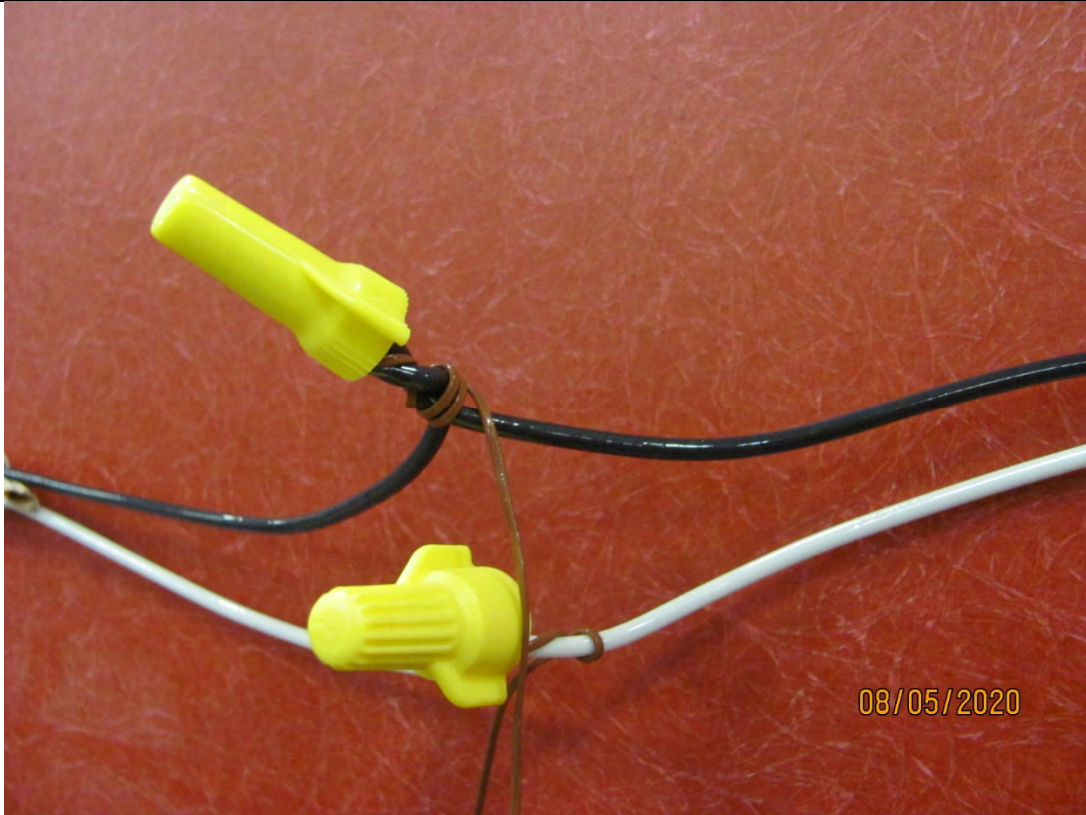


Photo 11 – Typical Installation of Wire Splicing Devices with Thermocouple



Photo 12 – Typical Installation of Receptacle using Wire Binding Screw

Appendix A - Photos

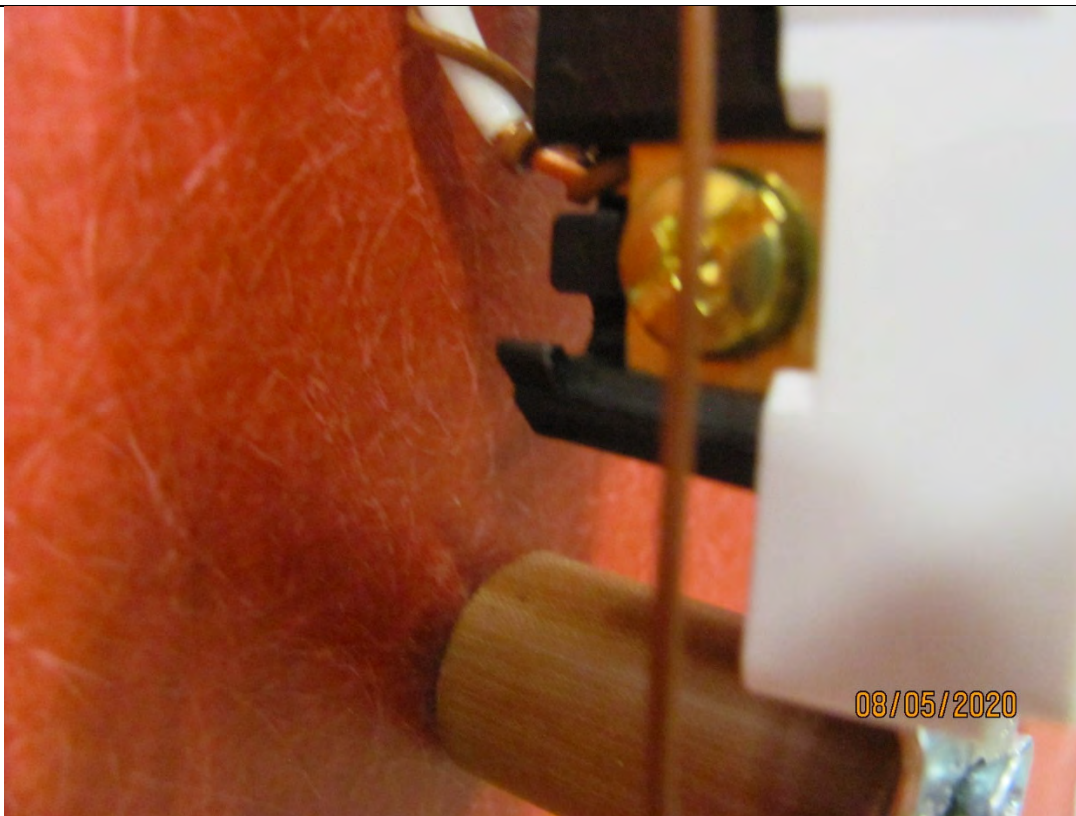


Photo 13 – Typical Installation of Receptacle Since Conductor Back Wired



Photo 14 – Typical Installation of Receptacle Two Conductors Back Wired

Appendix A - Photos

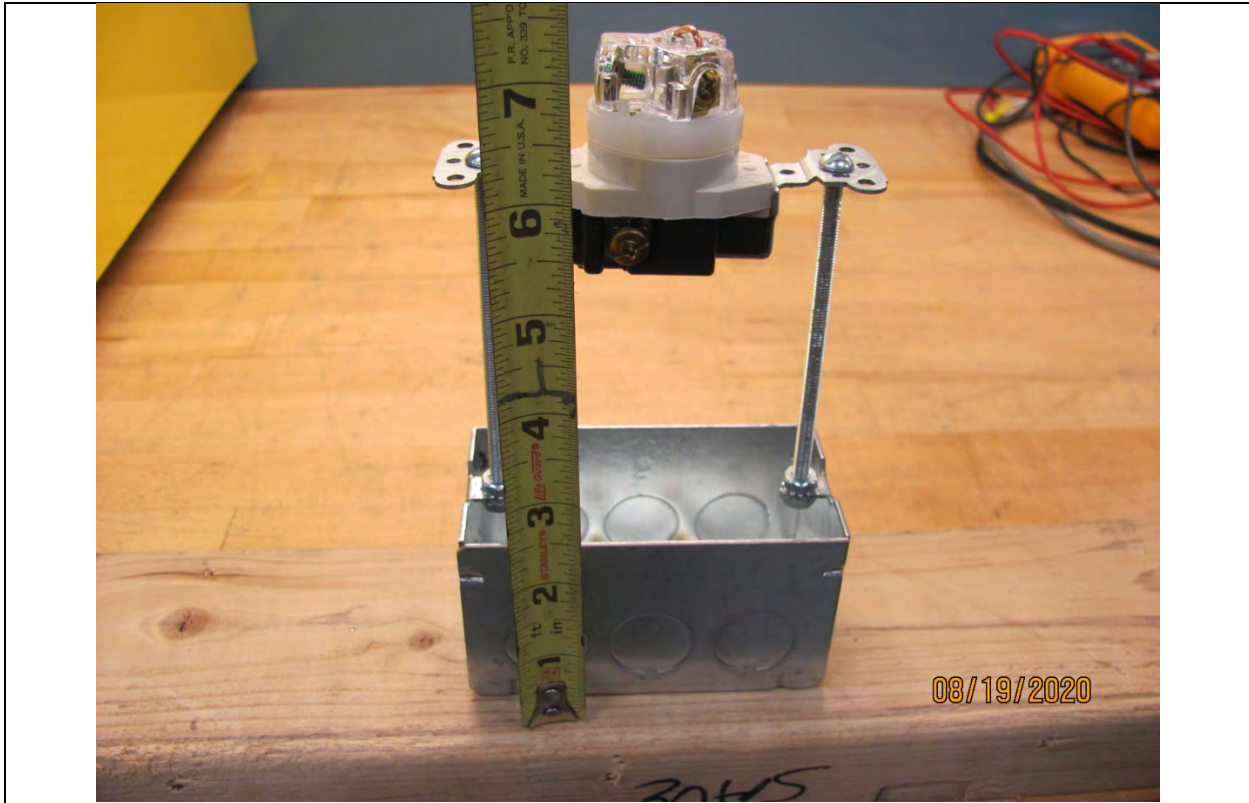


Photo 15 – Flexing Test Setup

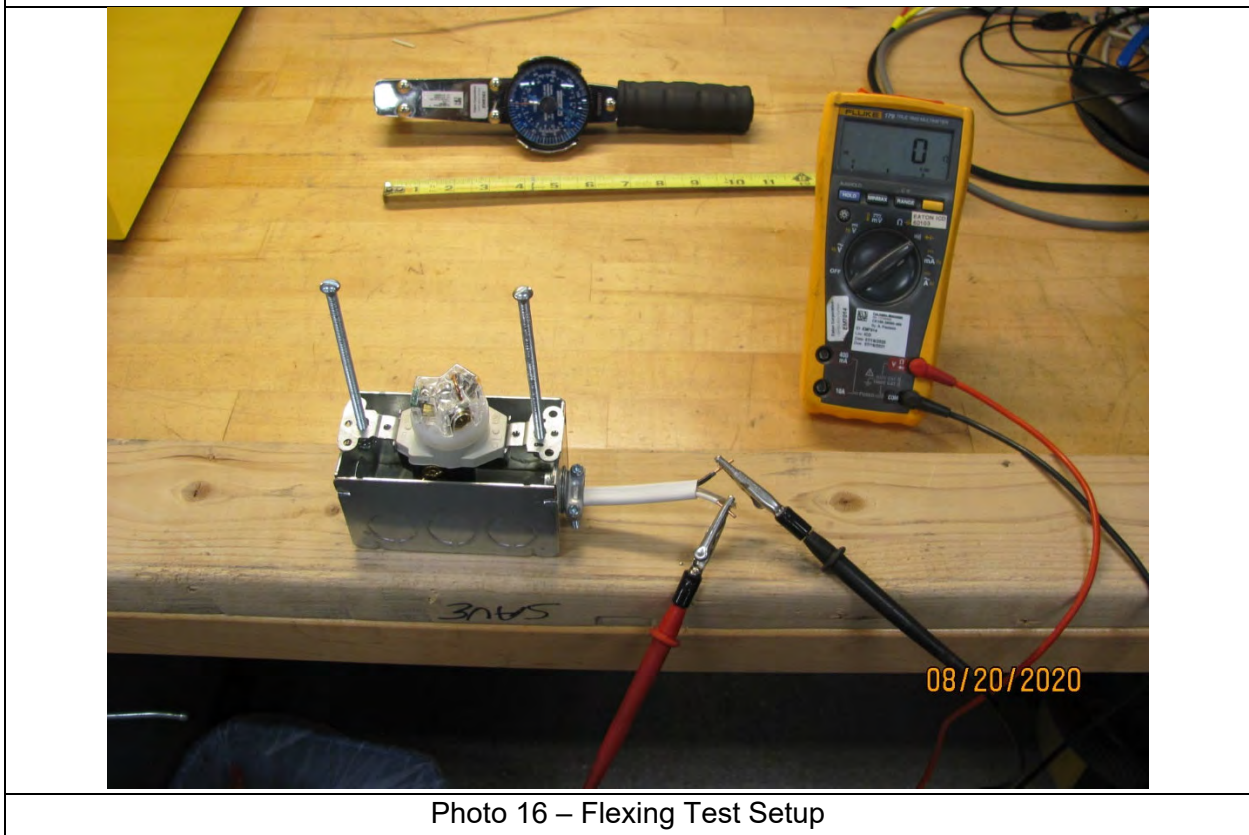


Photo 16 – Flexing Test Setup

Appendix A - Photos

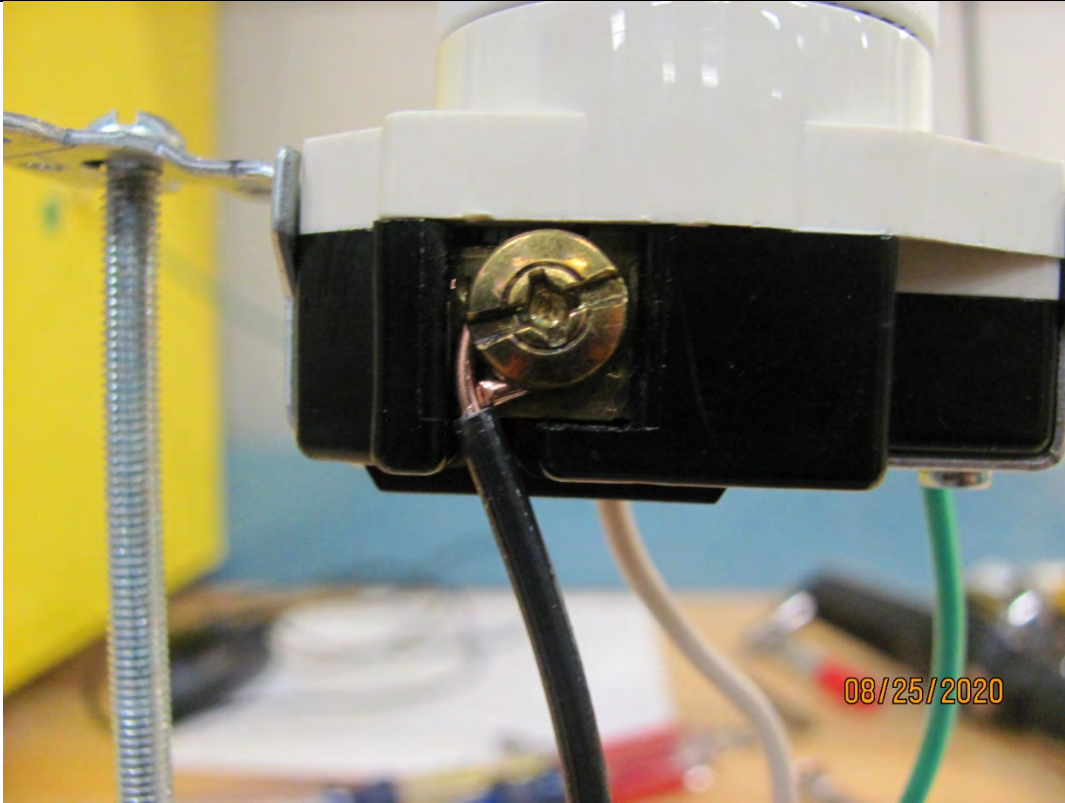


Photo 17 – Flexing Test Fully Extended

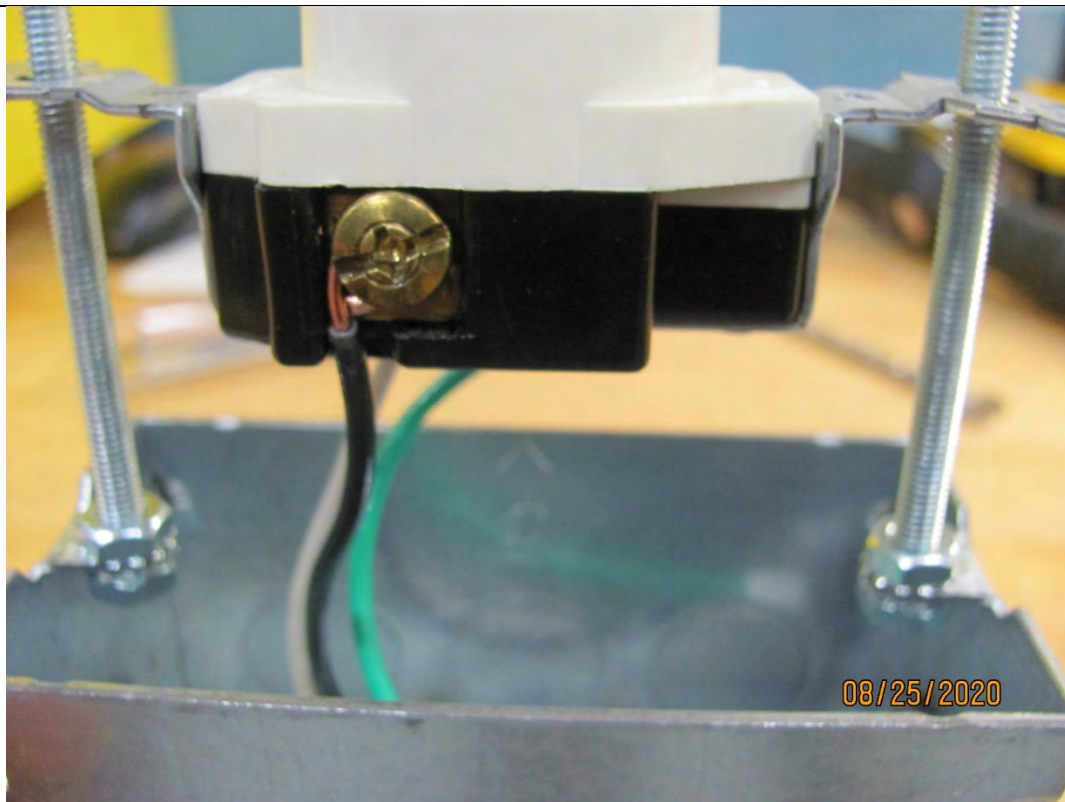


Photo 18 – Flexing Test Partial Insertion

Appendix A - Photos

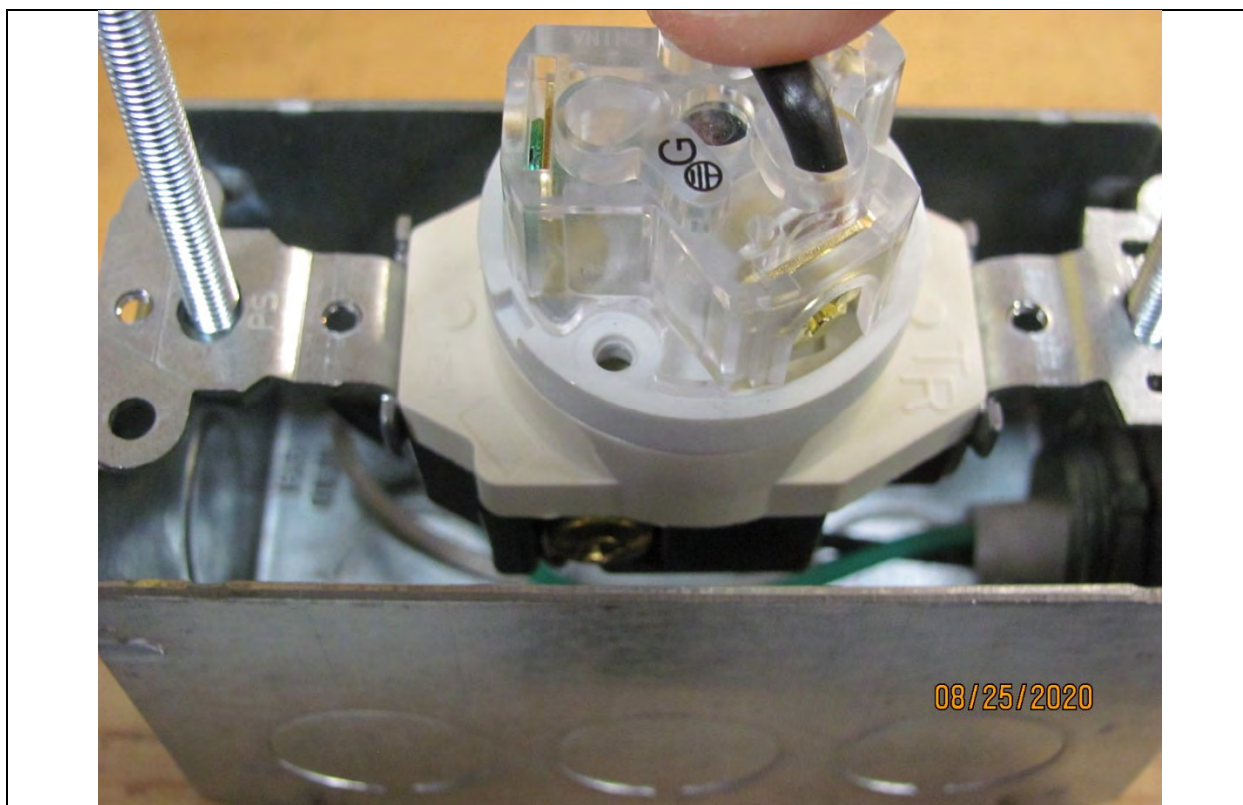


Photo 19 – Flexing Test Fully Inserted

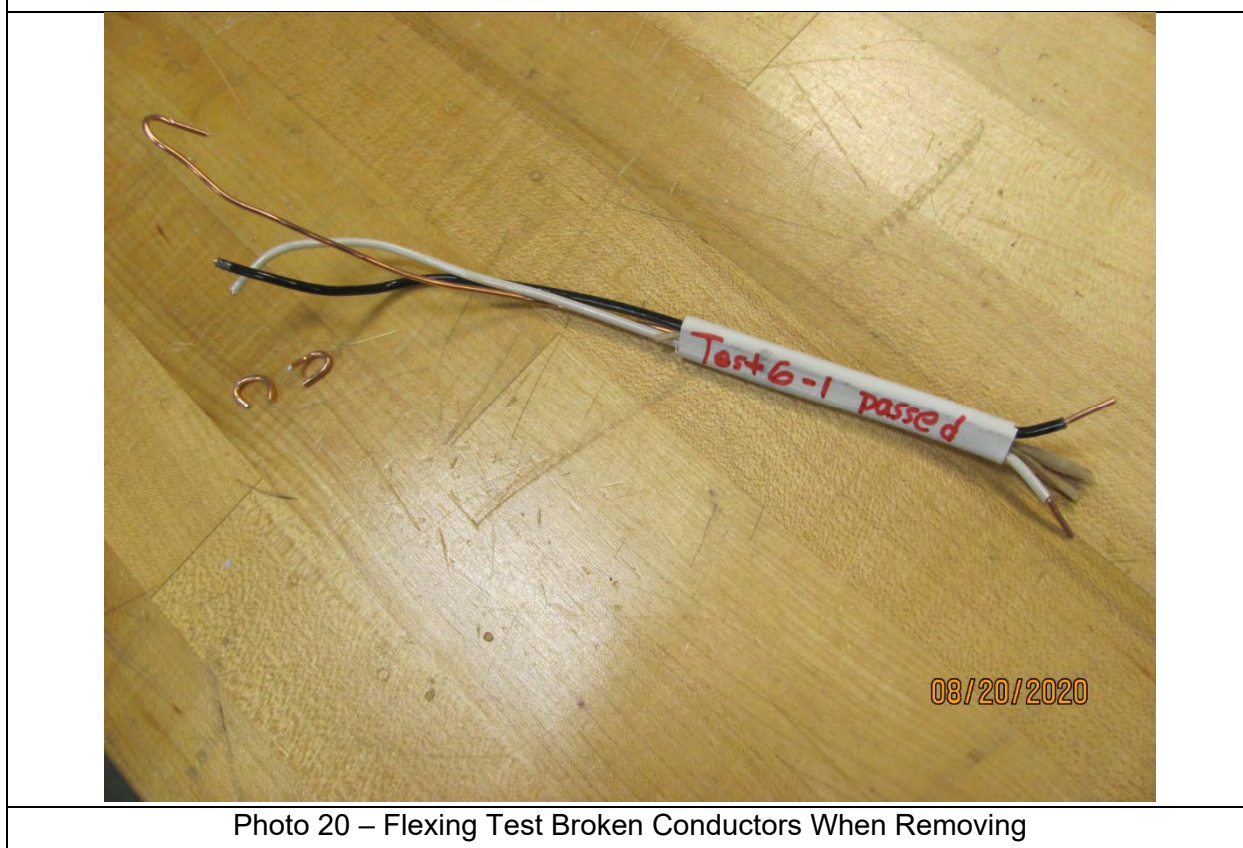


Photo 20 – Flexing Test Broken Conductors When Removing

Appendix A - Photos

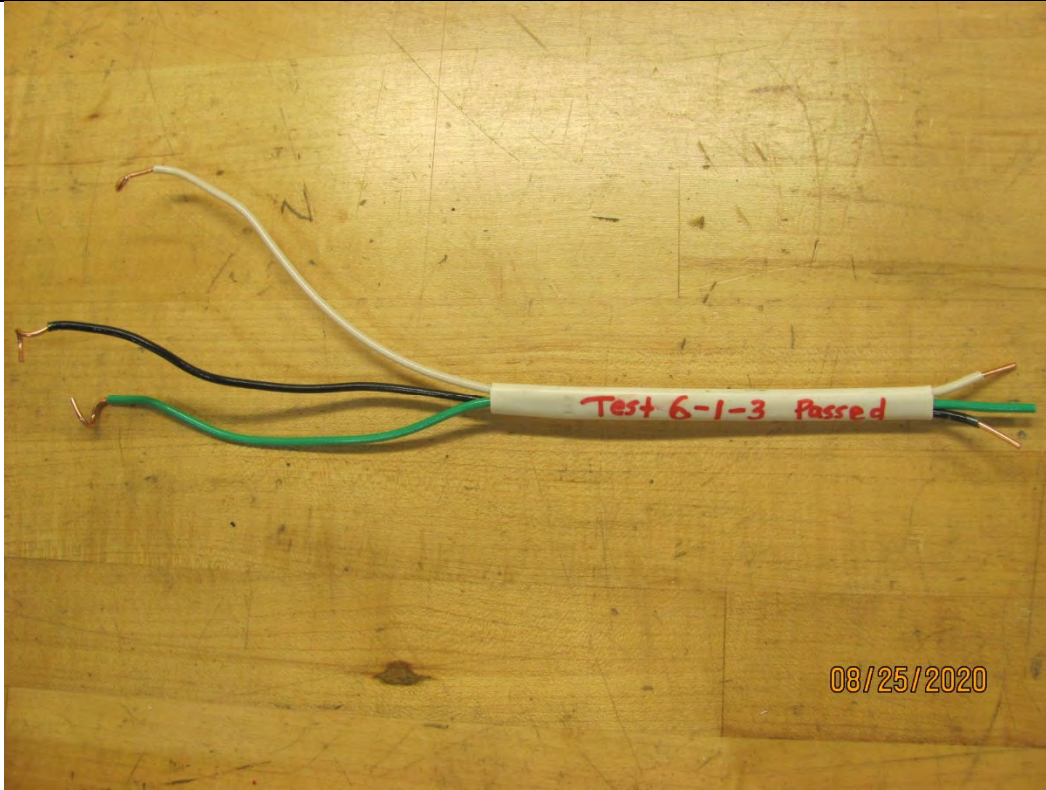


Photo 21 – Flexing Test Repeat No Conductor Breakage

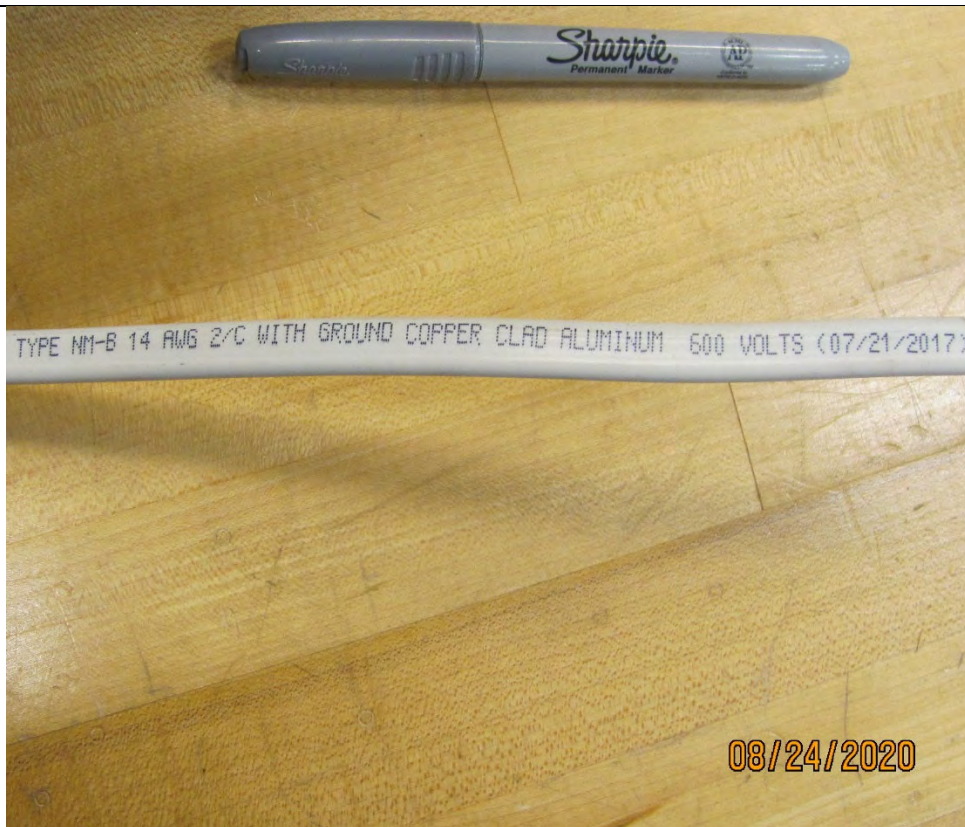


Photo 22 – Copper-Clad Aluminum NM-B Sample Packaging at Eaton

Appendix A - Photos

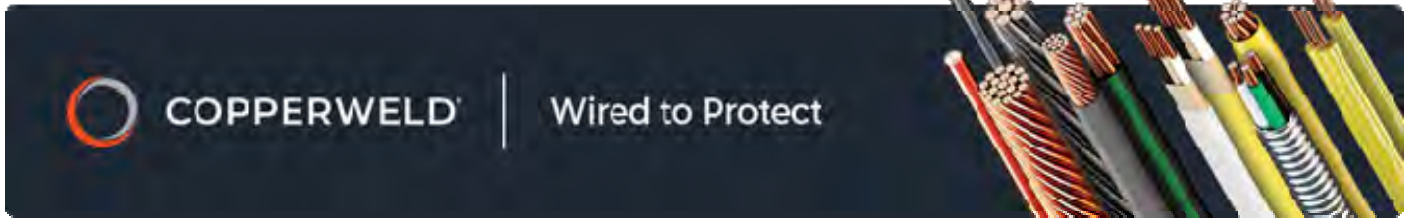


Photo 23 – Copper-Clad Aluminum THHN Sample Packaging at Eaton



Photo 24 – Copper-Clad Aluminum Sample Packaging at Eaton

Appendix B - Copper-Clad Aluminum Lab Report



The power of two

Metallurgical Laboratory Report

Customer:	NEC Bimetallics Task Group		
Subject:	14 AWG Building Wire—NMB and THHN		
Date:	8-27-2020	Report No:	456

Analysis By:	Sammy Hampton --Metallographer
Authored By:	Sammy Hampton --Metallographer
Approved By:	Bill Lewey-- QA Manager

Tested to ASTM Designation: B 566-- 04a

The NM and THHN class samples in this report were sent to Copperweld via a sealed package by Eaton Menomonee Falls test lab. The chain of custody was not broken. The testing was witnessed by a third party as part of routine auditing service. The witnessing session was recorded. The copper clad aluminum conductor material from these samples that was tested on August 27, 2020 by the Copperweld Metallurgical Lab was manufactured by Copperweld Bimetallics to ASTM B566 standards.



Package as received from Eaton

Appendix B - Copper-Clad Aluminum Lab Report



Opening the Package



Package Contents

Appendix B - Copper-Clad Aluminum Lab Report

The wire consists of a core of aluminum with a continuous outer cladding of copper metallurgically bonded to the core throughout and meets the requirements of this specification (5.1).

Test required	Test result	ASTM B 566 requirement	Result
Diameter	0.0641"	± 0.0001 0.0640" minimum 0.0642" maximum	Pass
Break load (lbs.)	55 pounds	64.4 pounds maximum	Pass
Tensile strength (psi)	17195 psi	20000 (psi) maximum	Pass
% elongation	22.78%	15.0% minimum	Pass
Copper thickness (minimum)	0.00148" = 4.6% of wire radius	minimum copper thickness= 3.5% of wire radius	Pass
Copper volume	10.05%	8% minimum 12% maximum	Pass
Adhesion test	No separation (see attached image 1)	The wire shall be repeatedly reverse bent to fracture by any convenient means. The copper clad aluminum wire shall be free from cladding delamination.	Pass
Cohesion test	No seams or splits (see attached images 2 and 3)	The copper clad aluminum wire shall be free from seams or splits	Pass

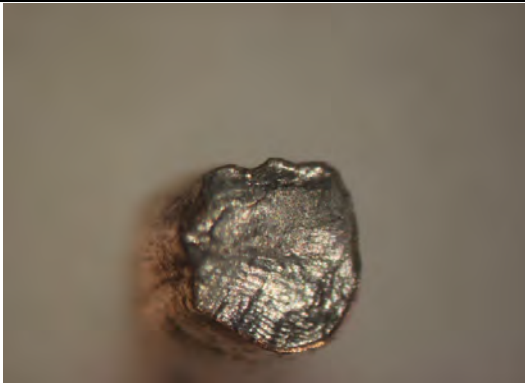


Image 1: adhesion test



Image 2: cohesion test
(torsion)



image 3: cohesion test
(reverse torsion)

Test and measurement equipment

Equipment	Gauge ID	In calibration	Next due calibration
Micrometer	CP-01	Yes	April 2021
Tensile tester	1755-2000	Yes	January 2022
Ohmmeter	62-1625	Yes	December 2020
Calibration Certificates Attached below			

Appendix B - Copper-Clad Aluminum Lab Report



PRECISION
CALIBRATION
SYSTEMS

107 N Porter St
Winchester, TN 37398
E-mail: info@pcslcm.com
Phone: 866-521-3823
Website: www.pcslcm.com

INSTRUMENT CALIBRATION REPORT



Copperweld

Instrument ID CP-01

Description Micrometer

Calibrated 8/3/2020

Performed At Customer Location

Manufacturer Mitutoyo

Model Number 293-344-30

Location Main

Building 254 Cotton Mill Rd.

Fayetteville, TN 37334

Frequency Semi-Annual

Certificate # CO080320JM-03

Serial Number 66936496

Cal Procedure QS0003JB2010

Department Quality

Status In Service

Temp 73°F

Humidity 59%

Calibration Specifications

Group # 1		Group Name OD							
Nom In Val / In Val	In Type	Std Accy	Acc %	+/-	Out Val	Out Type	End As	Lft As	In Tol
0.25000 / 0.25000	Inch	Plus / Minus	0.000000	±0.00010	0.25000	Inch	0.25000	0.25000	Yes
0.50000 / 0.50000	Inch	Plus / Minus	0.000000	±0.00010	0.50000	Inch	0.50000	0.50000	Yes
1.00000 / 1.00000	Inch	Plus / Minus	0.000000	±0.00010	1.00000	Inch	1.00000	1.00000	Yes

Test Instruments Used During the Calibration

Test Instrument ID	Description	Manufacturer	Model Number	Serial Number	(As Of Cal Entry Date)	
					Last Cal Date	Next Cal Date
Z-GA-010 GAGE	Gage Block 81pc Set Standard	China	Rectangular Steel	E1599	4/8/2016	4/30/2021
BLCK SET STD SHOP						

Notes about this calibration

Uncertainty = ± (64.9+5.2L) μin (95%CL; K=2)

Calibration Result Calibration Successful

Who Calibrated James Meadows

Finalized By James Meadows

Date Finalized 8/3/2020 9:19:05AM

Total expanded measurement uncertainties expressed are based on a confidence level of 95%, coverage factor of (k=2). Decision Rule: The statement of compliance in this certificate was issued without taking the uncertainty of measurement into consideration. The customer shall assess the results and uncertainty when determining if the results meet their needs. This is considered "shared responsibility." This calibration was conducted using standards traceable to the SI through NIST. The results on this certificate of accuracy apply only to the item described above.

Accredited to ISO/IEC 17025: 2017.

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Laboratory Authorized Signature

James Meadows

Revision Date: 05/08/2020
Rev: 04

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Appendix B - Copper-Clad Aluminum Lab Report

INSTRUMENT CALIBRATION REPORT

Copperweld

Instrument ID 1755-2000

Description Tensile Tester (2 Load cells)

Calibrated 8/4/2020

Performed At Customer Location

Manufacturer Thwing-Albert Instruments
Model Number EJA

Location Main
Building 254 Cotton Mill Rd.
Fayetteville, TN 37334

Frequency Semi-Annual
Certificate # CO080420JM-13

Serial Number 1755-2000
Cal Procedure QS0033BG2013

Department Quality
Status In Service

Temp 70°F
Humidity 57%

Calibration Specifications

Group # 1									
Group Name 0-11lb Load Cell 627022									
Nom In Val / In Val	In Type	Std Accy	Acc %	±/-	Out Val	Out Type	End As	Lft As	In Tol
1 / 1	lbf	Pct of Range	0.500000	0.00	1.00	lbf	1.01	1.01	Yes
2 / 2	lbf	Pct of Range	0.500000	0.00	2.00	lbf	2.01	2.01	Yes
3 / 3	lbf	Pct of Range	0.500000	0.00	3.00	lbf	3.01	3.01	Yes
5 / 5	lbf	Pct of Range	0.500000	0.00	5.00	lbf	5.02	5.02	Yes
7 / 7	lbf	Pct of Range	0.500000	0.00	7.00	lbf	7.03	7.03	Yes
10 / 10	lbf	Pct of Range	0.500000	0.00	10.00	lbf	10.04	10.04	Yes
Group # 2									
Group Name 0-225 lb Load cell 608236									
Nom In Val / In Val	In Type	Std Accy	Acc %	±/-	Out Val	Out Type	End As	Lft As	In Tol
5 / 5	lbf	Pct of Range	0.500000	0.00	5.00	lbf	5.00	5.00	Yes
20.446 / 20.446	lbf	Pct of Range	0.500000	0.00	20.45	lbf	20.48	20.48	Yes
50.414 / 50.414	lbf	Pct of Range	0.500000	0.00	50.41	lbf	50.48	50.48	Yes
88.532 / 88.532	lbf	Pct of Range	0.500000	0.00	88.53	lbf	88.64	88.64	Yes
99.044 / 99.044	lbf	Pct of Range	0.500000	0.00	99.04	lbf	99.15	99.15	Yes
117.60 / 117.60	lbf	Pct of Range	0.500000	0.00	117.60	lbf	117.73	117.73	Yes
131.71 / 131.71	lbf	Pct of Range	0.500000	0.00	131.71	lbf	131.83	131.83	Yes
151.04 / 151.04	lbf	Pct of Range	0.500000	0.00	151.04	lbf	151.22	151.22	Yes
161.19 / 161.19	lbf	Pct of Range	0.500000	0.00	161.19	lbf	161.38	161.38	Yes
207.76 / 207.76	lbf	Pct of Range	0.500000	0.00	207.76	lbf	207.99	207.99	Yes

Revision Date 05/08/2020
Rev: 04

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INSTRUMENT CALIBRATION REPORT

Copperweld

Instrument ID 1755-2000

Description Tensile Tester (2 Load cells)

Calibrated 8/4/2020

Performed At Customer Location

Test Instruments Used During the Calibration

Test Instrument ID	Description	Manufacturer	Model Number	Serial Number	(As Of Cal Entry Date)	
					Last Cal Date	Next Cal Date
Z-LO-005 5K LOAD CELL	Load Cell, 5000lb, Tension & Compression	Futek	LSB453	575093	1/7/2020	1/31/2022
Z-WE-003 HANGING WEIGHTS	Weight Set, 1-20lbs, Cast Iron	Rice Lake	ASTM Class 6	D7-D10 (20), D1-D4 (10), D1-D2 (2), 8MD8 (1), 8MB4 (2), 8MB5 (5)	3/26/2019	3/31/2021

Notes about this calibration

Uncertainty = ± 0.23% of Reading (95%CL; K=2)

Calibration Result Calibration Successful

Who Calibrated James Meadows

Finalized By James Meadows

Date Finalized 8/4/2020 1:12:08PM

Total expanded measurement uncertainties expressed are based on a confidence level of 95%, coverage factor of (k=2). Decision Rule: The statement of compliance in this certificate was issued without taking the uncertainty of measurement into consideration. The customer shall assess the results and uncertainty when determining if the results meet their needs. This is considered "shared responsibility." This calibration was conducted using standards traceable to the SI through NIST. The results on this certificate of accuracy apply only to the items described above. Accredited to ISO/IEC 17025:2017.

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Laboratory Authorized Signature

James Meadows

Revision Date 05/08/2020
Rev: 04

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Confidential

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9/2/2020

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Appendix B - Copper-Clad Aluminum Lab Report



PRECISION
CALIBRATION
SYSTEMS

107 N Porter St
Winchester, TN 37398
E-mail: info@pcslcm.com
Phone: 866-521-3823
Website: www.pcslcm.com

INSTRUMENT CALIBRATION REPORT



Copperweld

Instrument ID 62-1625

Description Micro Ohm Meter

Calibrated 8/4/2020

Performed At Customer Location

Manufacturer Valhalla Scientific
Model Number 4176

Location Main
Building 254 Cotton Mill Rd.
Fayetteville, TN 37334

Frequency Semi-Annual
Certificate # CO080420JM-03

Serial Number 62-1625

Cal Procedure QS0011JB2010

Department Quality
Status In Service

Temp 70°F
Humidity 57%

Calibration Specifications

Group # 1									
Group Name Ohm - Source									
Nom In Val / In Val	In Type	Std Accy	Acc %	±/-	Out Val	Out Type	End As	Lft As	In Tol
1.000 / 1.000	Ohm	Pct of Reading	0.040000	0.0000	1.0000	Ohm	0.9998	0.9998	Yes
10.000 / 10.000	Ohm	Pct of Reading	0.040000	0.000	10.000	Ohm	9.999	9.999	Yes
100.000 / 100.000	Ohm	Pct of Reading	0.040000	0.00	100.00	Ohm	99.99	99.99	Yes

Test Instruments Used During the Calibration

Test Instrument ID	Description	Manufacturer	Model Number	Serial Number	(As Of Cal Entry Date)	
					Last Cal Date	Next Cal Date
Z-EL-020 DECADE RESISTANCE BOX	General Radio Small Decade Resistance Box	General Radio	1433-U	2545	12/18/2018	12/31/2020

Notes about this calibration

Uncertainty = ± 2 mOhm (95%CL; K=2)

Calibration Result Calibration Successful

Who Calibrated James Meadows

Finalized By James Meadows

Date Finalized 8/4/2020 12:47:33PM

Total expanded measurement uncertainties expressed are based on a confidence level of 95%, coverage factor of (k=2). Decision Rule: The statement of compliance in this certificate was issued without taking the uncertainty of measurement into consideration. The customer shall assess the results and uncertainty when determining if the results meet their needs. This is considered "shared responsibility." This calibration was conducted using standards traceable to the SI through NIST. The results on this certificate of accuracy apply only to the item described above.

Accredited to ISO/IEC 17025:2017.

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Laboratory Authorized Signature *James Meadows*

Revision Date: 05/09/2020
Rev: 04

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Appendix B - Copper-Clad Aluminum Lab Report



Follow-up Service Inspection Report E4911851200827165202

INSPECTION DETAILS			
Date:	2020-08-27	File Number.:	E491185
Responsible Office:	Melville	Volume:	1
Inspection Center:	232	CCN:	DVVU2
Product Type:	CCA Conductor	UL Rep Name:	Gregory Cornett
Deliverable Type:	Recognized	UL Rep ID:	20708
Party Site Number:	1626131	Subscriber Factory No.:	
Manufacturer Name:	Copperweld Bimetallics LLC	Factory Rep Name	Mr. Sammy Hampton
Manufacturer Address:	254 Cotton Mill Rd Fayetteville, TN 37334	Factory Rep Phone:	931-433-0495
		Factory Rep Email:	shampton@copperweld.com
Nature of visit:	Regular Inspection	Sample Status:	Sample requirements fulfilled for sample period
UL Marks Used?	Yes	UL Marks Removed?	No
Variation Notice Issued?	No	Inspection Conducted Remotely?	Yes
Comments After Submission:			

PRODUCT DOCUMENTS/PRODUCTION READY VISIT			
Model	Product	Section	Multiple Listed
14 Awg Class 10A	Copper Clad Aluminum	1	No

SAMPLE DOCUMENTS			
If samples are required to be sent to UL, indicate below. If required samples are not sent, explain in the Comments area.			
No Samples			
Additional Comments	14 Awg conductors from the NMB and THHN samples passed the UL tests for DVVU2, including Tensile, Elongation, copper thickness and DC Resistance.		

In addition to the requirements specified in the applicable UL Services agreement and Follow-Up Service Procedure, UL further defines responsibilities, duties and requirements for both manufacturers and UL representatives in the document titled "UL Mark Surveillance Requirements" that can be located at www.ul.com/fus, and in accordance with the applicable terms and conditions of the document at www.ul.com/responsibilities. Manufacturers without Internet access may obtain the current versions of these documents from their local UL customer service representative or UL field representative.

Appendix C1 Static Heating Testing at 100% Rated Current

Test 1a - thru Mfg. 1 10-amp breaker at 100% current (10A * 100% = 10A); max temps, reading every 60s

data logger CH #	Location	Recorded Temperatures (°C)			Calculated Temperature Rise (°C)		
scan #		124	129	134			
time (HH:MM:SS)		1:53:00	1:58:00	2:03:00			
1a	Mfg. 11 - 1	28.70	28.86	28.73	6.47	6.63	6.50
2a	Mfg. 11 - 2	28.89	29.01	28.84	6.66	6.78	6.61
3a	Mfg. 11 - 3	27.88	28.00	27.72	5.65	5.77	5.49
4a	Mfg. 8 - 1	29.18	29.27	29.25	6.95	7.04	7.02
5a	Mfg. 8 - 2	28.99	29.11	28.99	6.76	6.88	6.76
6a	Mfg. 8 - 3	29.00	29.15	28.92	6.77	6.92	6.69
7a	circuit breaker	32.68	32.65	32.75	10.45	10.42	10.52
8a	line wire	32.25	32.29	32.43	10.02	10.06	10.20
	line wire splicing device						
9a		29.84	29.65	29.07	7.61	7.42	6.84
10a	load wire	30.67	30.92	30.94	8.44	8.69	8.71
	load wire splicing device						
11a		30.11	29.88	29.27	7.88	7.65	7.04
12a	room ambient	22.39	22.44	21.87			
13a	current (amps)	10.03	10.03	10.03			

Test 1a - thru Mfg. 1 15-amp breaker at 100% current (15A * 100% = 15A); max temps, reading every 60s

data logger CH #	Location	Recorded Temperatures (°C)			Calculated Temperature Rise (°C)		
scan #		80	85	90			
time (HH:MM:SS)		1:17:00	1:22:00	1:27:00			
1a	Mfg. 11 - 1	33.06	33.61	33.40	11.02	11.58	11.36
2a	Mfg. 11 - 2	33.64	33.95	33.94	11.60	11.91	11.90
3a	Mfg. 11 - 3	31.05	31.56	31.60	9.01	9.52	9.56
4a	Mfg. 8 - 1	34.10	34.15	34.23	12.06	12.11	12.19
5a	Mfg. 8 - 2	33.60	34.20	33.86	11.56	12.16	11.82
6a	Mfg. 8 - 3	32.94	33.68	33.29	10.91	11.64	11.25
7a	circuit breaker	40.86	40.44	40.64	18.82	18.41	18.60
8a	line wire	33.93	34.21	33.87	11.89	12.17	11.83
	line wire splicing device						
9a		36.89	37.11	36.82	14.85	15.07	14.78
10a	load wire	32.70	33.48	32.99	10.66	11.44	10.95
	load wire splicing device						
11a		32.72	33.49	32.70	10.68	11.45	10.66
12a	room ambient	21.84	22.27	22.01			
13a	current (amps)	15.02	15.01	15.02			

Appendix C1 Static Heating Testing at 100% Rated Current

Test 1b - thru Mfg. 2 10-amp breaker at 100% current (10A * 100% = 10A); max temps, reading every 60s

data logger CH #	Location	Recorded Temperatures (°C)			Calculated Temperature Rise (°C)		
scan #		124	129	134			
time (HH:MM:SS)		1:53:00	1:58:00	2:03:00			
1b	Mfg. 11 - 1	28.57	28.60	28.36	6.49	6.52	6.27
2b	Mfg. 11 - 2	28.65	28.68	28.48	6.57	6.60	6.40
3b	Mfg. 11 - 3	27.37	27.39	27.10	5.28	5.31	5.02
4b	Mfg. 8 - 1	29.14	29.23	29.15	7.05	7.15	7.07
5b	Mfg. 8 - 2	30.65	30.75	30.48	8.57	8.66	8.40
6b	Mfg. 8 - 3	28.04	28.10	27.73	5.96	6.02	5.64
7b	circuit breaker	36.63	36.79	37.20	14.55	14.70	15.12
8b	line wire	30.98	31.03	30.93	8.90	8.95	8.85
	line wire splicing device						
9b		28.97	28.69	28.06	6.89	6.61	5.98
10b	load wire	28.60	28.55	28.00	6.52	6.47	5.92
	load wire splicing device						
11b		28.64	28.49	27.92	6.56	6.41	5.84
12b	room ambient	22.35	22.28	21.62			
13b	current (amps)	10.00	10.00	10.00			

Test 1b - thru Mfg. 2 15-amp breaker at 100% current (15A * 100% = 15A); max temps, reading every 60s

data logger CH #	Location	Recorded Temperatures (°C)			Calculated Temperature Rise (°C)		
scan #		80	85	90			
time (HH:MM:SS)		1:17:00	1:22:00	1:27:00			
1b	Mfg. 11 - 1	33.38	33.85	33.55	11.43	11.89	11.59
2b	Mfg. 11 - 2	33.29	33.49	33.67	11.34	11.54	11.72
3b	Mfg. 11 - 3	30.94	31.47	31.45	8.99	9.52	9.49
4b	Mfg. 8 - 1	34.03	34.28	34.44	12.07	12.32	12.48
5b	Mfg. 8 - 2	33.61	34.03	33.75	11.66	12.08	11.80
6b	Mfg. 8 - 3	33.00	33.71	33.25	11.05	11.75	11.29
7b	circuit breaker	44.97	44.86	45.02	23.02	22.91	23.06
8b	line wire	33.21	33.70	33.32	11.25	11.74	11.37
	line wire splicing device						
9b		30.81	31.77	30.80	8.86	9.82	8.85
10b	load wire	32.53	33.49	32.83	10.58	11.54	10.88
	load wire splicing device						
11b		31.51	32.52	31.43	9.56	10.56	9.47
12b	room ambient	21.76	22.22	21.88			
13b	current (amps)	15.01	15.01	15.01			

Appendix C1 Static Heating Testing at 100% Rated Current

Test 1c - thru Mfg. 3 10-amp breaker at 100% current (10A * 100% = 10A); max temps, reading every 60s

data logger CH #	Location	Recorded Temperatures (°C)			Calculated Temperature Rise (°C)		
scan #		124	129	134			
time (HH:MM:SS)		1:53:00	1:58:00	2:03:00			
1c	Mfg. 11 - 1	29.46	29.56	29.18	7.40	7.50	7.12
2c	Mfg. 11 - 2	28.97	29.12	28.68	6.91	7.06	6.62
3c	Mfg. 11 - 3	27.82	28.02	27.47	5.76	5.96	5.41
4c	Mfg. 8 - 1	29.30	29.40	29.33	7.24	7.34	7.27
5c	Mfg. 8 - 2	28.68	28.72	28.43	6.62	6.66	6.37
6c	Mfg. 8 - 3	28.19	28.27	27.81	6.13	6.21	5.75
7c	circuit breaker	35.04	35.28	35.13	12.98	13.22	13.07
8c	line wire	31.23	31.27	30.87	9.17	9.21	8.81
	line wire splicing device						
9c		28.59	28.61	27.53	6.53	6.55	5.47
10c	load wire	30.74	30.84	30.26	8.68	8.78	8.20
	load wire splicing device						
11c		29.74	29.67	28.50	7.68	7.61	6.44
12c	room ambient	22.29	22.23	21.67			
13c	current (amps)	10.01	10.01	10.01			

Test 1c - thru Mfg. 3 15-amp breaker at 100% current (15A * 100% = 15A); max temps, reading every 60s

data logger CH #	Location	Recorded Temperatures (°C)			Calculated Temperature Rise (°C)		
scan #		80	85	90			
time (HH:MM:SS)		1:17:00	1:22:00	1:27:00			
1c	Mfg. 11 - 1	32.95	33.38	33.25	11.06	11.48	11.36
2c	Mfg. 11 - 2	33.50	33.89	33.73	11.61	12.00	11.84
3c	Mfg. 11 - 3	32.27	32.60	32.50	10.38	10.71	10.61
4c	Mfg. 8 - 1	33.33	33.66	33.62	11.44	11.77	11.72
5c	Mfg. 8 - 2	33.87	34.28	34.11	11.98	12.39	12.21
6c	Mfg. 8 - 3	32.50	32.88	32.80	10.61	10.99	10.91
7c	circuit breaker	42.51	42.65	42.50	20.62	20.75	20.60
8c	line wire	31.74	32.44	32.16	9.84	10.54	10.27
	line wire splicing device						
9c		32.46	33.55	32.53	10.57	11.66	10.64
10c	load wire	32.23	33.29	32.70	10.34	11.40	10.81
	load wire splicing device						
11c		29.96	31.50	30.18	8.07	9.61	8.29
12c	room ambient	21.65	22.13	21.90			
13c	current (amps)	15.02	15.02	15.02			

Appendix C1 Static Heating Testing at 100% Rated Current

Test 1a - thru Mfg. 1 10-amp breaker at 100% current (10A * 100% = 10A); max temps, reading every 60s

data logger CH #	Location	Recorded Temperatures (°C)			Calculated Temperature Rise (°C)		
scan #		67	72	77			
time (HH:MM:SS)		1:04:00	1:09:00	1:14:00			
1a	Mfg. 10 - 1	33.35	33.09	33.35	11.17	10.90	11.17
2a	Mfg. 10 - 2	29.93	29.88	29.88	7.75	7.70	7.70
3a	Mfg. 10 - 3	28.83	28.80	28.74	6.65	6.62	6.56
4a	Mfg. 9 - 1	28.96	28.89	28.94	6.78	6.71	6.76
5a	Mfg. 9 - 2	29.33	29.07	29.09	7.15	6.89	6.91
6a	Mfg. 9 - 3	28.20	28.02	27.93	6.01	5.84	5.75
7a	circuit breaker	32.75	32.55	32.65	10.57	10.37	10.47
8a	line wire	32.76	32.27	32.44	10.58	10.09	10.26
9a	line wire splicing device	29.85	29.45	29.15	7.67	7.27	6.97
10a	load wire	31.09	30.73	31.01	8.91	8.55	8.83
11a	load wire splicing device	30.90	30.16	30.15	8.72	7.98	7.97
12a	room ambient	22.53	22.20	21.82			
13a	current (amps)	10.02	10.02	10.02			

Test 1a - thru Mfg. 1 15-amp breaker at 100% current (15A * 100% = 15A); max temps, reading every 60s

data logger CH #	Location	Recorded Temperatures (°C)			Calculated Temperature Rise (°C)		
scan #		122	127	132			
time (HH:MM:SS)		2:00:00	2:05:00	2:10:00			
1a	Mfg. 10 - 1	38.41	38.10	38.31	17.09	16.78	16.99
2a	Mfg. 10 - 2	39.48	39.23	39.28	18.16	17.91	17.96
3a	Mfg. 10 - 3	34.47	34.18	34.12	13.15	12.87	12.80
4a	Mfg. 9 - 1	37.47	37.35	37.38	16.16	16.03	16.06
5a	Mfg. 9 - 2	38.46	38.17	38.12	17.14	16.85	16.80
6a	Mfg. 9 - 3	31.54	31.29	31.18	10.22	9.97	9.86
7a	circuit breaker	40.70	40.66	40.65	19.38	19.34	19.33
8a	line wire	34.07	34.00	34.12	12.75	12.69	12.80
9a	line wire splicing device	35.66	35.31	35.13	14.34	13.99	13.81
10a	load wire	32.81	32.43	32.75	11.49	11.11	11.43
11a	load wire splicing device	33.16	32.96	32.94	11.84	11.64	11.62
12a	room ambient	21.37	21.31	21.27			
13a	current (amps)	15.02	15.02	15.02			

Appendix C1 Static Heating Testing at 100% Rated Current

Test 1b - thru Mfg. 2 10-amp breaker at 100% current (10A * 100% = 10A); max temps, reading every 60s

data logger CH #	Location	Recorded Temperatures (°C)			Calculated Temperature Rise (°C)		
scan #		129	134	139			
time (HH:MM:SS)		2:06:07	2:11:06	2:16:07			
1b	Mfg. 10 - 1	31.13	31.54	31.37	9.64	10.05	9.88
2b	Mfg. 10 - 2	30.12	30.39	30.44	8.63	8.90	8.95
3b	Mfg. 10 - 3	28.95	29.13	29.19	7.46	7.64	7.70
4b	Mfg. 9 - 1	28.47	28.67	28.85	6.98	7.18	7.36
5b	Mfg. 9 - 2	28.62	29.01	28.85	7.13	7.52	7.36
6b	Mfg. 9 - 3	29.94	30.21	30.11	8.45	8.72	8.62
7b	circuit breaker	41.81	41.46	41.80	20.32	19.97	20.31
8b	line wire	31.66	31.83	32.15	10.17	10.34	10.66
	line wire splicing device						
9b		29.57	30.02	30.13	8.08	8.53	8.64
10b	load wire	28.92	29.64	29.57	7.43	8.15	8.08
	load wire splicing device						
11b		30.62	31.06	31.03	9.13	9.57	9.54
12b	room ambient	21.30	21.89	21.28			
13b	current (amps)	10.01	10.01	10.01			

Test 1b - thru Mfg. 2 15-amp breaker at 100% current (15A * 100% = 15A); max temps, reading every 60s

data logger CH #	Location	Recorded Temperatures (°C)			Calculated Temperature Rise (°C)		
scan #		122	127	132			
time (HH:MM:SS)		2:00:00	2:05:00	2:10:00			
1b	Mfg. 10 - 1	39.02	38.87	38.81	17.86	17.72	17.65
2b	Mfg. 10 - 2	38.54	38.42	38.37	17.38	17.26	17.22
3b	Mfg. 10 - 3	35.00	34.94	34.56	13.84	13.78	13.40
4b	Mfg. 9 - 1	34.32	34.17	34.19	13.16	13.01	13.03
5b	Mfg. 9 - 2	33.68	33.52	33.44	12.52	12.36	12.29
6b	Mfg. 9 - 3	32.62	32.41	32.27	11.46	11.25	11.11
7b	circuit breaker	44.60	44.48	44.38	23.44	23.32	23.22
8b	line wire	33.27	33.12	33.14	12.11	11.96	11.98
	line wire splicing device						
9b		31.50	31.19	31.26	10.34	10.03	10.10
10b	load wire	31.96	31.65	31.72	10.81	10.49	10.56
	load wire splicing device						
11b		30.27	29.89	29.93	9.12	8.73	8.78
12b	room ambient	21.26	21.14	21.08			
13b	current (amps)	15.01	15.01	15.01			

Appendix C1 Static Heating Testing at 100% Rated Current

Test 1c - thru Mfg. 3 10-amp breaker at 100% current (10A * 100% = 10A); max temps, reading every 60s

data logger CH #	Location	Recorded Temperatures (°C)			Calculated Temperature Rise (°C)		
scan #		67	72	77			
time (HH:MM:SS)		1:04:00	1:09:00	1:14:00			
1c	Mfg. 10 - 1	31.05	30.92	30.45	9.04	8.91	8.44
2c	Mfg. 10 - 2	32.97	32.85	32.26	10.96	10.84	10.25
3c	Mfg. 10 - 3	29.07	28.94	28.28	7.06	6.93	6.27
4c	Mfg. 9 - 1	29.52	29.28	29.21	7.51	7.27	7.20
5c	Mfg. 9 - 2	30.06	29.90	29.40	8.05	7.89	7.39
6c	Mfg. 9 - 3	28.41	28.41	27.55	6.40	6.40	5.54
7c	circuit breaker	34.97	34.66	34.67	12.96	12.65	12.66
8c	line wire	31.77	31.18	30.88	9.76	9.17	8.87
9c	line wire splicing device	28.89	28.20	27.63	6.88	6.19	5.62
10c	load wire	31.27	30.69	30.26	9.26	8.68	8.25
11c	load wire splicing device	31.39	30.47	29.53	9.38	8.46	7.52
12c	room ambient	22.35	21.99	21.69			
13c	current (amps)	10.01	10.01	10.01			

Test 1c - thru Mfg. 3 15-amp breaker at 100% current (15A * 100% = 15A); max temps, reading every 60s

data logger CH #	Location	Recorded Temperatures (°C)			Calculated Temperature Rise (°C)		
scan #		122	127	132			
time (HH:MM:SS)		2:00:00	2:05:00	2:10:00			
1c	Mfg. 10 - 1	36.19	35.94	35.85	15.02	14.77	14.68
2c	Mfg. 10 - 2	39.95	39.76	39.70	18.78	18.59	18.53
3c	Mfg. 10 - 3	39.01	39.15	38.69	17.85	17.98	17.52
4c	Mfg. 9 - 1	33.32	33.13	33.09	12.15	11.96	11.92
5c	Mfg. 9 - 2	34.01	33.90	33.74	12.84	12.74	12.57
6c	Mfg. 9 - 3	32.95	32.95	32.64	11.78	11.78	11.47
7c	circuit breaker	41.75	41.55	41.58	20.59	20.38	20.41
8c	line wire	30.73	30.68	30.61	9.56	9.51	9.44
9c	line wire splicing device	32.20	31.82	31.87	11.04	10.65	10.70
10c	load wire	31.34	31.12	31.14	10.17	9.95	9.97
11c	load wire splicing device	29.64	29.52	29.42	8.47	8.35	8.25
12c	room ambient	21.29	21.13	21.09			
13c	current (amps)	15.01	15.01	15.01			

Appendix C2 Static Heating Tests at 135% Rated Current

Test 2a - thru Mfg. 1 10-amp breaker at 135% current ($10A * 135\% = 13.5A$); max temps, reading every 20s

data logger CH #	Location	Recorded Temperatures (°C)			Calculated Temperature Rise (°C)		
scan #							
time (MM:SS)		7:20	7:40	8:00			
	Breaker trip time	8:20					
1a	Mfg. 11 - 1	30.60	30.69	30.76	8.65	8.73	8.80
2a	Mfg. 11 - 2	30.73	30.83	30.87	8.78	8.88	8.92
3a	Mfg. 11 - 3	29.72	29.82	29.85	7.76	7.87	7.89
4a	Mfg. 8 - 1	30.66	30.77	30.88	8.70	8.81	8.93
5a	Mfg. 8 - 2	30.87	30.96	31.05	8.91	9.01	9.09
6a	Mfg. 8 - 3	30.39	30.50	30.55	8.43	8.54	8.59
7a	circuit breaker	34.21	34.43	34.65	12.26	12.47	12.70
8a	line wire	38.55	38.70	38.80	16.59	16.74	16.85
9a	line wire splicing device	34.64	34.68	34.50	12.68	12.72	12.55
10a	load wire	36.44	36.44	36.36	14.49	14.48	14.40
11a	load wire splicing device	35.04	35.05	34.84	13.09	13.09	12.88
12a	room ambient	22.00	21.97	21.91			
13a	current (amps)	13.52	13.52	13.52			

Test 2a - thru Mfg. 1 15-amp breaker at 135% current ($15A * 135\% = 20.25A$); max temps, reading every 20s

data logger CH #	Location	Recorded Temperatures (°C)			Calculated Temperature Rise (°C)		
scan #		60	61	62			
time (MM:SS)		18:20	18:40	19:00			
	Breaker trip time	19:20					
1a	Mfg. 11 - 1	39.87	39.91	39.90	18.05	18.09	18.08
2a	Mfg. 11 - 2	40.66	40.69	40.70	18.84	18.87	18.88
3a	Mfg. 11 - 3	36.77	36.77	36.76	14.95	14.95	14.94
4a	Mfg. 8 - 1	40.83	40.88	40.89	19.01	19.06	19.07
5a	Mfg. 8 - 2	40.41	40.45	40.47	18.59	18.63	18.65
6a	Mfg. 8 - 3	39.06	39.09	39.15	17.24	17.27	17.33
7a	circuit breaker	51.78	51.96	52.02	29.96	30.14	30.20
8a	line wire	43.47	43.51	43.49	21.65	21.69	21.67
9a	line wire splicing device	48.83	48.80	48.22	27.02	26.99	26.40
10a	load wire	41.01	41.02	41.12	19.19	19.20	19.30
11a	load wire splicing device	42.69	42.60	42.48	20.87	20.78	20.66
12a	room ambient	21.84	21.84	21.78			
13a	current (amps)	19.97	19.97	20.24			

Appendix C2 Static Heating Tests at 135% Rated Current

Test 2b - thru Mfg. 2 10-amp breaker at 135% current ($10A * 135\% = 13.5A$); max temps, reading every 20s

data logger CH #	Location	Recorded Temperatures (°C)			Calculated Temperature Rise (°C)	
scan #		16	17	18		
time (MM:SS)		4:20	4:40	5:00		
	Breaker trip time	5:20				
1b	Mfg. 11 - 1	29.25	29.41	29.55	6.91	7.21
2b	Mfg. 11 - 2	28.86	29.03	29.22	6.52	6.88
3b	Mfg. 11 - 3	28.34	28.44	28.54	6.00	6.20
4b	Mfg. 8 - 1	29.37	29.59	29.79	7.03	7.45
5b	Mfg. 8 - 2	30.27	30.43	30.67	7.93	8.33
6b	Mfg. 8 - 3	28.84	28.97	29.10	6.50	6.76
7b	circuit breaker	34.99	35.63	36.29	12.65	13.95
8b	line wire	34.20	34.58	34.92	11.86	12.58
9b	line wire splicing device	33.21	33.11	33.12	10.87	10.77
10b	load wire	30.95	31.14	31.38	8.61	9.04
11b	load wire splicing device	32.76	32.73	32.78	10.42	10.44
12b	room ambient	22.40	22.34	22.29		
13b	current (amps)	13.51	13.51	13.51		

Test 2b - thru Mfg. 2 15-amp breaker at 135% current ($15A * 135\% = 20.25A$); max temps, reading every 20s

data logger CH #	Location	Recorded Temperatures (°C)			Calculated Temperature Rise (°C)	
scan #		13	14	15		
time (MM:SS)		2:20	2:40	3:00		
	Breaker trip time	3:20				
1b	Mfg. 11 - 1	31.85	32.56	33.17	9.91	11.23
2b	Mfg. 11 - 2	31.27	32.00	32.64	9.33	10.70
3b	Mfg. 11 - 3	30.01	30.61	31.08	8.07	9.14
4b	Mfg. 8 - 1	31.78	32.43	33.07	9.84	11.13
5b	Mfg. 8 - 2	32.35	32.97	33.48	10.41	11.54
6b	Mfg. 8 - 3	31.74	32.37	32.83	9.80	10.89
7b	circuit breaker	36.50	38.10	39.50	14.56	17.56
8b	line wire	32.89	33.90	34.83	10.95	12.89
9b	line wire splicing device	34.98	35.61	36.11	13.04	14.17
10b	load wire	33.90	34.76	35.58	11.96	13.64
11b	load wire splicing device	35.84	36.48	37.04	13.90	15.10
12b	room ambient	21.94	21.93	21.96		
13b	current (amps)	20.28	20.27	20.27		

Appendix C2 Static Heating Tests at 135% Rated Current

Test 2c - thru Mfg. 3 10-amp breaker at 135% current ($10A * 135\% = 13.5A$); max temps, reading every 20s

data logger CH #	Location	Recorded Temperatures (°C)			Calculated Temperature Rise (°C)		
scan #		59	60	61			
time (MM:SS)		18:40	19:00	19:20			
	Breaker trip time	19:40					
1c	Mfg. 11 - 1	34.08	34.15	34.18	11.70	11.78	11.81
2c	Mfg. 11 - 2	33.23	33.27	33.31	10.85	10.89	10.93
3c	Mfg. 11 - 3	31.22	31.25	31.28	8.85	8.87	8.90
4c	Mfg. 8 - 1	33.48	33.50	33.56	11.10	11.13	11.19
5c	Mfg. 8 - 2	32.68	32.75	32.80	10.31	10.37	10.42
6c	Mfg. 8 - 3	31.96	32.03	32.09	9.58	9.66	9.71
7c	circuit breaker	43.05	43.08	43.19	20.67	20.71	20.81
8c	line wire	38.04	38.09	38.14	15.67	15.72	15.76
9c	line wire splicing device	33.55	33.75	33.89	11.17	11.38	11.51
10c	load wire	37.55	37.62	37.70	15.17	15.24	15.33
11c	load wire splicing device	35.83	36.09	36.28	13.46	13.71	13.91
12c	room ambient	22.51	22.28	22.34			
13c	current (amps)	13.51	13.51	13.51			

Test 2c - thru Mfg. 3 15-amp breaker at 135% current ($15A * 135\% = 20.25A$); max temps, reading every 20s

data logger CH #	Location	Recorded Temperatures (°C)			Calculated Temperature Rise (°C)		
scan #		20	21	22			
time (MM:SS)		5:00	5:20	5:40			
	Breaker trip time	6:00					
1c	Mfg. 11 - 1	34.62	34.96	35.21	12.63	12.97	13.22
2c	Mfg. 11 - 2	35.65	35.96	36.17	13.65	13.97	14.18
3c	Mfg. 11 - 3	33.85	34.05	34.25	11.85	12.05	12.25
4c	Mfg. 8 - 1	34.94	35.23	35.47	12.95	13.24	13.48
5c	Mfg. 8 - 2	35.87	36.13	36.37	13.87	14.13	14.38
6c	Mfg. 8 - 3	34.38	34.60	34.74	12.38	12.61	12.75
7c	circuit breaker	42.69	43.47	44.15	20.69	21.47	22.16
8c	line wire	36.07	36.49	36.77	14.08	14.50	14.78
9c	line wire splicing device	38.93	39.23	39.49	16.94	17.24	17.49
10c	load wire	37.64	37.92	38.15	15.64	15.92	16.16
11c	load wire splicing device	35.65	35.84	35.95	13.66	13.85	13.96
12c	room ambient	21.95	22.09	21.93			
13c	current (amps)	20.19	20.19	20.17			

Appendix C2 Static Heating Tests at 135% Rated Current

Test 2a - thru Mfg. 1 10-amp breaker at 135% current (10A * 135% = 13.5A); max temps, reading every 20s

data logger CH #	Location	Recorded Temperatures (°C)			Calculated Temperature Rise (°C)		
scan #		26	27	28			
time (MM:SS)		7:40	8:00	8:20			
	Breaker trip time	8:40					
1a	Mfg. 10 - 1	33.38	33.55	33.72	11.54	11.72	11.89
2a	Mfg. 10 - 2	32.41	32.50	32.60	10.58	10.67	10.77
3a	Mfg. 10 - 3	30.50	30.58	30.68	8.66	8.75	8.85
4a	Mfg. 9 - 1	30.51	30.62	30.74	8.67	8.79	8.91
5a	Mfg. 9 - 2	30.63	30.73	30.86	8.80	8.89	9.02
6a	Mfg. 9 - 3	29.45	29.52	29.63	7.62	7.69	7.79
7a	circuit breaker	34.35	34.60	34.84	12.51	12.77	13.00
8a	line wire	38.69	38.85	39.02	16.85	17.01	17.18
9a	line wire splicing device	34.03	34.11	34.24	12.19	12.27	12.40
10a	load wire	36.42	36.48	36.58	14.59	14.65	14.74
11a	load wire splicing device	36.28	36.41	36.59	14.45	14.58	14.76
12a	room ambient	21.84	21.90	21.76			
13a	current (amps)	13.52	13.52	13.52			

Test 2a - thru Mfg. 1 15-amp breaker at 135% current (15A * 135% = 20.25A); max temps, reading every 20s

data logger CH #	Location	Recorded Temperatures (°C)			Calculated Temperature Rise (°C)		
scan #		65	66	67			
time (MM:SS)		20:00	20:20	20:40			
	Breaker trip time	21:00					
1a	Mfg. 10 - 1	47.14	47.05	47.05	26.19	26.10	26.09
2a	Mfg. 10 - 2	49.33	49.35	49.30	28.38	28.39	28.35
3a	Mfg. 10 - 3	43.32	43.29	43.14	22.36	22.34	22.19
4a	Mfg. 9 - 1	45.67	45.67	45.73	24.72	24.71	24.78
5a	Mfg. 9 - 2	46.98	46.95	46.85	26.03	25.99	25.90
6a	Mfg. 9 - 3	38.91	38.80	38.65	17.95	17.84	17.69
7a	circuit breaker	52.18	52.30	52.40	31.23	31.34	31.45
8a	line wire	43.36	43.34	43.31	22.40	22.39	22.35
9a	line wire splicing device	46.95	46.94	46.87	26.00	25.99	25.91
10a	load wire	41.51	41.36	41.20	20.56	20.41	20.25
11a	load wire splicing device	42.93	42.85	42.57	21.97	21.89	21.62
12a	room ambient	20.94	20.94	20.98			
13a	current (amps)	20.29	20.28	20.28			

Appendix C2 Static Heating Tests at 135% Rated Current

Test 2b - thru Mfg. 2 10-amp breaker at 135% current ($10A * 135\% = 13.5A$); max temps, reading every 20s

data logger CH #	Location	Recorded Temperatures (°C)			Calculated Temperature Rise (°C)		
scan #		21	22	23			
time (MM:SS)		5:40	6:00	6:20			
	Breaker trip time	6:40					
1b	Mfg. 10 - 1	31.86	32.13	32.38	9.94	10.21	10.46
2b	Mfg. 10 - 2	32.09	32.28	32.45	10.17	10.36	10.53
3b	Mfg. 10 - 3	30.06	30.24	30.38	8.14	8.32	8.46
4b	Mfg. 9 - 1	29.45	29.60	29.73	7.53	7.68	7.81
5b	Mfg. 9 - 2	30.16	30.32	30.49	8.23	8.40	8.57
6b	Mfg. 9 - 3	29.34	29.52	29.64	7.42	7.60	7.72
7b	circuit breaker	37.11	37.68	38.17	15.19	15.76	16.25
8b	line wire	35.37	35.59	35.81	13.44	13.67	13.88
9b	line wire splicing device	32.21	32.37	32.46	10.28	10.45	10.54
10b	load wire	31.36	31.58	31.73	9.44	9.66	9.80
11b	load wire splicing device	35.28	35.40	35.49	13.36	13.47	13.56
12b	room ambient	21.93	21.95	21.88			
13b	current (amps)	13.50	13.50	13.50			

Test 2b - thru Mfg. 2 15-amp breaker at 135% current ($15A * 135\% = 20.25A$); max temps, reading every 20s

data logger CH #	Location	Recorded Temperatures (°C)			Calculated Temperature Rise (°C)		
scan #		13	14	15			
time (MM:SS)		2:40	3:00	3:20			
	Breaker trip time	3:40					
1b	Mfg. 10 - 1	34.43	35.44	36.33	13.42	14.43	15.32
2b	Mfg. 10 - 2	35.56	36.51	37.33	14.56	15.51	16.33
3b	Mfg. 10 - 3	33.00	33.73	34.31	12.00	12.73	13.30
4b	Mfg. 9 - 1	32.70	33.42	34.00	11.69	12.41	13.00
5b	Mfg. 9 - 2	32.65	33.31	33.89	11.64	12.30	12.89
6b	Mfg. 9 - 3	30.85	31.44	31.99	9.85	10.43	10.98
7b	circuit breaker	36.44	37.96	39.35	15.44	16.96	18.34
8b	line wire	32.46	33.42	34.28	11.45	12.41	13.28
9b	line wire splicing device	35.23	35.84	36.40	14.22	14.84	15.39
10b	load wire	33.42	34.26	35.03	12.42	13.26	14.02
11b	load wire splicing device	33.28	33.92	34.50	12.27	12.91	13.49
12b	room ambient	20.93	21.01	21.08			
13b	current (amps)	20.28	20.28	20.28			

Appendix C2 Static Heating Tests at 135% Rated Current

Test 2c - thru Mfg. 3 10-amp breaker at 135% current ($10A \times 135\% = 13.5A$); max temps, reading every 20s

data logger CH #	Location	Recorded Temperatures (°C)			Calculated Temperature Rise (°C)	
scan #		53	54	55		
time (MM:SS)		16:20	16:40	17:00		
	Breaker trip time	17:20				
1c	Mfg. 10 - 1	35.58	35.62	35.62	13.37	13.41
2c	Mfg. 10 - 2	36.59	36.62	36.62	14.38	14.41
3c	Mfg. 10 - 3	32.94	32.95	32.98	10.73	10.77
4c	Mfg. 9 - 1	33.08	33.07	33.07	10.87	10.86
5c	Mfg. 9 - 2	33.95	33.93	33.90	11.73	11.72
6c	Mfg. 9 - 3	31.62	31.62	31.58	9.40	9.41
7c	circuit breaker	41.72	41.81	41.92	19.51	19.60
8c	line wire	38.68	38.60	38.52	16.47	16.39
9c	line wire splicing device	33.41	33.23	33.04	11.19	11.02
10c	load wire	37.53	37.41	37.27	15.31	15.20
11c	load wire splicing device	38.23	37.83	37.38	16.01	15.62
12c	room ambient	22.28	22.22	22.14		
13c	current (amps)	13.50	13.50	13.50		

Test 2c - thru Mfg. 3 15-amp breaker at 135% current ($15A \times 135\% = 20.25A$); max temps, reading every 20s

data logger CH #	Location	Recorded Temperatures (°C)			Calculated Temperature Rise (°C)	
scan #		22	23	24		
time (MM:SS)		5:40	6:00	6:20		
	Breaker trip time	6:40				
1c	Mfg. 10 - 1	37.66	38.19	38.64	16.09	16.61
2c	Mfg. 10 - 2	44.95	45.50	45.96	23.38	23.93
3c	Mfg. 10 - 3	44.95	45.37	45.69	23.38	23.80
4c	Mfg. 9 - 1	35.48	35.83	36.20	13.90	14.26
5c	Mfg. 9 - 2	38.33	38.69	39.10	16.75	17.12
6c	Mfg. 9 - 3	36.86	37.22	37.59	15.28	15.65
7c	circuit breaker	42.83	43.50	44.14	21.26	21.93
8c	line wire	35.89	36.21	36.61	14.32	14.64
9c	line wire splicing device	40.91	41.17	41.52	19.33	19.60
10c	load wire	37.99	38.35	38.72	16.42	16.78
11c	load wire splicing device	39.30	39.51	39.86	17.72	17.93
12c	room ambient	21.55	21.59	21.59		
13c	current (amps)	20.30	20.26	20.27		

Appendix C3 Static Heating Tests at 150% Rated Current

Test 3a - thru Mfg. 1 10-amp breaker at 150% current (10A * 150% = 15A); max temps, reading every 10s

data logger CH #	Location	Recorded Temperatures (°C)			Calculated Temperature Rise (°C)	
scan #		19	20	21		
time (MM:SS)		2:00	2:10	2:20		
	Breaker trip time	2:30				
1a	Mfg. 11 - 1	27.90	28.21	28.45	5.51	6.06
2a	Mfg. 11 - 2	27.85	28.17	28.44	5.46	6.06
3a	Mfg. 11 - 3	27.44	27.71	27.97	5.05	5.58
4a	Mfg. 8 - 1	28.03	28.30	28.55	5.64	6.17
5a	Mfg. 8 - 2	28.67	28.93	29.21	6.28	6.83
6a	Mfg. 8 - 3	28.12	28.37	28.63	5.73	6.24
7a	circuit breaker	29.23	29.65	30.04	6.84	7.65
8a	line wire	33.45	33.99	34.55	11.06	12.16
9a	line wire splicing device	33.38	33.88	34.38	10.99	11.99
10a	load wire	32.35	32.80	33.28	9.96	10.89
11a	load wire splicing device	34.69	35.13	35.60	12.30	13.21
12a	room ambient	22.40	22.39	22.37		
13a	current (amps)	15.02	15.02	15.02		

Test 3a - thru Mfg. 1 15-amp breaker at 150% current (15A * 150% = 22.5A); max temps, reading every 10s

data logger CH #	Location	Recorded Temperatures (°C)			Calculated Temperature Rise (°C)	
scan #		31	32	33		
time (MM:SS)		3:40	3:50	4:00		
	Breaker trip time	4:10				
1a	Mfg. 11 - 1	36.08	36.34	36.60	13.46	13.98
2a	Mfg. 11 - 2	36.41	36.67	36.97	13.79	14.35
3a	Mfg. 11 - 3	34.72	34.88	35.08	12.10	12.46
4a	Mfg. 8 - 1	36.33	36.58	36.86	13.71	14.24
5a	Mfg. 8 - 2	37.14	37.38	37.62	14.53	15.00
6a	Mfg. 8 - 3	36.40	36.56	36.84	13.78	14.22
7a	circuit breaker	40.83	41.35	41.83	18.21	19.21
8a	line wire	39.85	40.31	40.75	17.23	18.13
9a	line wire splicing device	49.53	49.93	50.18	26.91	27.56
10a	load wire	40.21	40.60	40.99	17.60	18.37
11a	load wire splicing device	45.48	45.83	46.22	22.86	23.60
12a	room ambient	22.65	22.62	22.58		
13a	current (amps)	22.56	22.53	22.53		

Appendix C3 Static Heating Tests at 150% Rated Current

Test 3b - thru Mfg. 2 10-amp breaker at 150% current (10A * 150% = 15A); max temps, reading every 10s

data logger CH #	Location	Recorded Temperatures (°C)			Calculated Temperature Rise (°C)	
scan #		19	20	21		
time (MM:SS)		2:00	2:10	2:20		
	Breaker trip time	2:30				
1b	Mfg. 11 - 1	28.11	28.40	28.72	5.67	6.28
2b	Mfg. 11 - 2	27.73	27.97	28.26	5.29	5.82
3b	Mfg. 11 - 3	27.57	27.80	28.05	5.12	5.60
4b	Mfg. 8 - 1	28.38	28.63	28.91	5.93	6.47
5b	Mfg. 8 - 2	29.23	29.50	29.82	6.79	7.37
6b	Mfg. 8 - 3	28.00	28.25	28.53	5.56	6.09
7b	circuit breaker	30.38	30.93	31.50	7.94	9.06
8b	line wire	31.30	31.79	32.30	8.85	9.86
9b	line wire splicing device	32.82	33.29	33.71	10.38	11.27
10b	load wire	28.66	29.10	29.50	6.21	7.06
11b	load wire splicing device	33.26	33.63	33.95	10.82	11.51
12b	room ambient	22.47	22.43	22.43		
13b	current (amps)	15.01	15.01	15.01		

Test 3b - thru Mfg. 2 15-amp breaker at 150% current (15A * 150% = 22.5A); max temps, reading every 10s

data logger CH #	Location	Recorded Temperatures (°C)			Calculated Temperature Rise (°C)	
scan #		13	14	15		
time (MM:SS)		:40	:50	1:00		
	Breaker trip time	1:10				
1b	Mfg. 11 - 1	26.84	27.76	28.60	4.39	6.15
2b	Mfg. 11 - 2	26.26	27.11	27.94	3.81	5.49
3b	Mfg. 11 - 3	26.03	26.75	27.44	3.58	4.99
4b	Mfg. 8 - 1	26.61	27.54	28.41	4.16	5.96
5b	Mfg. 8 - 2	27.59	28.55	29.46	5.14	7.01
6b	Mfg. 8 - 3	27.23	28.09	28.93	4.78	6.48
7b	circuit breaker	27.33	28.59	29.90	4.88	7.45
8b	line wire	26.59	27.53	28.44	4.14	5.99
9b	line wire splicing device	29.28	30.58	31.77	6.83	9.32
10b	load wire	27.88	28.93	29.91	5.43	7.46
11b	load wire splicing device	29.84	31.22	32.45	7.39	10.00
12b	room ambient	22.46	22.43	22.45		
13b	current (amps)	22.51	22.49	22.49		

Appendix C3 Static Heating Tests at 150% Rated Current

Test 3c - thru Mfg. 3 10-amp breaker at 150% current (10A * 150% = 15A); max temps, reading every 10s

data logger CH #	Location	Recorded Temperatures (°C)			Calculated Temperature (°C)		Rise
scan #		37	38	39			
time (MM:SS)		5:00	5:10	5:20			
	Breaker trip time	5:30					
1c	Mfg. 11 - 1	32.34	32.46	32.62	9.83	9.96	10.12
2c	Mfg. 11 - 2	31.80	31.94	32.06	9.30	9.44	9.56
3c	Mfg. 11 - 3	29.96	30.07	30.17	7.46	7.56	7.67
4c	Mfg. 8 - 1	31.82	31.94	32.07	9.32	9.44	9.57
5c	Mfg. 8 - 2	31.64	31.77	31.86	9.13	9.26	9.36
6c	Mfg. 8 - 3	31.07	31.17	31.31	8.57	8.67	8.81
7c	circuit breaker	37.24	37.53	37.80	14.74	15.03	15.30
8c	line wire	38.50	38.75	39.00	16.00	16.25	16.50
9c	line wire splicing device	35.73	35.83	35.94	13.23	13.33	13.43
10c	load wire	37.84	38.06	38.26	15.33	15.56	15.75
11c	load wire splicing device	38.75	38.81	38.93	16.24	16.31	16.43
12c	room ambient	22.50	22.49	22.52			
13c	current (amps)	15.01	15.01	15.01			

Test 3c - thru Mfg. 3 15-amp breaker at 150% current (15A * 150% = 22.5A); max temps, reading every 10s

data logger CH #	Location	Recorded Temperatures (°C)			Calculated Temperature (°C)		Rise
scan #		23	24	25			
time (MM:SS)		2:20	2:30	2:40			
	Breaker trip time	2:50					
1c	Mfg. 11 - 1	32.80	33.29	33.73	10.40	10.89	11.33
2c	Mfg. 11 - 2	34.13	34.67	35.12	11.73	12.27	12.72
3c	Mfg. 11 - 3	32.29	32.77	33.17	9.89	10.37	10.77
4c	Mfg. 8 - 1	33.21	33.67	34.07	10.81	11.27	11.67
5c	Mfg. 8 - 2	34.62	35.08	35.48	12.22	12.68	13.08
6c	Mfg. 8 - 3	32.76	33.21	33.64	10.36	10.81	11.24
7c	circuit breaker	37.29	38.07	38.83	14.89	15.67	16.43
8c	line wire	33.28	33.93	34.55	10.88	11.53	12.15
9c	line wire splicing device	40.01	40.55	41.07	17.61	18.15	18.67
10c	load wire	36.15	36.74	37.30	13.75	14.34	14.90
11c	load wire splicing device	37.79	38.32	38.82	15.39	15.92	16.42
12c	room ambient	22.38	22.41	22.41			
13c	current (amps)	22.43	22.44	22.42			

Appendix C3 Static Heating Tests at 150% Rated Current

Test 3a - thru Mfg. 1 10-amp breaker at 150% current ($10A * 150\% = 15A$); max temps, reading every 10s

data logger CH #	Location	Recorded Temperatures (°C)			Calculated Temperature Rise (°C)		
scan #		23	24	25			
time (MM:SS)		2:20	2:30	2:40			
	Breaker trip time	2:50					
1a	Mfg. 10 - 1	29.81	30.21	30.55	7.56	7.96	8.30
2a	Mfg. 10 - 2	29.70	30.02	30.29	7.44	7.77	8.04
3a	Mfg. 10 - 3	28.37	28.62	28.85	6.12	6.37	6.60
4a	Mfg. 9 - 1	28.22	28.46	28.69	5.97	6.21	6.44
5a	Mfg. 9 - 2	28.46	28.71	28.94	6.21	6.46	6.69
6a	Mfg. 9 - 3	27.73	27.96	28.13	5.48	5.71	5.88
7a	circuit breaker	29.83	30.21	30.53	7.58	7.96	8.28
8a	line wire	34.40	34.90	35.38	12.15	12.65	13.13
9a	line wire splicing device	32.53	32.88	33.18	10.28	10.63	10.93
10a	load wire	33.43	33.88	34.25	11.17	11.63	12.00
11a	load wire splicing device	37.25	37.47	37.66	15.00	15.22	15.41
12a	room ambient	22.28	22.24	22.24			
13a	current (amps)	15.02	15.02	15.02			

Test 3a - thru Mfg. 1 15-amp breaker at 150% current ($15A * 150\% = 22.5A$); max temps, reading every 10s

data logger CH #	Location	Recorded Temperatures (°C)			Calculated Temperature Rise (°C)		
scan #		38	39	40			
time (MM:SS)		4:00	4:10	4:20			
	Breaker trip time	4:30					
1a	Mfg. 10 - 1	40.53	40.89	41.27	18.74	19.10	19.48
2a	Mfg. 10 - 2	42.28	42.67	43.05	20.49	20.88	21.26
3a	Mfg. 10 - 3	39.25	39.54	39.81	17.46	17.75	18.02
4a	Mfg. 9 - 1	39.03	39.37	39.68	17.24	17.58	17.89
5a	Mfg. 9 - 2	40.06	40.40	40.75	18.27	18.61	18.96
6a	Mfg. 9 - 3	35.92	36.14	36.35	14.14	14.35	14.56
7a	circuit breaker	41.66	42.13	42.62	19.87	20.34	20.83
8a	line wire	40.15	40.56	40.91	18.36	18.77	19.12
9a	line wire splicing device	47.60	47.94	48.23	25.81	26.16	26.44
10a	load wire	40.83	41.12	41.46	19.04	19.33	19.67
11a	load wire splicing device	46.50	46.62	46.74	24.72	24.83	24.95
12a	room ambient	21.81	21.79	21.76			
13a	current (amps)	22.35	22.35	22.35			

Appendix C3 Static Heating Tests at 150% Rated Current

Test 3b - thru Mfg. 2 10-amp breaker at 150% current (10A * 150% = 15A); max temps, reading every 10s

data logger CH #	Location	Recorded Temperatures (°C)			Calculated Temperature Rise (°C)		
scan #		21	22	23			
time (MM:SS)		2:00	2:10	2:20			
	Breaker trip time	2:30					
1b	Mfg. 10 - 1	28.72	29.12	29.50	6.58	6.98	7.36
2b	Mfg. 10 - 2	29.55	29.94	30.33	7.41	7.80	8.19
3b	Mfg. 10 - 3	28.01	28.30	28.56	5.87	6.16	6.42
4b	Mfg. 9 - 1	27.72	28.02	28.27	5.58	5.88	6.13
5b	Mfg. 9 - 2	27.97	28.28	28.55	5.83	6.14	6.41
6b	Mfg. 9 - 3	27.58	27.82	28.09	5.44	5.68	5.95
7b	circuit breaker	30.55	31.13	31.74	8.41	8.99	9.60
8b	line wire	31.18	31.69	32.20	9.04	9.55	10.06
9b	line wire splicing device	31.46	31.83	32.14	9.32	9.69	10.00
10b	load wire	28.42	28.81	29.21	6.28	6.67	7.07
11b	load wire splicing device	36.24	36.63	36.93	14.10	14.49	14.79
12b	room ambient	22.20	22.13	22.09			
13b	current (amps)	15.00	15.00	15.00			

Test 3b - thru Mfg. 2 15-amp breaker at 150% current (15A * 150% = 22.5A); max temps, reading every 10s

data logger CH #	Location	Recorded Temperatures (°C)			Calculated Temperature Rise (°C)		
scan #		18	19	20			
time (MM:SS)		:40	:50	1:00			
	Breaker trip time	1:10					
1b	Mfg. 10 - 1	25.84	26.82	27.77	4.13	5.12	6.06
2b	Mfg. 10 - 2	29.58	31.10	32.54	7.88	9.40	10.83
3b	Mfg. 10 - 3	32.64	34.09	35.41	10.93	12.39	13.71
4b	Mfg. 9 - 1	25.84	26.77	27.65	4.14	5.07	5.94
5b	Mfg. 9 - 2	27.74	28.90	29.94	6.03	7.19	8.24
6b	Mfg. 9 - 3	27.36	28.35	29.32	5.65	6.65	7.62
7b	circuit breaker	26.69	27.90	29.05	4.98	6.20	7.35
8b	line wire	25.29	26.13	26.94	3.59	4.42	5.23
9b	line wire splicing device	28.85	30.25	31.50	7.14	8.54	9.80
10b	load wire	27.35	28.42	29.40	5.65	6.72	7.70
11b	load wire splicing device	29.03	30.42	31.68	7.33	8.71	9.98
12b	room ambient	21.68	21.70	21.73			
13b	current (amps)	22.56	22.55	22.52			

Appendix C3 Static Heating Tests at 150% Rated Current

Test 3c - thru Mfg. 3 10-amp breaker at 150% current ($10A * 150\% = 15A$); max temps, reading every 10s

data logger CH #	Location	Recorded Temperatures (°C)			Calculated Temperature Rise (°C)		
scan #		44	45	46			
time (MM:SS)		5:50	6:00	6:10			
	Breaker trip time	6:20					
1c	Mfg. 10 - 1	33.95	34.06	34.18	12.26	12.38	12.49
2c	Mfg. 10 - 2	34.86	35.03	35.17	13.17	13.34	13.48
3c	Mfg. 10 - 3	32.06	32.16	32.23	10.37	10.47	10.55
4c	Mfg. 9 - 1	31.67	31.77	31.89	9.98	10.08	10.20
5c	Mfg. 9 - 2	31.89	31.99	32.07	10.20	10.30	10.39
6c	Mfg. 9 - 3	30.51	30.58	30.63	8.82	8.89	8.94
7c	circuit breaker	37.51	37.73	37.94	15.82	16.04	16.25
8c	line wire	38.17	38.32	38.46	16.48	16.63	16.77
9c	line wire splicing device	33.48	33.53	33.58	11.79	11.84	11.89
10c	load wire	37.25	37.38	37.51	15.57	15.70	15.82
11c	load wire splicing device	39.05	39.08	39.09	17.36	17.39	17.40
12c	room ambient	21.68	21.69	21.69			
13c	current (amps)	15.00	15.00	15.00			

Test 3c - thru Mfg. 3 15-amp breaker at 150% current ($15A * 150\% = 22.5A$); max temps, reading every 10s

data logger CH #	Location	Recorded Temperatures (°C)			Calculated Temperature Rise (°C)		
scan #		28	29	30			
time (MM:SS)		2:20	2:30	2:40			
	Breaker trip time	2:50					
1c	Mfg. 10 - 1	28.08	27.72	27.38	6.22	5.87	5.53
2c	Mfg. 10 - 2	27.85	27.43	27.08	5.99	5.58	5.23
3c	Mfg. 10 - 3	26.82	26.45	26.13	4.97	4.59	4.27
4c	Mfg. 9 - 1	26.62	26.30	26.02	4.76	4.45	4.17
5c	Mfg. 9 - 2	26.78	26.44	26.12	4.92	4.58	4.27
6c	Mfg. 9 - 3	26.00	25.71	25.47	4.15	3.86	3.62
7c	circuit breaker	30.09	29.81	29.54	8.23	7.95	7.68
8c	line wire	27.46	27.28	27.08	5.61	5.42	5.22
9c	line wire splicing device	27.03	26.55	26.12	5.18	4.69	4.26
10c	load wire	27.36	27.10	26.84	5.50	5.24	4.98
11c	load wire splicing device	27.70	27.09	26.53	5.84	5.23	4.67
12c	room ambient	21.89	21.86	21.82			
13c	current (amps)	22.40	22.39	22.39			

Appendix C4 Static Heating Tests at 200% Rated Current

Test 4a - thru Mfg. 1 10-amp breaker at 200% current (10A * 200% = 20A); max temps, reading every 7s

data logger CH #	Location	Recorded Temperatures (°C)			Calculated Temperature Rise (°C)	
scan #		10	11	12		
time (MM:SS)		:15	:21	:28		
	Breaker trip time	:35				
1a	Mfg. 11 - 1	24.11	24.67	25.32	2.07	3.28
2a	Mfg. 11 - 2	24.06	24.59	25.25	2.02	3.20
3a	Mfg. 11 - 3	24.07	24.57	25.16	2.03	3.12
4a	Mfg. 8 - 1	24.08	24.69	25.40	2.03	3.35
5a	Mfg. 8 - 2	24.66	25.33	26.11	2.61	4.06
6a	Mfg. 8 - 3	24.22	24.83	25.55	2.17	3.50
7a	circuit breaker	24.11	24.82	25.62	2.07	3.57
8a	line wire	27.40	28.75	30.11	5.35	8.06
9a	line wire splicing device	25.44	26.76	28.29	3.40	6.24
10a	load wire	26.61	27.77	28.96	4.57	6.91
11a	load wire splicing device	26.63	28.24	30.08	4.59	8.04
12a	room ambient	22.05	22.06	22.03		
13a	current (amps)	19.99	20.01	20.01		

Test 4a - thru Mfg. 1 15-amp breaker at 200% current (15A * 200% = 30A); max temps, reading every 7s

data logger CH #	Location	Recorded Temperatures (°C)			Calculated Temperature Rise (°C)	
scan #		20	21	22		
time (MM:SS)		:28	:35	:42		
	Breaker trip time	:49				
1a	Mfg. 11 - 1	27.71	28.87	30.04	5.22	7.55
2a	Mfg. 11 - 2	27.71	28.87	30.05	5.22	7.56
3a	Mfg. 11 - 3	27.95	28.97	30.04	5.46	7.54
4a	Mfg. 8 - 1	27.60	28.90	30.19	5.11	7.70
5a	Mfg. 8 - 2	28.56	29.91	31.25	6.06	8.76
6a	Mfg. 8 - 3	29.13	30.23	31.51	6.63	9.02
7a	circuit breaker	27.85	29.29	30.80	5.35	8.30
8a	line wire	29.17	30.44	31.74	6.68	9.24
9a	line wire splicing device	36.20	38.78	41.38	13.71	18.89
10a	load wire	29.69	31.07	32.48	7.20	9.98
11a	load wire splicing device	36.64	39.18	41.65	14.14	19.15
12a	room ambient	22.48	22.48	22.52		
13a	current (amps)	29.87	29.79	29.76		

Appendix C4 Static Heating Tests at 200% Rated Current

Test 4b - thru Mfg. 2 10-amp breaker at 200% current (10A * 200% = 20A); max temps, reading every 7s

data logger CH #	Location	Recorded Temperatures (°C)			Calculated Temperature Rise (°C)		
scan #		10	11	12			
time (MM:SS)		:15	:21	:28			
	Breaker trip time	:35					
1b	Mfg. 11 - 1	23.92	24.53	25.23	2.00	2.60	3.30
2b	Mfg. 11 - 2	23.87	24.40	25.03	1.95	2.48	3.10
3b	Mfg. 11 - 3	24.04	24.56	25.19	2.11	2.64	3.27
4b	Mfg. 8 - 1	24.03	24.67	25.43	2.11	2.74	3.51
5b	Mfg. 8 - 2	24.81	25.54	26.38	2.89	3.62	4.46
6b	Mfg. 8 - 3	24.09	24.69	25.38	2.17	2.77	3.46
7b	circuit breaker	23.99	24.68	25.52	2.07	2.75	3.60
8b	line wire	25.64	26.65	27.71	3.72	4.73	5.78
9b	line wire splicing device	25.15	26.44	27.96	3.22	4.52	6.03
10b	load wire	23.65	24.33	25.10	1.73	2.41	3.18
11b	load wire splicing device	26.05	27.55	29.19	4.13	5.63	7.27
12b	room ambient	21.94	21.92	21.90			
13b	current (amps)	20.00	20.00	20.00			

Test 4b - thru Mfg. 2 15-amp breaker at 200% current (15A * 200% = 30A); max temps, reading every 7s

data logger CH #	Location	Recorded Temperatures (°C)			Calculated Temperature Rise (°C)		
scan #		16	17	18			
time (MM:SS)		:00	:09	:15			
	Breaker trip time	:21					
1b	Mfg. 11 - 1	22.78	24.58	25.64	0.28	2.08	3.14
2b	Mfg. 11 - 2	22.55	23.95	24.94	0.05	1.45	2.44
3b	Mfg. 11 - 3	22.78	24.32	25.15	0.28	1.82	2.65
4b	Mfg. 8 - 1	22.67	24.22	25.26	0.17	1.72	2.76
5b	Mfg. 8 - 2	23.01	25.35	26.56	0.52	2.85	4.06
6b	Mfg. 8 - 3	23.06	25.22	26.32	0.57	2.72	3.83
7b	circuit breaker	22.89	24.64	25.66	0.39	2.15	3.17
8b	line wire	22.78	24.14	25.26	0.28	1.64	2.76
9b	line wire splicing device	22.80	25.27	27.08	0.30	2.77	4.59
10b	load wire	22.73	25.29	26.72	0.23	2.79	4.22
11b	load wire splicing device	22.84	25.76	27.75	0.34	3.26	5.26
12b	room ambient	22.49	22.49	22.51			
13b	current (amps)	29.72	29.67	29.65			

Appendix C4 Static Heating Tests at 200% Rated Current

Test 4c - thru Mfg. 3 10-amp breaker at 200% current (10A * 200% = 20A); max temps, reading every 7s

data logger CH #	Location	Recorded Temperatures (°C)			Calculated Temperature Rise (°C)		
scan #		16	17	18			
time (MM:SS)		:56	1:03	1:10			
	Breaker trip time	1:17					
1c	Mfg. 11 - 1	27.91	28.45	29.02	5.96	6.50	7.07
2c	Mfg. 11 - 2	27.83	28.34	28.85	5.88	6.39	6.90
3c	Mfg. 11 - 3	26.46	26.84	27.26	4.51	4.89	5.31
4c	Mfg. 8 - 1	28.33	28.89	29.46	6.38	6.94	7.51
5c	Mfg. 8 - 2	28.77	29.28	29.81	6.82	7.33	7.86
6c	Mfg. 8 - 3	27.76	28.25	28.71	5.81	6.30	6.76
7c	circuit breaker	30.95	31.72	32.52	8.99	9.77	10.56
8c	line wire	32.07	32.86	33.68	10.12	10.91	11.73
9c	line wire splicing device	31.50	32.36	33.19	9.54	10.41	11.24
10c	load wire	32.53	33.29	34.09	10.58	11.34	12.14
11c	load wire splicing device	36.35	37.44	38.34	14.40	15.49	16.39
12c	room ambient	22.03	21.91	21.92			
13c	current (amps)	20.00	20.00	20.00			

Test 4c - thru Mfg. 3 15-amp breaker at 200% current (15A * 200% = 30A); max temps, reading every 7s

data logger CH #	Location	Recorded Temperatures (°C)			Calculated Temperature Rise (°C)		
scan #		18	19	20			
time (MM:SS)		:15	:21	:28			
	Breaker trip time	:35					
1c	Mfg. 11 - 1	24.86	25.82	26.97	2.56	3.52	4.67
2c	Mfg. 11 - 2	25.87	27.00	28.27	3.57	4.70	5.97
3c	Mfg. 11 - 3	25.45	26.38	27.49	3.15	4.08	5.19
4c	Mfg. 8 - 1	25.11	26.19	27.48	2.81	3.89	5.18
5c	Mfg. 8 - 2	26.49	27.73	29.14	4.19	5.43	6.85
6c	Mfg. 8 - 3	25.08	26.08	27.24	2.78	3.78	4.94
7c	circuit breaker	25.44	26.60	28.04	3.14	4.30	5.74
8c	line wire	24.49	25.44	26.52	2.20	3.15	4.22
9c	line wire splicing device	27.39	29.24	31.37	5.09	6.95	9.07
10c	load wire	26.18	27.74	29.43	3.88	5.44	7.13
11c	load wire splicing device	26.21	27.89	29.79	3.91	5.59	7.49
12c	room ambient	22.31	22.30	22.29			
13c	current (amps)	29.59	29.78	29.83			

Appendix C4 Static Heating Tests at 200% Rated Current

Test 4a - thru Mfg. 1 10-amp breaker at 200% current (10A * 200% = 20A); max temps, reading every 7s

data logger CH #	Location	Recorded Temperatures (°C)			Calculated Temperature Rise (°C)	
scan #		27	28	29		
time (MM:SS)		:15	:21	:28		
	Breaker trip time	:35				
1a	Mfg. 10 - 1	24.20	24.89	25.74	2.53	4.07
2a	Mfg. 10 - 2	24.11	24.81	25.65	2.45	3.99
3a	Mfg. 10 - 3	23.82	24.42	25.12	2.16	3.45
4a	Mfg. 9 - 1	23.70	24.28	24.96	2.04	3.29
5a	Mfg. 9 - 2	23.89	24.51	25.23	2.22	3.57
6a	Mfg. 9 - 3	23.66	24.22	24.90	1.99	3.23
7a	circuit breaker	23.81	24.47	25.29	2.14	3.63
8a	line wire	26.99	28.37	29.76	5.32	8.09
9a	line wire splicing device	24.05	25.15	26.46	2.39	4.79
10a	load wire	26.61	27.85	29.13	4.94	7.47
11a	load wire splicing device	28.24	30.24	32.42	6.58	10.75
12a	room ambient	21.68	21.67	21.66		
13a	current (amps)	20.02	20.03	20.03		

Test 4a - thru Mfg. 1 15-amp breaker at 200% current (15A * 200% = 30A); max temps, reading every 7s

data logger CH #	Location	Recorded Temperatures (°C)			Calculated Temperature Rise (°C)	
scan #		17	18	19		
time (MM:SS)		:28	:35	:42		
	Breaker trip time	:49				
1a	Mfg. 10 - 1	27.27	28.75	30.17	5.77	8.67
2a	Mfg. 10 - 2	28.89	30.53	32.07	7.38	10.56
3a	Mfg. 10 - 3	27.89	29.33	30.74	6.38	9.24
4a	Mfg. 9 - 1	27.16	28.54	29.90	5.66	8.39
5a	Mfg. 9 - 2	28.09	29.55	30.97	6.58	9.46
6a	Mfg. 9 - 3	27.93	29.14	30.27	6.43	8.77
7a	circuit breaker	26.82	28.27	29.71	5.32	8.20
8a	line wire	28.15	29.45	30.67	6.65	9.17
9a	line wire splicing device	34.08	36.63	38.99	12.57	17.49
10a	load wire	28.54	29.95	31.29	7.03	9.79
11a	load wire splicing device	35.97	38.68	41.18	14.47	19.67
12a	room ambient	21.49	21.52	21.51		
13a	current (amps)	29.88	29.83	29.82		

Appendix C4 Static Heating Tests at 200% Rated Current

Test 4b - thru Mfg. 2 10-amp breaker at 200% current (10A * 200% = 20A); max temps, reading every 7s

data logger CH #	Location	Recorded Temperatures (°C)			Calculated Temperature Rise (°C)	
scan #		27	28	29		
time (MM:SS)		:15	:21	:28		
	Breaker trip time	:35				
1b	Mfg. 10 - 1	23.68	24.31	25.08	2.15	3.55
2b	Mfg. 10 - 2	24.00	24.79	25.66	2.47	4.13
3b	Mfg. 10 - 3	23.96	24.59	25.27	2.43	3.74
4b	Mfg. 9 - 1	23.67	24.25	24.93	2.14	3.40
5b	Mfg. 9 - 2	23.75	24.36	25.10	2.22	3.58
6b	Mfg. 9 - 3	23.79	24.37	25.03	2.26	3.50
7b	circuit breaker	23.69	24.36	25.21	2.16	3.69
8b	line wire	25.34	26.37	27.40	3.81	5.88
9b	line wire splicing device	24.37	25.54	26.91	2.84	5.38
10b	load wire	23.38	24.06	24.84	1.86	3.32
11b	load wire splicing device	28.62	30.57	32.60	7.09	11.07
12b	room ambient	21.54	21.54	21.50		
13b	current (amps)	19.99	19.99	19.99		

Test 4b - thru Mfg. 2 15-amp breaker at 200% current (15A * 200% = 30A); max temps, reading every 7s

data logger CH #	Location	Recorded Temperatures (°C)			Calculated Temperature Rise (°C)	
scan #		13	14	15		
time (MM:SS)		0:00	:09	:15		
	Breaker trip time	:21				
1b	Mfg. 10 - 1	21.91	23.26	24.56	0.52	3.16
2b	Mfg. 10 - 2	21.93	24.79	26.37	0.54	4.97
3b	Mfg. 10 - 3	21.91	23.93	25.26	0.52	3.87
4b	Mfg. 9 - 1	21.95	24.22	25.49	0.56	4.10
5b	Mfg. 9 - 2	21.93	24.57	25.87	0.54	4.48
6b	Mfg. 9 - 3	21.90	24.12	25.30	0.51	3.90
7b	circuit breaker	22.03	23.68	24.72	0.64	3.33
8b	line wire	22.07	23.08	24.22	0.68	2.83
9b	line wire splicing device	21.89	24.14	26.27	0.50	4.87
10b	load wire	21.93	24.17	25.69	0.54	4.30
11b	load wire splicing device	21.95	26.40	28.99	0.56	7.60
12b	room ambient	21.40	21.38	21.40		
13b	current (amps)	30.03	29.98	29.94		

Appendix C4 Static Heating Tests at 200% Rated Current

Test 4c - thru Mfg. 3 10-amp breaker at 200% current (10A * 200% = 20A); max temps, reading every 7s

data logger CH #	Location	Recorded Temperatures (°C)			Calculated Temperature Rise (°C)	
scan #		33	34	35		
time (MM:SS)		:56	1:03	1:10		
	Breaker trip time	1:17				
1c	Mfg. 10 - 1	28.89	29.56	30.22	7.33	8.67
2c	Mfg. 10 - 2	29.13	29.80	30.47	7.57	8.92
3c	Mfg. 10 - 3	28.24	28.82	29.43	6.69	7.87
4c	Mfg. 9 - 1	27.96	28.54	29.11	6.41	6.98
5c	Mfg. 9 - 2	27.95	28.55	29.13	6.40	6.99
6c	Mfg. 9 - 3	27.87	28.37	28.89	6.31	6.82
7c	circuit breaker	30.46	31.20	31.96	8.91	9.65
8c	line wire	31.76	32.54	33.32	10.20	10.99
9c	line wire splicing device	30.32	31.15	31.96	8.77	9.60
10c	load wire	32.17	32.94	33.69	10.62	11.39
11c	load wire splicing device	39.40	40.57	41.66	17.85	19.02
12c	room ambient	21.59	21.54	21.53		
13c	current (amps)	20.00	20.00	20.00		

Test 4c - thru Mfg. 3 15-amp breaker at 200% current (15A * 200% = 30A); max temps, reading every 7s

data logger CH #	Location	Recorded Temperatures (°C)			Calculated Temperature Rise (°C)	
scan #		16	17	18		
time (MM:SS)		:21	:28	:35		
	Breaker trip time	:42				
1c	Mfg. 10 - 1	24.57	25.84	27.05	3.19	4.45
2c	Mfg. 10 - 2	28.42	30.54	32.56	7.04	9.16
3c	Mfg. 10 - 3	33.47	35.78	37.86	12.09	14.40
4c	Mfg. 9 - 1	24.87	26.08	27.27	3.49	4.70
5c	Mfg. 9 - 2	27.04	28.63	30.11	5.66	7.25
6c	Mfg. 9 - 3	26.95	28.35	29.72	5.57	6.97
7c	circuit breaker	25.75	27.15	28.60	4.37	5.77
8c	line wire	24.57	25.65	26.68	3.19	4.27
9c	line wire splicing device	27.76	29.81	31.74	6.38	8.43
10c	load wire	26.52	28.22	29.72	5.14	6.84
11c	load wire splicing device	27.66	29.85	31.88	6.28	8.47
12c	room ambient	21.40	21.37	21.36		
13c	current (amps)	29.34	29.29	30.17		

Appendix C5 Static Heating Testing Schneider Circuit Breaker

Test 1b - thru Mfg. 2 10-amp breaker at 100% current (10A * 100% = 10A); max temps, reading every 60s

data logger CH #	Location	Recorded Temperatures (°C)			Calculated Temperature Rise (°C)		
scan #		67	72	77			
time (HH:MM:SS)		1:04:00	1:09:00	1:14:00			
1b	Mfg. 10 - 1	33.66	33.62	33.48	12.17	12.13	11.99
2b	Mfg. 10 - 2	30.46	30.56	30.61	8.97	9.07	9.12
3b	Mfg. 10 - 3	28.97	29.03	28.87	7.48	7.54	7.38
4b	Mfg. 9 - 1	28.59	28.61	28.68	7.10	7.12	7.19
5b	Mfg. 9 - 2	29.99	29.94	29.81	8.50	8.45	8.32
6b	Mfg. 9 - 3	28.44	28.40	28.15	6.95	6.91	6.66
7b	circuit breaker	41.26	41.48	41.60	19.77	19.99	20.11
8b	line wire	31.15	30.97	30.89	9.66	9.48	9.40
	line wire splicing device						
9b		28.63	28.27	28.01	7.14	6.78	6.52
10b	load wire	28.45	28.20	28.09	6.96	6.71	6.60
	load wire splicing device						
11b		30.47	29.94	29.87	8.98	8.45	8.38
12b	room ambient	22.46	22.07	21.66			
13b	current (amps)	10.01	10.01	10.01			

Test 2b - thru Mfg. 2 10-amp breaker at 135% current (10A * 135% = 13.5A); max temps, reading every 20s

data logger CH #	Location	Recorded Temperatures (°C)			Calculated Temperature Rise (°C)		
scan #		202	203	204			
time (MM:SS)		66:20	66:40	67:00			
	Breaker trip time	> 67 mins. (no trip)					
1b	Mfg. 10 - 1	40.89	40.89	40.88	18.96	18.97	18.96
2b	Mfg. 10 - 2	37.03	37.03	37.04	15.11	15.11	15.12
3b	Mfg. 10 - 3	34.24	34.26	34.21	12.31	12.34	12.29
4b	Mfg. 9 - 1	33.52	33.50	33.53	11.60	11.58	11.61
5b	Mfg. 9 - 2	35.79	35.78	35.75	13.87	13.86	13.83
6b	Mfg. 9 - 3	33.44	33.45	33.39	11.52	11.53	11.47
7b	circuit breaker	56.60	56.56	56.59	34.68	34.64	34.67
8b	line wire	38.73	38.68	38.65	16.81	16.76	16.72
	line wire splicing device						
9b		33.69	33.57	33.57	11.76	11.65	11.65
10b	load wire	33.57	33.50	33.50	11.65	11.57	11.58
	load wire splicing device						
11b		37.08	36.99	37.04	15.16	15.07	15.12
12b	room ambient	22.10	22.03	21.97			
13b	current (amps)	13.49	13.49	13.49			

Appendix D Flexing Tests

Conductor Flexing tests on 14-2 AWG copper-clad aluminum NMB cable:

test #	wire connection method	pass / fail (10x flexion)	comments
6-1	wrap around terminal screw	pass	ends of hot and neutral wires broke when removing them from their terminals after the test
6-2	single compression	pass	
6-3	double compression	pass	
6-1-1	wrap around terminal screw	failed	retest of 6-1; hot wire (black) broke on 8th flexion
6-1-2	wrap around terminal screw	pass	retest of 6-1 using copper wire
6-1-3	wrap around terminal screw	pass	retest of 6-1

NOTE: One Legrand receptacle was used for all 3 tests above and 9in/lbs was applied to all three terminal screws.



PO Box 2363, Clackamas, OR 97015
15648 114th Ave. Suite 109, Clackamas OR 97015
Phone: 503-406-4373 Fax: 503 905 0457
www.pacifictestandmeasurement.com

Certificate of Conformance

Issued to:	CDCMello Consulting LLC PO Box 872317 Vancouver, WA 98687
Customer PO:	Verbal Chuck Mello
Model:	UL3055
Lot Number:	952103-019
Report:	JK202006300-003
Description:	Type J, 30 Gauge FEP/FEP Teflon, Special Limits of Error Tolerance, 15 feet length, Thermocouple

Pacific Test and Measurement Inc certifies that the order of thermocouples meets all applicable instructions, specifications, and in accordance with DAP UL 00-OP-C0037 version 10.0. The preferred method of welding to produce a single point weld or bead using ThermX model 258B welder has been used to assemble the thermocouple junction which has been proven as reliable and repeatable through validation. The finish products were assembled from UL4047, a spool of described wire calibrated to accredited standards as described in the calibration report.

Certified by: 
(Quality Department)

Date: 7-10-2020



Appendix E - Certificates of Calibration Report of Calibration

Eustis Co., Inc./Pyrocom Calibration Lab
12407-B Mukilteo Speedway #200
Lynnwood, wa 98087

Report No: JK202006300-003

Page 1 of 2

Model: UL4047 Serial: 952103-019 Description: TYPE J, 30AWG, FEP/FEP	Customer: CDCMello Consulting LLC PO Box 872317 Vancouver, WA 98687
Calibration Range: Limited Received Condition: New Current: N/A Procedure: ECP 339/341	

The unit under test (UUT) on this certificate has been calibrated by comparison method as covered by ASTM E220-13, and calibrated against standards traceable to the National Institute of Standards and Technology (NIST). Eustis Co., Inc./Pyrocom Calibration Lab meets the requirements of ANSI/NCSL Z540-1-1994 and ISO/IEC 17025 and is accredited by A2LA via Certificate Number 2496.01 for calibrations within the scope to which it applies. The uncertainty represents an expanded uncertainty expressed at approximately the 95% confidence level using a coverage factor of $k=2$. All results contained within this certificate relate only to the item calibrated. Any number of factors may cause the calibrated item to drift out of calibration.

Nominal Value (Set-point) (C)	Actual Value (Reference) (C)	UUT (Test Sensor) (C)	Error (C)	Measurement Uncertainty (C)	Method of Realization
21.00	21.41	21.38	-0.03	+/- 0.31	COMP
40.00	40.08	40.02	-0.06	+/- 0.40	COMP
95.00	95.02	94.97	-0.05	+/- 0.40	COMP
150.00	150.02	150.10	0.08	+/- 0.50	COMP
200.00	200.01	200.23	0.22	+/- 0.50	COMP

Test Equipment

Manufacturer	Model	Description	Serial Number	Recall Date
Hart Scientific	1560	"Black Stack" Base Unit	96539	NCR
Hart Scientific	2560	SPRT Module	A25631	3/24/2021
Fluke	5628	4 Wire SPRT	4303	3/26/2021
Fluke	2566	Thermocouple Scanner	B7A380	3/24/2021
Fluke	9173	Metrology Well, 700 C	B47975	NCR
Fluke	7380	Bath, Ultra Low-Temperature	B2A527	NCR

Calibration Date: 6/18/2020
Temperature: 23.0 C
Humidity: 47%
Customer Order: 74523

Technician:

Julia Kalin

Approved By:

Walter Paulson
QA Manager

Appendix E - Certificates of Calibration

Report of Calibration

Report No: JK202006300-003

Page 2 of 2

Notes: The thermocouple wire meets or exceeds the criteria established for type "J" SPECIAL LIMITS OF ERROR per ASTM E230/E230M-17 table 1 & ISA-MC96.1-1982 Par. 2.5 Table 8 $\pm 1.1^{\circ}\text{C}$ OR $\pm .4\%$ whichever is greater. Lot calibration data supplied for your reference.

Calibrated item meets special limits of error for all results given according to the comparison of "error" reading to the specifications found in ASTM E230/E230M-17 table 1 & MC96.1-1982 table 8; acceptance determination is ultimately the responsibility of the customer, taking into account all uncertainties and other factors. The closer the results are to the specification limits, the greater the risk that the unit under test will be out of tolerance.

Report issue date: JUN 19 2020

Appendix E - Certificates of Calibration

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CERTIFICATE OF CALIBRATION



Certificate No. ACT-1272

Certification Number CK198-33105-466

For Eaton Corporation - ICD
W126 N7250 Flint Drive
Menomonee Falls, WI 53051

Purchase Order # 4044-671109

Test Instrument Data Acquisition Unit

Make Keysight

Model 34972A

Serial Number MY49002695

Identification EM7054



Customer Location ICD

Condition Received In Tolerance

Condition Returned In Tolerance

Calibrated By Alex Paulsen

Technical Review By Tim Bending

Calibration Location FVM

Calibration Conditions 67.8°F, 19.9°C, 57.3%RH

Calibration Date 07/16/2020

Recalibration Due 07/16/2021

Procedures Followed

FVE-000 rev. 2

FVE-006 rev. 2

This certificate shall not be altered in any form or reproduced, except in full, without prior written approval from originating lab. These results relate only to the item(s) calibrated. Form Revision 6: 02/04/2012

Standards Used

Instrument	Serial Number	Trace Number	Next Cal
FVS-275A	RY11838	CJ191-70508-513	07/28/2020
FVS-737	4542903	CK041-57440-531	02/28/2021

Total expanded measurement uncertainties expressed are based on a confidence level of 95%; coverage factor of (k=2). The statement of compliance in this certificate was issued without taking the uncertainty of measurement into consideration. The customer shall assess the results and uncertainty when determining if the results meet their needs. (This is considered "shared responsibility.") Uncertainties expressed in nominal units.

All instruments have been calibrated against standards traceable to NIST. Calibration was completed in accordance with ISO/IEC 17025:2017, ANSI/NCSL Z540-1-1994 and ANSI/NCSL Z540.3-2006. Other standards listed upon request.

Calibration Results

* denotes "Out of Tolerance"

Feature	Nominal	Lower Limit	Upper Limit	As Found	As Left	Uncertainty
Root Difference Square guardbanding method used.						
UUT IDENTIFICATION						
Serial Number: MY49002695 Firmware Level: 1.11-1.12-02-01						
INPUT MODULE CHARACTERISTI CS						
Model: 34901A Firmware Level: 2.3						
SELF TEST				Pass	Pass	

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CERTIFICATE OF CALIBRATION



Certificate No. ACT-1272

Feature	Nominal	Lower Limit	Upper Limit	As Found	As Left	Uncertainty
INTERNAL DMM VERIFICATION						
ZERO OFFSET VERIFICATION						
DC CURRENT						
10 mA Range 0.00000 mA	0.00000	-0.00200	0.00200	0.00003	0.00003	0.000007
100 mA Range 0.0000 mA	0.0000	-0.0050	0.0050	0.0000	0.0000	0.00006
1 A Range 0.000000 A	0.000000	-0.000100	0.000100	0.000001	0.000001	0.0000006
DC VOLTS						
100 mV Range 0.0000 mV	0.0000	-0.0040	0.0040	0.0004	0.0004	0.00007
1 V Range 0.000000 V	0.000000	-0.000007	0.000007	0.000001	0.000001	0.0000007
10 V Range 0.00000 V	0.00000	-0.00005	0.00005	0.00000	0.00000	0.000007
100 V Range 0.0000 V	0.0000	-0.0006	0.0006	0.0000	0.0000	0.00006
300 V Range 0.000 V	0.000	-0.009	0.009	0.000	0.000	0.0006
2 WIRE $\square$						
100 $\square$ Range 0.0000 Ohm	0.0000	-4.0040	4.0040	0.0626	0.0626	0.00007
1 k $\square$ Range 0.000000 kOhm	0.000000	-0.004010	0.004010	0.000065	0.000065	0.0000006
10 k $\square$ Range 0.00000 kOhm	0.00000	-0.00410	0.00410	0.00008	0.00008	0.000006
100 k $\square$ Range 0.0000 kOhm	0.0000	-0.0050	0.0050	0.0002	0.0002	0.00007
1 M $\square$ Range 0.000000 MOhm	0.000000	-0.000014	0.000014	0.000000	0.000000	0.0000007
10 M $\square$ Range						

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CERTIFICATE OF CALIBRATION



Certificate No. ACT-1272

Feature	Nominal	Lower Limit	Upper Limit	As Found	As Left	Uncertainty
0.00000 MOhm	0.00000	-0.00010	0.00010	0.00000	0.00000	0.000007
100 M Ω Range						
0.0000 MOhm	0.0000	-0.0100	0.0100	0.0000	0.0000	0.00006
4 WIRE $\square$						
100 $\square$ Range						
0.0000 Ohm	0.0000	-0.0040	0.0040	-0.0023	-0.0023	0.00006
1 k $\square$ Range						
0.000000 kOhm	0.000000	-0.000010	0.000010	0.000000	0.000000	0.0000006
10 k $\square$ Range						
0.00000 kOhm	0.00000	-0.00010	0.00010	0.00000	0.00000	0.000007
100 k $\square$ Range						
0.0000 kOhm	0.0000	-0.0010	0.0010	0.0000	0.0000	0.00007
1 M $\square$ Range						
0.000000 MOhm	0.000000	-0.000010	0.000010	0.000000	0.000000	0.0000006
10 M $\square$ Range						
0.00000 MOhm	0.00000	-0.00010	0.00010	0.00000	0.00000	0.000006
100 M $\square$ Range						
0.0000 MOhm	0.0000	-0.0100	0.0100	0.0000	0.0000	0.00007
GAIN VERIFICATION						
DC VOLTS						
100 mV Range						
100.0000 mV	100.0000	99.9910	100.0090	100.0000	100.0000	0.00006
-100.0000 mV	-100.0000	-100.0090	-99.9910	-99.9987	-99.9987	0.00007
1 V Range						
1.000000 V	1.000000	0.999953	1.000047	0.999993	0.999993	0.0000007
-1.000000 V	-1.000000	-1.000047	-0.999953	-0.999989	-0.999989	0.0000007
10 V Range						
10.00000 V	10.00000	9.99960	10.00040	9.99994	9.99994	0.000006
-10.00000 V	-10.00000	-10.00040	-9.99960	-9.99992	-9.99992	0.000006
100 V Range						
100.0000 V	100.0000	99.9949	100.0051	99.9996	99.9996	0.00007
-100.0000 V	-100.0000	-100.0051	-99.9949	-99.9993	-99.9993	0.00007
300 V Range						
300.000 V	300.000	299.978	300.022	299.998	299.998	0.0006

Appendix E - Certificates of Calibration

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Certificate No. ACT-1272

Feature	Nominal	Lower Limit	Upper Limit	As Found	As Left	Uncertainty
2 WIRE □						
100 □ Range						
100.0000 Ohm	100.0000	95.9860	104.0140	100.0067	100.0067	0.00007
1 k□ Range						
1.000000 kOhm	1.000000	0.995890	1.004110	1.000032	1.000032	0.0000006
10 k□ Range						
10.00000 kOhm	10.00000	9.99490	10.00510	10.00035	10.00035	0.000007
100 k□ Range						
100.0000 kOhm	100.0000	99.9850	100.0150	100.0029	100.0029	0.00006
1 M□ Range						
1.000000 MOhm	1.000000	0.999886	1.000114	1.000016	1.000016	0.0000006
10 M□ Range						
10.00000 MOhm	10.00000	9.99590	10.00410	9.99768	9.99768	0.000006
100 M□ Range						
100.0000 MOhm	100.0000	99.1900	100.8100	100.3688	100.3688	0.00007
4 WIRE □						
100 □ Range						
100.0000 Ohm	100.0000	99.9860	100.0140	100.0039	100.0039	0.00006
1 k□ Range						
1.000000 kOhm	1.000000	0.999890	1.000110	1.000030	1.000030	0.0000007
10 k□ Range						
10.00000 kOhm	10.00000	9.99890	10.00110	10.00032	10.00032	0.000006
100 k□ Range						
100.0000 kOhm	100.0000	99.9890	100.0110	100.0021	100.0021	0.00007
1 M□ Range						
1.000000 MOhm	1.000000	0.999890	1.000110	0.999970	0.999970	0.0000007
10 M□ Range						
10.00000 MOhm	10.00000	9.99590	10.00410	9.99595	9.99595	0.000006
100 M□ Range						
100.0000 MOhm	100.0000	99.1900	100.8100	99.8275	99.8275	0.00006
DC CURRENT						
10 mA Range						
10.00000 mA	10.00000	9.99300	10.00700	9.99898	9.99898	0.000007
-10.00000 mA	-10.00000	-10.00700	-9.99300	-9.99887	-9.99887	0.000007

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Certificate No. ACT-1272

Feature	Nominal	Lower Limit	Upper Limit	As Found	As Left	Uncertainty
100 mA Range						
100.0000 mA	100.0000	99.9450	100.0550	99.9882	99.9882	0.00006
-100.0000 mA	-100.0000	-100.0550	-99.9450	-99.9879	-99.9879	0.00006
1 A Range						
1.000000 A	1.000000	0.998900	1.001100	0.999534	0.999534	0.0000006
-1.000000 A	-1.000000	-1.001100	-0.998900	-0.999537	-0.999537	0.0000006
AC VOLTS						
100 mV Range						
10.0000 mV @ 1 kHz	10.0000	9.9540	10.0460	9.9997	9.9997	0.00006
100.0000 mV @ 1 kHz	100.0000	99.9000	100.1000	99.9912	99.9912	0.00006
100.0000 mV @ 50 kHz	100.0000	99.8300	100.1700	99.9383	99.9383	0.00006
1 V Range						
1.000000 V @ 20 Hz	1.000000	0.999000	1.001000	0.999803	0.999803	0.0000006
1.000000 V @ 1 kHz	1.000000	0.999000	1.001000	0.999950	0.999950	0.0000006
1.000000 V @ 20 kHz	1.000000	0.999000	1.001000	0.999888	0.999888	0.0000006
1.000000 V @ 50 kHz	1.000000	0.998300	1.001700	0.999504	0.999504	0.0000007
1.000000 V @ 100 kHz	1.000000	0.993200	1.006800	0.998811	0.998811	0.0000006
1.000000 V @ 200 kHz	1.000000	0.955000	1.045000	0.999068	0.999068	0.0000006
1.000000 V @ 250 kHz	1.000000	0.955000	1.045000	0.999202	0.999202	0.0000007
1.000000 V @ 300 kHz	1.000000	0.955000	1.045000	0.998797	0.998797	0.0000006
10 V Range						
0.10000 V @ 1 kHz	0.10000	0.08594	0.11406	0.10086	0.10086	0.000006
1.00000 V @ 1 kHz	1.00000	0.99540	1.00460	0.99992	0.99992	0.000006
10.00000 V @ 10 Hz	10.00000	9.99000	10.01000	9.99743	9.99743	0.000007
10.00000 V @ 1 kHz	10.00000	9.99000	10.01000	9.99855	9.99855	0.000006
10.00000 V @ 50 kHz	10.00000	9.98300	10.01700	9.99499	9.99499	0.000006
100 V Range						
100.0000 V @ 1 kHz	100.0000	99.9000	100.1000	99.9653	99.9653	0.00006
100.0000 V @ 50 kHz	100.0000	99.8300	100.1700	99.8943	99.8943	0.00006

Appendix E - Certificates of Calibration

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Certificate No. ACT-1272

Feature	Nominal	Lower Limit	Upper Limit	As Found	As Left	Uncertainty
300 V Range						
300.000 V @ 1 kHz	300.000	299.580	300.420	299.884	299.884	0.0006
200.000 V @ 50 kHz	200.000	199.400	200.600	199.750	199.750	0.0007
AC CURRENT						
10 mA Range						
10.00000 mA @ 1 kHz	10.00000	9.98600	10.01400	9.99766	9.99766	0.000007
100 mA Range						
100.0000 mA @ 1 kHz	100.0000	99.4000	100.6000	99.9484	99.9484	0.00007
1 A Range						
0.010000 A @ 1 kHz	0.010000	0.008590	0.011410	0.009960	0.009960	0.0000007
1.000000 A @ 1 kHz	1.000000	0.998600	1.001400	0.999502	0.999502	0.0000006
FREQUENCY						
100 Hz Range						
100.0000 Hz	100.0000	99.9000	100.1000	100.0056	100.0056	0.00007
100 kHz Range						
100.0000 kHz	100.0000	99.9900	100.0100	100.0001	100.0001	0.00007

Appendix E - Certificates of Calibration

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CERTIFICATE OF CALIBRATION



Certificate No. ACT-1272

Certification Number CK198-39504-466		Procedures Followed FVE-000 rev. 2 FVE-001 rev. 2		This certificate shall not be altered in any form or reproduced, except in full, without prior written approval from originating lab. These results relate only to the item(s) calibrated. Form Revision 6: 02/04/2012
For Eaton Corporation - ICD W126 N7250 Flint Drive Menomonee Falls, WI 53051				
Purchase Order #	4044-671109	Standards Used		
Test Instrument	Multimeter	Instrument	Serial Number	Trace Number
	Digital Multimeter	FVS-275A	RY11838	CJ191-70508-513
Make	Fluke	FVS-737	4542903	CK041-57440-531
Model	179			07/28/2020
Serial Number	77840008			02/28/2021
Identification	EM4437			
Customer Location	ICD			
Condition Received	In Tolerance	Total expanded measurement uncertainties expressed are based on a confidence level of 95%; coverage factor of (k=2). The statement of compliance in this certificate was issued without taking the uncertainty of measurement into consideration. The customer shall assess the results and uncertainty when determining if the results meet their needs. (This is considered "shared responsibility.") Uncertainties expressed in base units.		
Condition Returned	In Tolerance			
Calibrated By	Alex Paulsen	All instruments have been calibrated against standards traceable to NIST. Calibration was completed in accordance with ISO/IEC 17025:2017, ANSI/NCSL Z540-1-1994 and ANSI/NCSL Z540.3-2006. Other standards listed upon request.		
Technical Review By	Tim Bending			
Calibration Location	FVM			
Calibration Conditions	68.3°F, 20.2°C, 56.2%RH			
Calibration Date	07/16/2020			
Recalibration Due	07/16/2021			

Calibration Results

* denotes "Out of Tolerance"

Feature	Nominal	Lower Limit	Upper Limit	As Found	As Left	Uncertainty
AC VOLTS						
600 mV Range						
300.0 mV @ 45 Hz	300.0	296.7	303.3	299.2	299.2	0.07
6 V Range						
5.000 V @ 500 Hz	5.000	4.947	5.053	4.987	4.987	0.0007
5.000 V @ 1 kHz	5.000	4.897	5.103	4.949	4.949	0.0007
60 V Range						
50.00 V @ 45 Hz	50.00	49.47	50.53	49.98	49.98	0.007
50.00 V @ 1 kHz	50.00	48.97	51.03	50.02	50.02	0.007
600 V Range						
300.0 V @ 45 Hz	300.0	296.7	303.3	299.9	299.9	0.07
500.0 V @ 500 Hz	500.0	494.7	505.3	500.5	500.5	0.06
500.0 V @ 1 kHz	500.0	489.7	510.3	500.5	500.5	0.06
1000 V Range						
1000 V @ 45 Hz	1000	987	1013	1002	1002	0.7

Appendix E - Certificates of Calibration

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CERTIFICATE OF CALIBRATION



Certificate No. ACT-1272

Feature	Nominal	Lower Limit	Upper Limit	As Found	As Left	Uncertainty
AC VOLTS FREQUENCY						
45.00 Hz @ 1 V	45.00	44.95	45.06	45.01	45.01	0.007
50.00 kHz @ 5 V	50.00	49.94	50.06	50.00	50.00	0.006
DC VOLTAGE						
6 V Range						
5.000 V	5.000	4.994	5.007	4.997	4.997	0.0006
600 V Range						
300.0 V	300.0	299.5	300.5	299.8	299.8	0.06
1000 V Range						
1000 V	1000	997	1004	999	999	0.6
-1000 V	-1000	-1004	-997	-1000	-1000	0.7
DC VOLTS FREQUENCY						
45.00 Hz @ 3 V	45.00	44.95	45.06	45.01	45.01	0.007
50.00 kHz @ 30 V	50.00	49.94	50.06	50.00	50.00	0.007
DC MILLIVOLTS						
30.0 mV	30.0	29.8	30.2	30.0	30.0	0.06
-300.0 mV	-300.0	-300.5	-299.5	-299.9	-299.9	0.06
600.0 mV	600.0	599.3	600.7	599.7	599.7	0.07
TEMPERATURE						
0.0 °C	0.0	-1.0	1.0	1.0	1.0	0.06
-40.0 °C	-40.0	-41.4	-38.6	-39.0	-39.0	0.07
400.0 °C	400.0	395.0	405.0	400.9	400.9	0.06
OHMS						
600 Ohm Range						
19.0 Ohm	19.0	18.6	19.4	19.3	19.3	0.07
50 MOhm Range						
19.00 MOhm	19.00	18.68	19.32	19.00	19.00	0.006
CAPACITANCE						
1000 nF Range						
900 nF	900	887	913	899	899	0.6
CONTINUITY						
0 Ohms: Beeper On				Pass	Pass	
190 Ohms: Beeper Off				Pass	Pass	
DIODE TEST						

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CERTIFICATE OF CALIBRATION



Certificate No. ACT-1272

Feature	Nominal	Lower Limit	Upper Limit	As Found	As Left	Uncertainty
2.000 V	2.000	1.978	2.022	2.000	2.000	0.0007
AC MILLIAMPS						
60 mA Range						
3.00 mA @ 45 Hz	3.00	2.92	3.08	3.00	3.00	0.007
50.00 mA @ 1 kHz	50.00	49.22	50.78	50.06	50.06	0.006
400 mA Range						
400.0 mA @ 1 kHz	400.0	393.7	406.3	400.4	400.4	0.07
AC AMPS						
6 A Range						
4.000 A @ 45 Hz	4.000	3.937	4.063	4.005	4.005	0.0007
10A Range						
9.00 A @ 1 kHz	9.00	8.84	9.16	9.04	9.04	0.007
DC MILLIAMPS						
60 mA Range						
3.00 mA	3.00	2.94	3.06	3.00	3.00	0.006
50.00 mA	50.00	49.47	50.53	49.92	49.92	0.007
400 mA Range						
-400.0 mA	-400.0	-404.3	-395.7	-399.8	-399.8	0.07
DC AMPS						
6 A Range						
4.000 A	4.000	3.957	4.043	3.999	3.999	0.0007
10 A Range						
-9.00 A	-9.00	-9.12	-8.88	-9.01	-9.01	0.006

Appendix E - Certificates of Calibration

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CERTIFICATE OF CALIBRATION



Certificate No. ACT-1272

Certification Number CK198-38060-466		Procedures Followed FVE-000 rev. 2 FVE-001 rev. 2		This certificate shall not be altered in any form or reproduced, except in full, without prior written approval from originating lab. These results relate only to the item(s) calibrated. Form Revision 6: 02/04/2012
For Eaton Corporation - ICD W126 N7250 Flint Drive Menomonee Falls, WI 53051				
Purchase Order #	4044-671109	Standards Used		
Test Instrument	Multimeter	Instrument	Serial Number	Trace Number
	Digital Multimeter	FVS-275A	RY11838	CJ191-70508-513
Make	Fluke	FVS-737	4542903	CK041-57440-531
Model	175			Next Cal
Serial Number	13700492			07/28/2020
Identification	EM7014			02/28/2021
				
Customer Location	ICD			
Condition Received	In Tolerance	Total expanded measurement uncertainties expressed are based on a confidence level of 95%; coverage factor of (k=2). The statement of compliance in this certificate was issued without taking the uncertainty of measurement into consideration. The customer shall assess the results and uncertainty when determining if the results meet their needs. (This is considered "shared responsibility.") Uncertainties expressed in base units.		
Condition Returned	In Tolerance			
Calibrated By	Alex Paulsen	All instruments have been calibrated against standards traceable to NIST. Calibration was completed in accordance with ISO/IEC 17025:2017, ANSI/NCSL Z540-1-1994 and ANSI/NCSL Z540.3-2006. Other standards listed upon request.		
Technical Review By	Tim Bending			
Calibration Location	FVM			
Calibration Conditions	68.2°F, 20.1°C, 56.6%RH			
Calibration Date	07/16/2020			
Recalibration Due	07/16/2021			

Calibration Results

* denotes "Out of Tolerance"

Feature	Nominal	Lower Limit	Upper Limit	As Found	As Left	Uncertainty
AC VOLTS						
600 mV Range						
300.0 mV @ 45 Hz	300.0	296.7	303.3	299.9	299.9	0.07
6 V Range						
5.000 V @ 500 Hz	5.000	4.947	5.053	4.994	4.994	0.0007
5.000 V @ 1 kHz	5.000	4.897	5.103	4.955	4.955	0.0006
60 V Range						
50.00 V @ 45 Hz	50.00	49.47	50.53	49.94	49.94	0.007
50.00 V @ 1 kHz	50.00	48.97	51.03	50.06	50.06	0.006
600 V Range						
300.0 V @ 45 Hz	300.0	296.7	303.3	299.8	299.8	0.07
500.0 V @ 500 Hz	500.0	494.7	505.3	500.4	500.4	0.07
500.0 V @ 1 kHz	500.0	489.7	510.3	500.4	500.4	0.06
1000 V Range						
1000 V @ 45 Hz	1000	987	1013	996	996	0.6

Appendix E - Certificates of Calibration

Fox Valley Metrology

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CERTIFICATE OF CALIBRATION



Certificate No. ACT-1272

Feature	Nominal	Lower Limit	Upper Limit	As Found	As Left	Uncertainty
AC VOLTS FREQUENCY						
45.00 Hz @ 1 V	45.00	44.95	45.06	45.00	45.00	0.007
50.00 kHz @ 5 V	50.00	49.94	50.06	50.00	50.00	0.007
DC VOLTAGE						
6 V Range						
5.000 V	5.000	4.990	5.010	5.000	5.000	0.0007
600 V Range						
300.0 V	300.0	299.4	300.6	300.0	300.0	0.06
1000 V Range						
1000 V	1000	997	1004	1000	1000	0.7
-1000 V	-1000	-1004	-997	-1000	-1000	0.7
DC VOLTS FREQUENCY						
45.00 Hz @ 3 V	45.00	44.95	45.06	45.00	45.00	0.007
50.00 kHz @ 30 V	50.00	49.94	50.06	50.00	50.00	0.007
DC MILLIVOLTS						
30.0 mV	30.0	29.8	30.2	30.0	30.0	0.07
-300.0 mV	-300.0	-300.6	-299.4	-299.9	-299.9	0.06
600.0 mV	600.0	598.9	601.1	599.9	599.9	0.06
OHMS						
600 Ohm Range						
19.0 Ohm	19.0	18.6	19.4	19.0	19.0	0.07
50 MOhm Range						
19.00 MOhm	19.00	18.68	19.32	18.99	18.99	0.006
CAPACITANCE						
1000 nF Range						
900 nF	900	887	913	900	900	0.7
CONTINUITY						
0 Ohms: Beeper On				Pass	Pass	
190 Ohms: Beeper Off				Pass	Pass	
DIODE TEST						
2.000 V	2.000	1.978	2.022	2.001	2.001	0.0006
AC MILLIAMPS						
60 mA Range						

Appendix E - Certificates of Calibration

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CERTIFICATE OF CALIBRATION



Certificate No. ACT-1272

Feature	Nominal	Lower Limit	Upper Limit	As Found	As Left	Uncertainty
3.00 mA @ 45 Hz	3.00	2.92	3.08	3.01	3.01	0.007
50.00 mA @ 1 kHz	50.00	49.22	50.78	49.96	49.96	0.007
400 mA Range						
400.0 mA @ 1 kHz	400.0	393.7	406.3	399.4	399.4	0.06
AC AMPS						
6 A Range						
4.000 A @ 45 Hz	4.000	3.937	4.063	3.997	3.997	0.0007
10A Range						
9.00 A @ 1 kHz	9.00	8.84	9.16	9.00	9.00	0.007
DC MILLIAMPS						
60 mA Range						
3.00 mA	3.00	2.94	3.06	3.02	3.02	0.006
50.00 mA	50.00	49.47	50.53	49.99	49.99	0.006
400 mA Range						
-400.0 mA	-400.0	-404.3	-395.7	-400.0	-400.0	0.07
DC AMPS						
6 A Range						
4.000 A	4.000	3.957	4.043	3.999	3.999	0.0007
10 A Range						
-9.00 A	-9.00	-9.12	-8.88	-9.00	-9.00	0.007

Appendix E - Certificates of Calibration

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CERTIFICATE OF CALIBRATION



Certificate No. ACT-1272

Certification Number CK198-38779-466		Procedures Followed FVE-000 rev. 2 FVE-001 rev. 2		This certificate shall not be altered in any form or reproduced, except in full, without prior written approval from originating lab. These results relate only to the item(s) calibrated. Form Revision 6: 02/04/2012
For Eaton Corporation - ICD W126 N7250 Flint Drive Menomonee Falls, WI 53051				
Purchase Order #	4044-671109	Standards Used		
Test Instrument	Multimeter	Instrument	Serial Number	Trace Number
	Digital Multimeter	FVS-275A	RY11838	CJ191-70508-513
Make	Fluke	FVS-737	4542903	CK041-57440-531
Model	179			Next Cal
Serial Number	14370601			07/28/2020
Identification	EM7024			02/28/2021
				
Customer Location	ICD			
Condition Received	In Tolerance	Total expanded measurement uncertainties expressed are based on a confidence level of 95%; coverage factor of (k=2). The statement of compliance in this certificate was issued without taking the uncertainty of measurement into consideration. The customer shall assess the results and uncertainty when determining if the results meet their needs. (This is considered "shared responsibility.") Uncertainties expressed in nominal units.		
Condition Returned	In Tolerance			
Calibrated By	Alex Paulsen	All instruments have been calibrated against standards traceable to NIST. Calibration was completed in accordance with ISO/IEC 17025:2017, ANSI/NCSL Z540-1-1994 and ANSI/NCSL Z540.3-2006. Other standards listed upon request.		
Technical Review By	Tim Bending			
Calibration Location	FVM			
Calibration Conditions	68.2°F, 20.1°C, 56.6%RH			
Calibration Date	07/16/2020			
Recalibration Due	07/16/2021			

Calibration Results

* denotes "Out of Tolerance"

Feature	Nominal	Lower Limit	Upper Limit	As Found	As Left	Uncertainty
AC VOLTS						
600 mV Range						
300.0 mV @ 45 Hz	300.0	296.7	303.3	300.0	300.0	0.06
6 V Range						
5.000 V @ 500 Hz	5.000	4.947	5.053	4.997	4.997	0.0006
5.000 V @ 1 kHz	5.000	4.897	5.103	4.961	4.961	0.0006
60 V Range						
50.00 V @ 45 Hz	50.00	49.47	50.53	49.97	49.97	0.006
50.00 V @ 1 kHz	50.00	48.97	51.03	50.10	50.10	0.007
600 V Range						
300.0 V @ 45 Hz	300.0	296.7	303.3	300.0	300.0	0.07
500.0 V @ 500 Hz	500.0	494.7	505.3	500.9	500.9	0.06
500.0 V @ 1 kHz	500.0	489.7	510.3	500.8	500.8	0.06
1000 V Range						
1000 V @ 45 Hz	1000	987	1013	997	997	0.7

Appendix E - Certificates of Calibration

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CERTIFICATE OF CALIBRATION



Certificate No. ACT-1272

Feature	Nominal	Lower Limit	Upper Limit	As Found	As Left	Uncertainty
AC VOLTS FREQUENCY						
45.00 Hz @ 1 V	45.00	44.95	45.06	45.00	45.00	0.007
50.00 kHz @ 5 V	50.00	49.94	50.06	50.00	50.00	0.006
DC VOLTAGE						
6 V Range						
5.000 V	5.000	4.994	5.007	5.000	5.000	0.0006
600 V Range						
300.0 V	300.0	299.5	300.5	299.9	299.9	0.06
1000 V Range						
1000 V	1000	997	1004	1000	1000	0.7
-1000 V	-1000	-1004	-997	-1000	-1000	0.7
DC VOLTS FREQUENCY						
45.00 Hz @ 3 V	45.00	44.95	45.06	45.00	45.00	0.007
50.00 kHz @ 30 V	50.00	49.94	50.06	50.00	50.00	0.006
DC MILLIVOLTS						
30.0 mV	30.0	29.8	30.2	30.0	30.0	0.06
-300.0 mV	-300.0	-300.5	-299.5	-299.9	-299.9	0.06
600.0 mV	600.0	599.3	600.7	599.8	599.8	0.06
TEMPERATURE						
0.0 °C	0.0	-1.0	1.0	0.5	0.5	0.06
-40.0 °C	-40.0	-41.4	-38.6	-39.3	-39.3	0.06
400.0 °C	400.0	395.0	405.0	400.4	400.4	0.06
OHMS						
600 Ohm Range						
19.0 Ohm	19.0	18.6	19.4	19.0	19.0	0.06
50 MOhm Range						
19.00 MOhm	19.00	18.68	19.32	18.98	18.98	0.006
CAPACITANCE						
1000 nF Range						
900 nF	900	887	913	900	900	0.6
CONTINUITY						
0 Ohms: Beeper On				Pass	Pass	
190 Ohms: Beeper Off				Pass	Pass	
DIODE TEST						

Appendix E - Certificates of Calibration

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Certificate No. ACT-1272

Feature	Nominal	Lower Limit	Upper Limit	As Found	As Left	Uncertainty
2.000 V	2.000	1.978	2.022	2.001	2.001	0.0007
AC MILLIAMPS						
60 mA Range						
3.00 mA @ 45 Hz	3.00	2.92	3.08	3.02	3.02	0.006
50.00 mA @ 1 kHz	50.00	49.22	50.78	50.03	50.03	0.006
400 mA Range						
400.0 mA @ 1 kHz	400.0	393.7	406.3	399.9	399.9	0.06
AC AMPS						
6 A Range						
4.000 A @ 45 Hz	4.000	3.937	4.063	4.004	4.004	0.0006
10A Range						
9.00 A @ 1 kHz	9.00	8.84	9.16	9.01	9.01	0.007
DC MILLIAMPS						
60 mA Range						
3.00 mA	3.00	2.94	3.06	3.01	3.01	0.007
50.00 mA	50.00	49.47	50.53	49.99	49.99	0.007
400 mA Range						
-400.0 mA	-400.0	-404.3	-395.7	-399.9	-399.9	0.06
DC AMPS						
6 A Range						
4.000 A	4.000	3.957	4.043	3.998	3.998	0.0006
10 A Range						
-9.00 A	-9.00	-9.12	-8.88	-9.00	-9.00	0.007

Appendix E - Certificates of Calibration

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CERTIFICATE OF CALIBRATION



Certificate No. ACT-1272

Certification Number CK198-41226-466		Procedures Followed FVE-007 rev. 2	This certificate shall not be altered in any form or reproduced, except in full, without prior written approval from originating lab. These results relate only to the item(s) calibrated. Form Revision 6: 02/04/2012															
For Eaton Corporation - ICD W126 N7250 Flint Drive Menomonee Falls, WI 53051																		
Purchase Order #	4044-671109																	
Test Instrument	Clamp Meter																	
Make	AEMC																	
Model	SR759																	
Serial Number	224137GKDV																	
Identification	EM6996																	
Customer Location	ICD																	
Condition Received	In Tolerance																	
Condition Returned	In Tolerance																	
Calibrated By	Alex Paulsen																	
Technical Review By	Tim Bending																	
Calibration Location	FVM																	
Calibration Conditions	67.8°F, 19.9°C, 56.3%RH																	
Calibration Date	07/16/2020																	
Recalibration Due	07/16/2021																	
		Standards Used																
		<table border="1"> <thead> <tr> <th>Instrument</th> <th>Serial Number</th> <th>Trace Number</th> <th>Next Cal</th> </tr> </thead> <tbody> <tr> <td>FVS-275A</td> <td>RY11838</td> <td>CJ191-70508-513</td> <td>07/28/2020</td> </tr> <tr> <td>FVS-546</td> <td>24560221</td> <td>CK093-41519-573</td> <td>04/30/2021</td> </tr> <tr> <td>FVS-737</td> <td>4542903</td> <td>CK041-57440-531</td> <td>02/28/2021</td> </tr> </tbody> </table>	Instrument	Serial Number	Trace Number	Next Cal	FVS-275A	RY11838	CJ191-70508-513	07/28/2020	FVS-546	24560221	CK093-41519-573	04/30/2021	FVS-737	4542903	CK041-57440-531	02/28/2021
Instrument	Serial Number	Trace Number	Next Cal															
FVS-275A	RY11838	CJ191-70508-513	07/28/2020															
FVS-546	24560221	CK093-41519-573	04/30/2021															
FVS-737	4542903	CK041-57440-531	02/28/2021															
		Total expanded measurement uncertainties expressed are based on a confidence level of 95%; coverage factor of (k=2). The statement of compliance in this certificate was issued without taking the uncertainty of measurement into consideration. The customer shall assess the results and uncertainty when determining if the results meet their needs. (This is considered "shared responsibility.") Uncertainties expressed in nominal units.																
		All instruments have been calibrated against standards traceable to NIST. Calibration was completed in accordance with ISO/IEC 17025:2017, ANSI/NCSL Z540-1-1994 and ANSI/NCSL Z540.3-2006. Other standards listed upon request.																

Calibration Results

* denotes "Out of Tolerance"

Feature	Nominal	Lower Limit	Upper Limit	As Found	As Left	Uncertainty
1A Range; 1000mV/A @60 Hz	(mV AC)	(mV AC)	(mV AC)	(mV AC)	(mV AC)	(mV AC)
10 mA	10.0	8.7	11.3	10.1	10.1	0.07
100 mA	100.0	96.0	104.0	101.3	101.3	0.06
500 mA	500.0	495.5	504.5	504.5	504.5	0.06
	(V AC)	(V AC)	(V AC)	(V AC)	(V AC)	(V AC)
1 A	1.000	0.992	1.008	1.008	1.008	0.0006
10A Range; 100mV/A @60 Hz	(mV AC)	(mV AC)	(mV AC)	(mV AC)	(mV AC)	(mV AC)
100 mA	10.0	9.7	10.3	10.0	10.0	0.07
1 A	100.0	99.3	100.7	100.4	100.4	0.07
5 A	500.0	497.5	502.5	501.8	501.8	0.06
	(V AC)	(V AC)	(V AC)	(V AC)	(V AC)	(V AC)
10 A	1.000	0.995	1.005	1.004	1.004	0.0007
100A Range; 10mV/A @60 Hz	(mV AC)	(mV AC)	(mV AC)	(mV AC)	(mV AC)	(mV AC)
1 A	10.0	9.7	10.3	10.0	10.0	0.07
10 A	100.0	99.3	100.7	100.1	100.1	0.06

Appendix E - Certificates of Calibration

Fox Valley Metrology

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CERTIFICATE OF CALIBRATION



Certificate No. ACT-1272

Feature	Nominal	Lower Limit	Upper Limit	As Found	As Left	Uncertainty
50 A	500.0	498.5	501.5	500.3	500.3	0.06
	(V AC)	(V AC)	(V AC)	(V AC)	(V AC)	(V AC)
100 A	1.000	0.998	1.002	1.001	1.001	0.0006
1000A Range; 1mV/A @60 Hz	(mV AC)	(mV AC)	(mV AC)	(mV AC)	(mV AC)	(mV AC)
10 A	10.0	9.7	10.3	10.0	10.0	0.06
100 A	100.0	99.3	100.7	100.1	100.1	0.07
500 A	500.0	499.0	501.0	500.5	500.5	0.07
900 A	900.0	898.0	902.0	901.2	901.2	0.07

Appendix E - Certificates of Calibration

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CERTIFICATE OF CALIBRATION



Certificate No. ACT-1272

Certification Number CK198-40179-466

For Eaton Corporation - ICD
W126 N7250 Flint Drive
Menomonee Falls, WI 53051

Purchase Order # 4044-671109

Test Instrument Clamp Meter

Make AEMC

Model SR759

Serial Number 224139GKDV

Identification EM6997



Customer Location ICD

Condition Received In Tolerance

Condition Returned In Tolerance

Calibrated By Alex Paulsen

Technical Review By Tim Bending

Calibration Location FVM

Calibration Conditions 67.8°F, 19.9°C, 56.3%RH

Calibration Date 07/16/2020

Recalibration Due 07/16/2021

Procedures Followed

FVE-007 rev. 2

This certificate shall not be altered in any form or reproduced, except in full, without prior written approval from originating lab. These results relate only to the item(s) calibrated.
Form Revision 6: 02/04/2012

Standards Used

Instrument	Serial Number	Trace Number	Next Cal
FVS-275A	RY11838	CJ191-70508-513	07/28/2020
FVS-546	24560221	CK093-41519-573	04/30/2021
FVS-737	4542903	CK041-57440-531	02/28/2021

Total expanded measurement uncertainties expressed are based on a confidence level of 95%; coverage factor of (k=2). The statement of compliance in this certificate was issued without taking the uncertainty of measurement into consideration. The customer shall assess the results and uncertainty when determining if the results meet their needs. (This is considered "shared responsibility.") Uncertainties expressed in nominal units.

All instruments have been calibrated against standards traceable to NIST. Calibration was completed in accordance with ISO/IEC 17025:2017, ANSI/NCSL Z540-1-1994 and ANSI/NCSL Z540.3-2006. Other standards listed upon request.

Calibration Results

* denotes "Out of Tolerance"

Feature	Nominal	Lower Limit	Upper Limit	As Found	As Left	Uncertainty
1A Range; 1000mV/A @60 Hz	(mV AC)	(mV AC)	(mV AC)	(mV AC)	(mV AC)	(mV AC)
10 mA	10.0	8.7	11.3	10.1	10.1	0.06
100 mA	100.0	96.0	104.0	101.1	101.1	0.06
500 mA	500.0	495.5	504.5	504.5	504.5	0.06
	(V AC)	(V AC)	(V AC)	(V AC)	(V AC)	(V AC)
1 A	1.000	0.992	1.008	1.008	1.008	0.0006
10A Range; 100mV/A @60 Hz	(mV AC)	(mV AC)	(mV AC)	(mV AC)	(mV AC)	(mV AC)
100 mA	10.0	9.7	10.3	10.0	10.0	0.07
1 A	100.0	99.3	100.7	100.2	100.2	0.06
5 A	500.0	497.5	502.5	500.9	500.9	0.06
	(V AC)	(V AC)	(V AC)	(V AC)	(V AC)	(V AC)
10 A	1.000	0.995	1.005	1.002	1.002	0.0006
100A Range; 10mV/A @60 Hz	(mV AC)	(mV AC)	(mV AC)	(mV AC)	(mV AC)	(mV AC)
1 A	10.0	9.7	10.3	10.0	10.0	0.06
10 A	100.0	99.3	100.7	100.1	100.1	0.07

Appendix E - Certificates of Calibration

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CERTIFICATE OF CALIBRATION



Certificate No. ACT-1272

Feature	Nominal	Lower Limit	Upper Limit	As Found	As Left	Uncertainty
50 A	500.0	498.5	501.5	500.1	500.1	0.06
	(V AC)	(V AC)	(V AC)	(V AC)	(V AC)	(V AC)
100 A	1.000	0.998	1.002	1.001	1.001	0.0006
1000A Range; 1mV/A @60 Hz	(mV AC)	(mV AC)	(mV AC)	(mV AC)	(mV AC)	(mV AC)
10 A	10.0	9.7	10.3	10.0	10.0	0.07
100 A	100.0	99.3	100.7	100.1	100.1	0.06
500 A	500.0	499.0	501.0	500.3	500.3	0.06
900 A	900.0	898.0	902.0	901.4	901.4	0.06

Appendix E - Certificates of Calibration

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CERTIFICATE OF CALIBRATION



Certificate No. ACT-1272

Certification Number CK198-41583-466

For Eaton Corporation - ICD
W126 N7250 Flint Drive
Menomonee Falls, WI 53051

Purchase Order # 4044-671109

Test Instrument Clamp Meter

Make AEMC

Model SR759

Serial Number 239584HKDV

Identification EM8032



Customer Location ICD

Condition Received In Tolerance

Condition Returned In Tolerance

Calibrated By Alex Paulsen

Technical Review By Tim Bending

Calibration Location FVM

Calibration Conditions 67.8°F, 19.9°C, 56.3%RH

Calibration Date 07/16/2020

Recalibration Due 07/16/2021

Procedures Followed

FVE-007 rev. 2

This certificate shall not be altered in any form or reproduced, except in full, without prior written approval from originating lab. These results relate only to the item(s) calibrated.
Form Revision 6: 02/04/2012

Standards Used

Instrument	Serial Number	Trace Number	Next Cal
FVS-275A	RY11838	CJ191-70508-513	07/28/2020
FVS-546	24560221	CK093-41519-573	04/30/2021
FVS-737	4542903	CK041-57440-531	02/28/2021

Total expanded measurement uncertainties expressed are based on a confidence level of 95%; coverage factor of (k=2). The statement of compliance in this certificate was issued without taking the uncertainty of measurement into consideration. The customer shall assess the results and uncertainty when determining if the results meet their needs. (This is considered "shared responsibility.") Uncertainties expressed in nominal units.

All instruments have been calibrated against standards traceable to NIST. Calibration was completed in accordance with ISO/IEC 17025:2017, ANSI/NCSL Z540-1-1994 and ANSI/NCSL Z540.3-2006. Other standards listed upon request.

Calibration Results

* denotes "Out of Tolerance"

Feature	Nominal	Lower Limit	Upper Limit	As Found	As Left	Uncertainty
1A Range; 1000mV/A @60 Hz	(mV AC)	(mV AC)	(mV AC)	(mV AC)	(mV AC)	(mV AC)
10 mA	10.0	8.7	11.3	10.2	10.2	0.07
100 mA	100.0	96.0	104.0	101.1	101.1	0.07
500 mA	500.0	495.5	504.5	504.3	504.3	0.06
	(V AC)	(V AC)	(V AC)	(V AC)	(V AC)	(V AC)
1 A	1.000	0.992	1.008	1.007	1.007	0.0007
10A Range; 100mV/A @60 Hz	(mV AC)	(mV AC)	(mV AC)	(mV AC)	(mV AC)	(mV AC)
100 mA	10.0	9.7	10.3	10.0	10.0	0.07
1 A	100.0	99.3	100.7	100.2	100.2	0.07
5 A	500.0	497.5	502.5	500.7	500.7	0.06
	(V AC)	(V AC)	(V AC)	(V AC)	(V AC)	(V AC)
10 A	1.000	0.995	1.005	1.002	1.002	0.0006
100A Range; 10mV/A @60 Hz	(mV AC)	(mV AC)	(mV AC)	(mV AC)	(mV AC)	(mV AC)
1 A	10.0	9.7	10.3	10.0	10.0	0.07
10 A	100.0	99.3	100.7	100.0	100.0	0.07

Appendix E - Certificates of Calibration

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CERTIFICATE OF CALIBRATION



Certificate No. ACT-1272

Feature	Nominal	Lower Limit	Upper Limit	As Found	As Left	Uncertainty
50 A	500.0	498.5	501.5	500.0	500.0	0.07
	(V AC)	(V AC)	(V AC)	(V AC)	(V AC)	(V AC)
100 A	1.000	0.998	1.002	1.000	1.000	0.0007
1000A Range; 1mV/A @60 Hz	(mV AC)	(mV AC)	(mV AC)	(mV AC)	(mV AC)	(mV AC)
10 A	10.0	9.7	10.3	10.0	10.0	0.07
100 A	100.0	99.3	100.7	100.0	100.0	0.06
500 A	500.0	499.0	501.0	500.3	500.3	0.07
900 A	900.0	898.0	902.0	900.6	900.6	0.07

Appendix E - Certificates of Calibration

Fox Valley Metrology

3114 Medalist Drive
Oshkosh, WI 54902
(920) 426-5894 • Fax (920) 426-8120
<http://www.FoxValleyMetrology.com>

CERTIFICATE OF CALIBRATION



Certificate No. ACT-1272

Certification Number CK196-72143-379

For Eaton Corporation - ICD
W126 N7250 Flint Drive
Menomonee Falls, WI 53051

Purchase Order # 4044-671109
Test Instrument Torque Wrench

Make CDI
Model 1502LDIN (3%)
Serial Number 0312910937
Identification EM8363



Customer Location ICD

Condition Received In Tolerance
Condition Returned In Tolerance
Calibrated By Jim Peterson
Technical Review By Kevin Dehne
Calibration Location FVM
Calibration Conditions 69.0°F, 20.6°C, 54.2%RH
Calibration Date 07/14/2020
Recalibration Due 07/14/2021

Procedures Followed
FVE-014 rev. 2

This certificate shall not be altered in any form or reproduced, except in full, without prior written approval from originating lab. These results relate only to the item(s) calibrated.
Form Revision 6: 02/04/2012

Standards Used

Instrument	Serial Number	Trace Number	Next Cal
FVS-093	03111	CK191-31886-628	10/31/2020
FVS-275A	RY11838	CJ191-70508-513	07/28/2020

Total expanded measurement uncertainties expressed are based on a confidence level of 95%; coverage factor of (k=2). The statement of compliance in this certificate was issued without taking the uncertainty of measurement into consideration. The customer shall assess the results and uncertainty when determining if the results meet their needs. (This is considered "shared responsibility.") Uncertainties expressed in nominal units.

All instruments have been calibrated against standards traceable to NIST. Calibration was completed in accordance with ISO/IEC 17025:2017, ANSI/NCSL Z540-1-1994 and ANSI/NCSL Z540.3-2006. Other standards listed upon request.

Calibration Results

* denotes "Out of Tolerance"

Feature	Nominal	Lower Limit	Upper Limit	As Found	As Left	Uncertainty
Clockwise	(in lb)	(in lb)	(in lb)	(in lb)	(in lb)	(in lb)
	30.00	29.10	30.90	29.89	29.89	0.091
	90.00	87.30	92.70	90.23	90.23	0.271
	150.00	145.50	154.50	152.00	152.00	0.450
Counter Clockwise	(in lb)	(in lb)	(in lb)	(in lb)	(in lb)	(in lb)
	30.00	29.10	30.90	30.31	30.31	0.091
	90.00	87.30	92.70	89.53	89.53	0.271
	150.00	145.50	154.50	148.58	148.58	0.450

Appendix E - Certificates of Calibration

Fox Valley Metrology

3114 Medalist Drive
Oshkosh, WI 54902
(920) 426-5894 • Fax (920) 426-8120
<http://www.FoxValleyMetrology.com>

CERTIFICATE OF CALIBRATION



Certificate No. ACT-1272

Certification Number CK198-49542-348

For Eaton Corporation - ICD
W126 N7250 Flint Drive
Menomonee Falls, WI 53051

Purchase Order # 4044-671109
Test Instrument Tape Measure

Make Stanley
Model 30-824

Serial Number
Identification EM6927



Customer Location ICD
Tony

Condition Received In Tolerance
Condition Returned In Tolerance
Calibrated By Matthew Roughen
Technical Review By Laura Fuhrmann
Calibration Location FVM
Calibration Conditions 69.5°F, 20.8°C, 34.8%RH
Calibration Date 07/16/2020
Recalibration Due 07/16/2021

Procedures Followed
FVM-042 rev. 1

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Form Revision 6: 02/04/2012

Standards Used

Instrument	Serial Number	Trace Number	Next Cal
FVM-044	C404R	CH121-20770-384	05/28/2022
FVM-079A	RY11924	CJ191-72229-513	07/28/2020

Total expanded measurement uncertainties expressed are based on a confidence level of 95%; coverage factor of (k=2). The statement of compliance in this certificate was issued without taking the uncertainty of measurement into consideration. The customer shall assess the results and uncertainty when determining if the results meet their needs. (This is considered "shared responsibility.") Uncertainties expressed in nominal units.

All instruments have been calibrated against standards traceable to NIST. Calibration was completed in accordance with ISO/IEC 17025:2017, ANSI/NCSL Z540-1-1994 and ANSI/NCSL Z540.3-2006. Other standards listed upon request.

Calibration Results

* denotes "Out of Tolerance"

Feature	Nominal	Lower Limit	Upper Limit	As Found	As Left	Uncertainty
Length	(in)	(in)	(in)	(in)	(in)	
	12.000	11.969	12.031	11.995	11.995	0.0006
	24.000	23.938	24.062	23.995	23.995	0.0007
	48.000	47.938	48.062	47.995	47.995	0.0007
	72.000	71.938	72.062	71.995	71.995	0.0007
	144.000	143.938	144.062	143.995	143.995	0.0006
	216.000	215.938	216.062	215.995	215.995	0.0006
Length	312.000	311.938	312.062	311.995	311.995	0.0007
	(cm)	(cm)	(cm)	(cm)	(cm)	
	500.00	499.00	501.00	499.87	499.87	0.007
	1000.00	999.00	1001.00	999.87	999.87	0.006
	5000.00	4999.00	5001.00	4999.87	4999.87	0.008
	8000.00	7999.00	8001.00	7999.87	7999.87	0.012

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NAT'L INST OF STANDARDS & TECH R.I.C.



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Meese, William J./Analysis of current tec
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U.S. DEPARTMENT OF COMMERCE / National Bureau of Standards



Analysis of Current Technology on Electrical Connections in Residential Branch Circuit Wiring

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JUL 11 1975

Analysis of Current Technology on Electrical Connections in Residential Branch Circuit Wiring

NBS

William J. Meese and
Ramon L. Cilimberg

Center for Building Technology
Institute for Applied Technology
National Bureau of Standards
Washington, D.C. 20234

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ADDENDUM TO NATIONAL BUREAU OF STANDARDS BSS 63 (MAR. 75) by Meese and Cilimberg

In late 1973, the Consumer Product Safety Commission requested the National Bureau of Standards to investigate the safety of aluminum branch circuit wiring in homes. This work included the evaluation of reports on the hazards, study of technical work of other organizations, and a technical study of the problem. The work at the National Bureau of Standards continued actively through 1974.

The NBS Programmatic Center for Consumer Product Safety issued a special report to the Commission on this subject, NBSIR 75-723 -- Aluminum Branch Circuit Wiring in Residences; Summary Report for the Consumer Product Safety Commission, January-September, 1974. This report is available for purchase from the National Technical Information Service, Springfield, Va., 22151, as is another NBS report, NBSIR 75-677 -- Hazard Assessment of Aluminum Electrical Wiring in Residential Use, published under date of March 27, 1975.

The Consumer Product Safety Commission held Public Hearings on the Safety of Aluminum Wire in Washington, D.C. in March 1974, and in Los Angeles in April 1974. An abstract of these hearings is included in NBSIR 75-723.

ERRATA TO BSS 63

Replace Figure 6 (p.9) with the following:

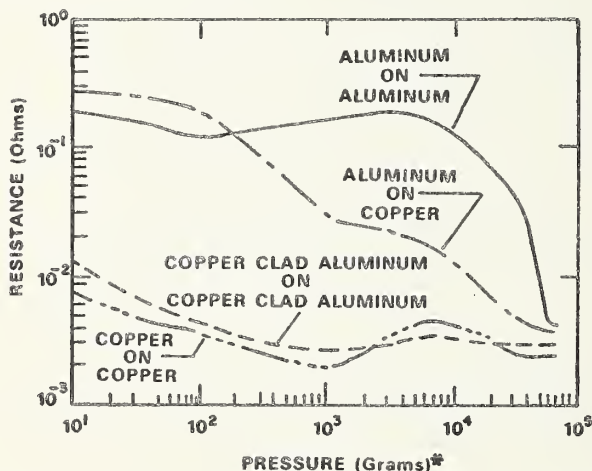


Figure 6. Contact Resistance versus Pressure (Two Conductors Crossed Under Load).

*Force (grams) — one gram-force = .009806650 newton

An Analysis of Current Technology on Electrical Connections in Residential Branch Circuit Wiring

William J. Meese and Ramon L. Cilimberg

In the Operation BREAKTHROUGH research and demonstration program the U.S. Department of Housing and Urban Development became concerned with the inability to properly evaluate innovative electrical connections. Long life requirements, fire safety considerations, the lack of adequate technical information, and long established conventional practices and evaluation procedures have led to slow-changing regulations concerning electrical connections used in branch circuit wiring in housing. This report discusses the present methods of evaluating electrical connections, the technical parameters involved, and innovative electrical connection developments. Innovations involving electrical connections may lead to significant advancements in housing construction if it can be demonstrated that functional and safety requirements over the expected life of the electrical connections are adequately satisfied. Research is needed to enable prediction of long-term performance of electrical connections based on the results of accelerated performance tests.

Key words: Contact resistance; electrical codes; electrical connections; fire safety; house wiring; materials properties; performance testing.

1. Introduction

In 1969 the U.S. Department of Housing and Urban Development initiated the Operation BREAKTHROUGH program; one of its purposes was to encourage and demonstrate innovations in housing [1, 2, 3, 4].¹ In the Operation BREAKTHROUGH program several innovations involving electrical connections were proposed, including connections which would be inaccessible after completion of building construction. Conservative reviews were required due to the fire hazard potential and the lack of durability and other technical information available. Approvals for innovations involving electrical systems were sparingly given. However, the possibilities of almost immediate significant breakthroughs were recognized.

The U.S. Department of Housing and Urban Development agreed to sponsor at the National Bureau of Standards a long-range research project on electrical connections in residential branch circuit wiring. The long-range goal of this project is to develop criteria and test methods for evaluating innovative electrical connections. This report is the first publication for this project.

1.1. Scope

This report covers the state of the art of electrical connections used in branch circuit wiring in housing. "Branch circuit" is defined by the National Electrical Code [5] as:

A branch circuit is that portion of the wiring system between the final overcurrent device protecting the circuit and the outlet(s). A device not approved for branch circuit protection such as thermal cutout or motor overload protective device is not considered as the overcurrent device protecting the circuit.

Branch circuits in housing are generally limited to nominal 115 or 230 volts with rated ampacity (current carrying capacity in amperes) of not less than 15 or more than 50. Generally, wires involved are not larger than #6 AWG nor smaller than #14 AWG for copper conductors, and #12 AWG for aluminum or copper clad aluminum conductors. Tap conductors for lighting fixtures (fixture wiring) and other equipment connected to branch circuits may be as small as #18 AWG for copper conductors.

Both wire-to-wire and wire-to-terminal (such as wire-to-terminal parts on receptacles, switches, lighting fixtures or permanent appliances, etc.) connections which are made in the field or in a housing or mobile home factory are included in this study. Connections which are normally made as a part of the manufacturing process of electrical equipment are not included.

This research project was not created in response to reported problems with aluminum wire electrical connections [6] and it is not the intent of this state-of-the-art report to evaluate the use of aluminum wire in branch circuits. However, nearly all recent research concerning branch circuit electrical connections has been addressed to aluminum wiring problems. Pertinent information based on this research is included in this report.

All electrical cables with aluminum conductors in sizes used in residential branch circuits which were listed by Underwriters' Laboratories (U.L.) prior to 1973 have been withdrawn from U.L. listings [7]. U.L. has subsequently listed a number of other electrical cables with specific aluminum alloys [8]. Also, U.L. has revised its requirements for connections listed for use with aluminum conductors [9]. This has out-dated all pre-1973 connectors (such as terminals on receptacles) listed for use with aluminum conductors in residential branch circuits. Information concerning what could or should be done with pre-1973 aluminum wiring installations is outside of the scope of this report and this project.

¹ Figures in brackets refer to references at end of paper.

1.2. Background

In the United States approximately 28,000 electrical contractors employ 237,000 electrical workers and 60,000 overhead workers [10]. (Electrical Contractor Magazine.) They have approximately \$12 billion annually in sales. Approximately 35.2 percent of this total is spent on electrical labor, 38.4 percent on materials, and 26.4 percent on indirect expenses, overhead, profit and taxes.

Of the \$12 billion in sales, approximately 25.8 percent is for one- and two-family residential, 6.3 percent for apartment residential, 24.6 percent for commercial, 22.3 percent for industrial, 12.0 percent for institutional, and 9.0 percent for other types of occupancies. The \$12 billion in sales primarily represents electrical work by contractors in conventional construction and does not include electrical work in mobile homes or factory-built housing. Also, it includes only a small portion of the electrical work done by utilities and only part of the electrical work done by industrial establishments.

The major portion of the electrical work by contractors in conventional residential construction is in branch circuit wiring. The major part of the work of branch circuit wiring is the making of electrical connections, including the installations of outlet, junction or other boxes and the mechanical fastening of electrical cable to boxes. Electrical connections in branch circuit wiring appear to be the primary area in electrical construction where considerable savings in cost and time are almost immediately possible.

a. Fire Hazard Considerations

Electrical wiring and equipment are among the leading causes of accidental fires. In 1971 they accounted for 160,900 of 996,600 building fires. Motors and power-consuming appliances accounted for 62,100 of these fires; wiring and general equipment accounted for the other 98,800 [11]. (NFPA Statistics.) While available statistics are not in sufficient detail to determine how many of these fires involve connections or terminals, it is believed that a large number of them which do not involve motors or other power-consuming equipment are started at connections.

By 1968 field reports indicated that aluminum wiring was sometimes overheating at screw terminals on receptacles in branch circuit residential applications [7]. Further indications of problems with aluminum wiring appeared in 1970 when 25 incidents of fire in 2000 California homes wired with aluminum were believed to have been caused by faulty electrical terminations [6]. Subsequently a study by Underwriters' Laboratories estimated that 80 percent of the failures in branch circuit wiring involved connections and showed that failures involved both aluminum and copper wire installations [9].

b. Electric Shock Considerations

Protection against electric shock and electrocution is a major consideration in determining requirements for

electrical installations. Approximately 1,000 deaths annually are attributable to electrocution. Of these approximately 300 are associated with residential occupancies [12] (National Safety Council Statistics).

It is usual practice to require that those parts of electrical equipment operating at 50 volts or more (Sec. 250-3 of NEC) be guarded against accidental contact. It is also usual practice to ground non-current-carrying conductive parts of electrical equipment. Large metal objects, such as metal siding, are often grounded for protection in the event they may come in contact with live electrical conductors. Section 250-44 of the National Code [5] recommends grounding of large metal objects.

c. Industrialized Housing Needs

Nearly all major parts of houses, such as exterior and interior walls, ceiling, and "floor-ceiling" assemblies, incorporate electric wire and equipment (switches, receptacles, lighting fixtures, etc.). Installing the type of electrical systems used in conventional housing becomes an impediment to industrialized or mass-produced housing since it is required that all electrical connections be in junction, outlet, switch or other boxes. The advantages of not requiring that electrical connections be accessible after completion of building construction became apparent with advancements in the construction processes.

1.3. Definitions of Special Terms

Several special terms used throughout this report are defined as follows:

a. Electrical Connection Component

Electrical connection component is defined as all parts of the hardware directly concerned with the proper functioning and safety of the electrical connection. As described below, this would include the continuous current path elements, the dielectric element, and the enclosure element.

b. Continuous Current Path Element

Continuous current path element is defined as the electric connection point or area and electric wire and other parts in the vicinity of the connection point through which current is intended to flow and which are directly involved in the proper functioning and safety of the connection. In conventional construction this would include metal portions of "wire-nuts" in wire-to-wire connections and wire binding screw terminals on wire-to-terminal connections. Also included are the grounding connection point or area; and the wire and metal parts in the vicinity directly involved in the proper functioning and safety of the grounding connection. In this report "continuous current path elements" are generally referred to in the plural because an electric connection usually involves more than one joint or connection.

c. Dielectric Element

Dielectric element is defined as insulating material in the vicinity of the electric connection point or area. Insulating material must completely surround the continuous current path elements. The dielectric element may be "air." This is the case where receptacles or switches are rigidly held in place within an outlet box and electrical connections are made by means of wire binding screws.

d. Enclosure Element

Enclosure element is defined as rigid metallic or non-metallic material which surrounds an electrical connection and prevents persons, other building components or other objects from coming in contact with the continuous current path elements. In conventional construction a switch, outlet or junction box is the enclosure. The same piece of hardware may perform both the function of the dielectric element, which is an electrical function, and the function of the enclosure, which is a mechanical function.

e. Other Building Components

Other building components is defined as parts of the building other than electrical connection components. This would include studs and other structural parts, nails, gypsum board, pipes, ducts, and wiring other than that included in Definition 1.3.b.

2. Traditional Approach

The traditional approach to branch circuit wiring connections is the on-site: (1) fastening of outlet, junction or other boxes to building components, (2) fastening of electrical cable to boxes, and (3) making of electrical connections in boxes. Wire-connectors (wire nuts) are normally used for "wire-to-wire" connections and wire binding screws or studs and nuts having up-turned lugs are normally used for "wire-to-terminal" connections. In some cases connections are soldered with a fusible metal alloy. Pressure cable connectors, pressure terminal connectors and soldering lugs are sometimes used.

There have been improvements in electrical cable insulation. New materials have been introduced, such as aluminum wire and non-metallic sheathed cable and non-metallic outlet boxes. However, the traditional approach to branch circuit wiring has changed very little over the past 25 or more years.

3. Current Evaluation System

In the United States, the evaluation and approval of electrical connections and other electrical construction in housing primarily involves three entities, which are; (1) local authorities, (2) the National Electrical Code (NEC) [5] and (3) Underwriters' Laboratories, Inc. (U.L.).

3.1. Local Authorities

Local authorities usually determine legal requirements which apply to electrical construction in their areas. In practice, however, local authorities usually follow the National Electrical Code for installation requirements and approve only manufactured electrical components which have been listed by Underwriters' Laboratories, Inc.

In some cases local authorities adopt the National Electrical Code with modifications. Such modifications usually make legal requirements more restrictive than corresponding NEC requirements. For example, some jurisdictions prohibit the installation of non-metallic sheathed cable [13] or electrical cable with aluminum conductors [7].

The inspection of electrical construction is usually done by local authorities. The National Electrical Code and any local amendments to the NEC are referred to in the event of any controversy concerning wiring methods or requirements. Otherwise, the safety and adequacy of electrical installations are evaluated by the judgment of electrical inspectors.

3.2. National Electrical Code

The National Electrical Code [5] is promulgated under procedures of the National Fire Protection Association (NFPA) and the American National Standards Institute (ANSI). The Rules of Procedure for amending the NEC are detailed in an appendix to the NEC.

The National Electrical Code, as published, is a voluntary standard. However, it affects construction throughout the United States because of its adoption by state, local, or other enforcing authorities. In areas where there are very limited or no legal requirements, or where legal requirements are not rigidly enforced, some contractors still conform to the National Electrical Code. In the event of fire or accident, courts generally accept the National Electrical Code as acceptable good practice. Eight hundred thousand copies of the 1968 NEC, which was superseded in 1971, were published.

The National Electrical Code is an "installation" code. It states in generic terms what may be installed for different types of construction and for given conditions, and sets forth installation requirements. It is a combination of performance (stating what is to be accomplished) and specification (detailing specific methods, materials or components) requirements. An Electrical Code for One and Two Family Dwellings, which is excerpted from the National Electrical Code [14] also has been published.

Responsibility for revision of the NEC is divided among approximately 22 panels (subcommittees) with a correlating committee overseeing and coordinating the work of the panels. The panels consist of representatives from varied interests such as electrical manufacturers, electrical contractors, electrical utilities, electricians, insurance, electrical and building inspectors, and other governmental authorities. The NEC is revised

on a three-year schedule and there are provisions for interim amendments. All properly submitted revisions are considered by the appropriate NEC panel. Approximately 1800 revisions to the 1974 NEC edition have been proposed.

The NEC covers requirements for electrical construction except for the suppliers' or utilities part of electrical systems. Requirements for electrical and communication utilities' facilities are generally covered by the National Electrical Safety Code [15, 16, 17, 18].

It is virtually impossible for new products to enter the market place in any significant quantity unless there is conformity with the National Electrical Code. Because of potential fire and shock hazards of electricity, it is difficult for innovations to gain approval without in-use experience. National Electrical Code requirements are principally the result of long experience with electrical construction.

a. NEC Requirements for Electrical Connections

Section 110-14 Electrical Connections, of the National Electrical Code, which is listed in Item A of the Appendix to this report, requires that connecting devices be "suitable for the purpose." This performance language permits the use of innovative connecting devices which have been properly tested and evaluated by organizations such as Underwriters' Laboratories. Developers of innovative connections do not consider rules strictly relating to electrical connections as being restrictive.

b. NEC Requirements for Boxes

Section 300-15(b) of the National Electrical Code states that a box shall be installed at each conductor splice connection point, outlet, switch point, junction point or pull point for the connection of metal clad cable, mineral insulated metal sheathed cable, aluminum sheathed cable, non-metallic sheathed cable, or other cables, and at each outlet and switch point for concealed knob and tube wiring. (See item B of appendix.) For concealed knob and tube work, splices may be made outside of boxes; however, boxes are required for terminal connections (see item F of appendix). Section 370-6 requires a certain volume of free space in each box depending on the number and size of the conductors and the fittings or devices such as switches or receptacles which are in the box (see item C of appendix). For example, each number 14 conductor requires 2 in³ of free space; each number 12 requires 2.25 in³. These requirements concerning boxes appear to constrain innovations.

The requirements concerning boxes appear to constitute an immediate issue which this research project must face. Reference [19] (National Electrical Handbook) states that the "purpose of an outlet box is to provide an enclosure for circuit wire where they are brought out for connection to a fixture or other device. This enclosure is particularly necessary on account of the splices which the box may contain. The enclosure should be made complete by means of a cover of some kind." Boxes are necessary for fire and electrical safety

purposes for conventional electrical systems. However, whether boxes are necessary in innovative electrical systems is a very important question. It appears that very significant cost and time saving advancements in branch circuit wiring systems could be effected, almost immediately, if the requirements for boxes were eliminated, provided, of course, that fire and electrical safety aspects were provided for in other ways.

There are exceptions to the requirements for boxes for (1) exposed cable wiring, (2) concealed work in rewiring existing buildings, and (3) wiring in mobile homes. A technical reason for these exceptions is not obvious.

Section 331-11, Devices of Insulating Material, permits the use of switch, outlet, and tap devices of insulating material without the use of boxes in exposed cable wiring and for concealed work for rewiring in existing buildings where the cable is concealed and fished (see item E of appendix).

Section 550-8(j) of the National Electrical Code permits outlet boxes of dimensions less than those required in Tables 370-6(a) (1) and 370-6(a) (2) in mobile homes (see item D of appendix). There is essentially "zero space" for some innovative connections which are described in this paper and are listed by Underwriters' Laboratories (see subsection 10.2 of this report).

Section 550-8(j), however, only applies to mobile homes. A technical reason for less stringent requirements for mobile homes is not known. Actually, mobile homes may need more stringent requirements because they may be subject to more severe vibrations than conventionally built homes.

Requirements for boxes in conventionally-built and factory-built homes need intensive evaluation because of the very significant and very immediate effect they have on housing technology.

c. NEC Accessibility Requirements

There has been a long established requirement that all electrical connections be accessible after building construction has been completed. Section 370-19 of the National Electrical Code states that "junction, pull, and outlet boxes shall be so installed that the wiring contained in them be rendered accessible without removing any part of the building, sidewalk or paving." (See item G of appendix.) In conventional electrical systems there is need for repairing or replacing connections or connecting devices. Because of this it appears certain that inaccessible connections will not be permitted unless there is convincing proof of their durability and safety.

However, with the advent of industrialized housing, there is a growing desire to make use of inaccessible connections. In Operation BREAKTHROUGH, two housing producers proposed using inaccessible "quick make-up" connectors. Neither was used because of the lack of technical knowledge and tests to evaluate the durability of these connectors.

3.3. Underwriters' Laboratories

Nearly all testing for safety of manufactured elec-

trical products is done by Underwriters' Laboratories (U.L.), a non-profit, private corporation. Underwriters' Laboratories lists manufactured products which they have tested and found satisfactory. U.L. develops its own test methods and standards. Non-metallic sheathed cable, armored cable, wire connectors and soldering lugs, and outlet boxes and fittings are some of the electrical products covered by Underwriters' standards which interface with branch circuit electrical connections [20, 21, 22, and 23]. Other U.L. standards which include specifications and tests for wire leads and wire terminals intended for connections to branch circuits, include equipment such as snap switches [24], attachment plugs and receptacles [25], and electric light fixtures [26].

In the case of innovative or other products for which a standard does not exist, the product is evaluated in accordance with the judgment of Underwriters' Laboratories, using established tests or procedures to the extent applicable or possible.

"Testing for Safety" [27], published by Underwriters' Laboratories, describes its purpose, procedures, facilities and equipment, services available, and policy-making councils. Underwriters' Laboratories has no legal authority to "approve" products for installation or sale. U.L. uses the word "list" and not "approve" in referring to products it has found satisfactory. Approval of products is the function of the enforcing authority having jurisdiction. The procedures of most enforcing authorities do not call for listing by Underwriters' Laboratories as the sole criterion for approving electrical products. However, in practice, listing by U.L. usually becomes tantamount to local approval provided local electrical regulations are not more stringent than those of the National Electrical Code, in which case the use of certain types of electrical products may be prohibited [13].

Electrical products are listed in two volumes; Electrical Construction Materials List [28], and Electric Appliance and Utilization Equipment List [29]. Thousands of specific manufactured electrical products are listed in each of these volumes. Additions and deletions to these lists and to other products listed by Underwriters' Laboratories are published quarterly [30].

A long-standing policy of Underwriters' Laboratories is to list only products which may be installed in accordance with the National Electrical Code. Special conditions and instructions governing the use of a product category or a specific listed product are published in their lists [28, 29].

For example, a part of the text for "wire connectors" states "wire connectors are listed for No. 18 AWG or larger copper conductors and/or No. 12 AWG or larger aluminum conductors. They are for use in accordance with the National Electrical Code."

The text, listing a type of receptacle described in subsection 10.2. of this report, states: "Receptacles for factory assembly on type NM or NMC cable in mobile homes without a separate outlet box, 15a, 125v, grounding type Type HW-1."

4. Other Electrical Connection Specifications, Standards and Tests

The state of the art concerning the requirements for and the evaluation of branch circuit electrical connections in the United States is represented by the National Electrical Code and appropriate standards of Underwriters' Laboratories as discussed in subsection 3.2., 3.3. and 6.1. of this report. Other standards, specifications, and test methods which may have some application are listed below.

4.1. American National Standards

The C73 series of American National Standards specifies dimensions and configurations of caps, plugs, and receptacles [31]. The other American National Standard on electrical connections concerns highly reliable soldered connections in Electronic and Electrical Applications [32].

4.2. Federal Specifications

The Index of Federal Specifications [33] lists two electrical connector specifications [34 and 35]. In the context of these Federal Specifications, attachment plugs and receptacles are connectors and the connection between these devices is the primary concern. The permanent connection between a receptacle and the branch circuit wiring is not specifically addressed.

4.3. Military Specifications

There are over 900 military specifications for electrical connectors [36]. Most of these are for very special or very limited applications. References 37 through 41 list some of these specifications. None of these specifications is concerned with electrical connections in branch circuit wiring. A number of test methods to determine various properties or characteristics are described. These tests appear to have little application to this project.

4.4. National Electrical Manufacturers' Association

Standards of the National Electrical Manufacturers' Association concerning electrical connectors generally involve connections using larger wires and applications other than branch circuit wiring. Reference 42 on Electric Power Connectors defines and describes various types of electrical conductors. Test methods are not described.

4.5. American Society for Testing and Materials

Reference 43 describes standard methods for measuring contact resistance of electrical connections (static contacts). (See subsection 8.1. of this report.) Contact resistance is not measured by Underwriters' Laboratories in their test procedures.

5. Field Performance of Electrical Connections

An attempt to determine the field performance of electrical connections is represented by Reference 9. U.L. responded to the aluminum wiring problem [6, 7] by sending 1000 questionnaires to industrial users of electrical equipment and 11,500 questionnaires to electrical contractors and electrical inspectors. The response from industry was 17 percent and from contractors and inspectors was 13.5 percent. The survey is briefly summarized as follows:

(a) There is a usage of copper to aluminum of 4 to 1.

(b) Estimated causes of failure and percent occurrence:

Loose connections	54%
Design	16%
Environment	14%
Improper Metals	9%
Overload Conditions	6%

(c) 71 percent of the failure problems were corrected by replacing damaged parts and 22 percent were corrected by replacing wire.

A second list of more detailed questions was sent by U.L. to 194 electrical inspectors who provided the following information:

(a) Loose connections are caused by failure to tighten screws (workmanship) and/or small bolts, small screwdriver slots and weak connector metals (design).

(b) Wire, particularly aluminum wire, often breaks when being bent to fit into available wiring spaces.

(c) Corrosion due to improper use of dissimilar metals or to wet or damp environments contributed to connector failures.

(d) Consideration of the properties of thermoplastic insulation is necessary to assure that involvement of the insulation in an overheating problem will not be a contributing cause to more rapid deterioration of the connection itself.

6. Electrical Connection Research and Testing

Branch circuit electrical connection research and testing consists principally of U.L. accelerated tests, seven years of testing by the United Kingdom, and unpublished work at the Battelle Memorial Institute. The goals of accelerated testing are (1) to induce, in a much shorter period of time, changes in properties representative of those caused by long-term service, and (2) to relate the time required to induce a property change to that required by long-term service.

The second goal of accelerated testing is seldom fulfilled and the lack of an accurate time relationship between the results of accelerated testing and long-term service makes difficult the interpretation of accelerated

test results. Therefore, predictions of durability involve judgmental factors which are based on changes in properties of materials relative to how these materials are installed in systems and the subsequent service conditions of the systems.

6.1. U.L. Accelerated Tests

In the United States acceptance testing of conventional electrical connections in branch circuit wiring is principally the accelerated tests performed by Underwriters' Laboratories [44]. Specific tests include (1) heat cycling with wire disturbance, (2) heat cycling with vibration, (3) environmental and (4) stripping torque.

6.2. Seven-Year Tests in the United Kingdom

British Insulated Callender's Cables Ltd. (BICC) performed tests (high currents, cyclic loading) on connectors not commonly used in the United States or Canada, over a period of seven years [45]. These tests compared the results of using solid copper, copper-clad aluminum and solid aluminum wire.

a. High Current Tests

The effects of high currents on standard connectors and wire were determined by measuring the time to cause failure in typical simulations. Connector temperatures were measured with thermocouples and failure was defined as the time taken to reach 175 °C.

Figure 1 shows current (in amperes) plotted against the time to failure (in hours) for a circuit. The dotted portions of the curves are extrapolated. Figure 2 provides data for a lighting circuit.

The significance of these curves is that they show the relative durability of copper, copper-clad aluminum, and solid aluminum wire as a function of wire gage, current rating, and failure. Thirty thousand hours are considered to be equivalent to a 20-year life for wiring.

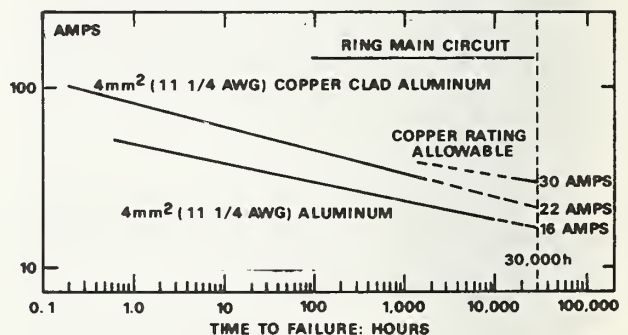


FIGURE 1. Twenty-year circuit ampacity—ring main circuit (branch circuit).

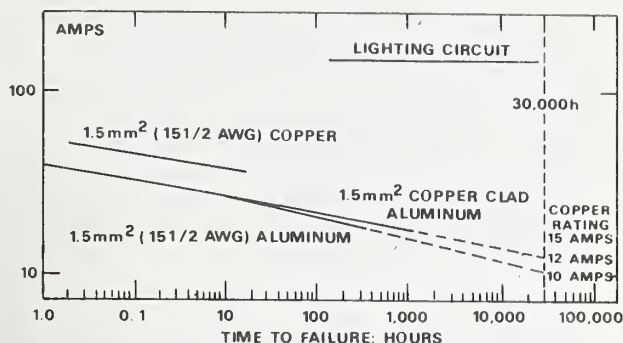


FIGURE 2. Twenty-year circuit ampacity—lighting circuit.

b. Cyclic Loading Tests

Cyclic loading tests were performed on groups of connectors wired as a ring main circuit with a terminal box between connectors so they could be isolated and replaced. A daily check was made on temperature rise, and a connector was considered to fail when it reached a temperature of 175 °C.

Figure 3 shows the relative durability of connectors wired with copper, copper-clad aluminum and solid aluminum as a function of cyclic loading at 30 amperes. The failure rate of aluminum appears to be clearly unacceptable under these conditions, and the failure rates of copper as well as copper-clad aluminum are questionable.

Figure 4 represents a more practical service condition with cyclic loading at 22 amperes representing typical use of a receptacle in the home. The failure rate of aluminum appears to remain unacceptable under these test conditions while copper-clad aluminum as well as copper exhibited no failures.

The BICC work points out the need for long-term testing of electrical connections with potential conductor materials to establish the validity of acceleration factors. Figure 4 probably represents 6- to 7-year performance for the designs tested. Data is needed for long-term performance of different designs to prove the durability of those designs. Long-term performance testing is especially needed where replacement provisions are not made.

6.3. Battelle Memorial Institute Research (BMI)

Research began in 1970 at the Battelle Memorial Institute in response to field service problems arising from the use of aluminum wiring with conventional connectors. The results of this work have not been published, because it has been funded by private industry sponsors who wish the information to remain proprietary at the present time. This research represents the most significant research effort in the United States on electrical connectors and includes stress relaxation, thermal, and environmental performance testing.

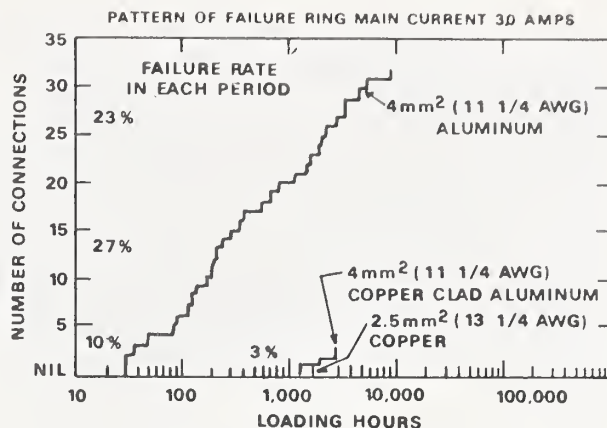


FIGURE 3. Service reliability test (the number of aluminum connections failed versus the hours energized—10 percent failed after 100 hours, 27 additional failed after 1000 hours, and 23 percent additional failed after 10,000 hours).

The number of copper connections failing is 3 percent after 1000 hours.

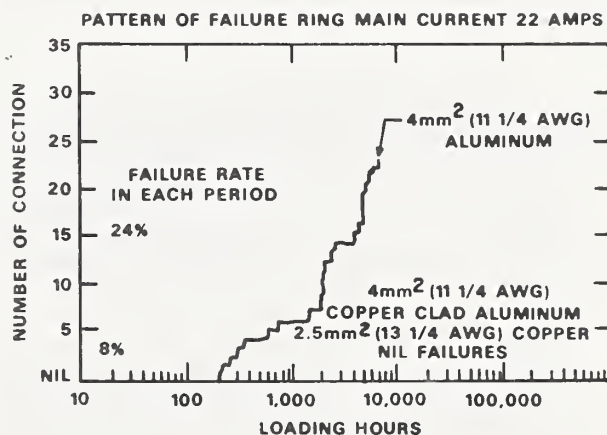


FIGURE 4. Service reliability test (the number of aluminum connections failed versus the hours energized—8 percent failed after 100 hours and 24 percent after 10,000 hours).

Copper and copper-clad connections did not fail after 10,000 hours energized at 22 amperes.

7. Failure Mechanisms

There does not appear to be any published research information which substantiates causes of failures in electric connections. An evaluation of available information (unpublished and published) indicates that failure might occur as a result of one of the three postulated mechanisms listed below.

7.1. Resistance Heating

Fire at electrical connections might be started by resistance heating in the wire-to-connector joints. Resistance heating may be caused by the presence of insulating layers in the joints. The insulating layers may form during power operation by a combination of low contact pressure in the joint and exposure of the joint to elements in the atmosphere which form insulating layers. Overheating accelerates the rate of formation of insulating layers and hence the rate of increase in the resistance of the joint, leading to additional overheating. This is a runaway phenomenon. Overheating might occur to such an extent that combustible material could ignite.

7.2. Loose Connections—Arcing

A loose connection may result in disconnection of a circuit but may also result in overheating. A potential fire hazard is created by arcing in a loose connection. Temperatures sufficiently high to melt metals in the joint may be reached. Accident investigations indicate that molten metal has been ejected explosively from high-voltage motor control centers as electricians opened the door to examine the cause of noises in a panel box.

Two theories can be expressed which might account for such an incident, as follows:

a) Hydrogen

Excessive temperatures in an electrical connection could generate hydrogen chloride by the decomposition of plastic insulation containing chlorine, with subsequent liberation of hydrogen by reaction of hydrogen chloride with metals. Hydrogen might also be produced by the electrolytic decomposition of water. Hydrogen gas might be ignited explosively by an arc in the electrical box.

b) Metal/Oxygen Reaction

Metal might react explosively with a sudden flow of oxygen into an electrical box after arcing has burned all of the oxygen in a box and removed oxide films from the conductor metals. A metal stripped of its oxide film might behave like a pyrophoric material. The tendency for such a reaction to occur increases as the metal changes state from solid to liquid vapor.

7.3. Wire Breakage

In the process of making electrical connections, the wire in the vicinity of the connection may receive stresses which may be a factor in subsequent wire breakage. Subjecting an electrical connection to vibration might increase the wire stresses sufficiently to cause wire breakage or reduce the wire cross section enough to result in overheating. Bending and pulling the wire during installation of connections could result in wire breakage or overheating.

8. Properties and Behavior of Materials Used in Electrical Connections

In conventional systems used in the United States, the current path at the interface in an electrical connection is established mechanically and maintained by a "wire-nut", binding head screw, or other means. Properties discussed in this section assume mechanically established connections. (See 9.2.b. for a discussion of metallurgical bonding.)

8.1. Contact Resistance

Establishing and maintaining a low contact resistance is the principal property necessary for a successful electrical connection. Reference 43 states:

"Contact resistance is a measure of the functional extent of true metallic contact area that has been achieved in making an electrical connection. High contact resistance indicates poor utilization of the apparent contact interface area with relatively small areas of true metallic contact. Zero contact resistance is achieved with full utilization of the clean contact interface. Acceptably low values of contact resistance are attained with less than complete metallurgical bonding of the contact interface. The practical evaluation and comparison of electrical connections depends in large part on their contact resistance characteristics."

As contact resistance increases, attributes which are directly necessary for the satisfactory performance of electrical connections, particularly "fire safety" (temperature rise), are greatly affected. Much of the other information discussed in this section and in section 9, Materials Property Problems in Electrical Connector Design, concern the problem of maintaining low contact resistance throughout the life of an electrical connection.

8.2. Surface Films

As indicated by Fan [45], surface films which are always present on exposed surfaces of the wire can have much higher resistivities than their base metals, so conduction paths must be created through these surface films or layers when making a connection.

The mechanism which permits current conduction through the oxide layer on copper is designated as "fritting" by Holm [46]. Fritting is defined as a mild electrical breakdown of surface film during current flow. Reference 45 emphasizes that the fritting voltage for a 100 angstrom layer of copper oxide is less than 0.0001 volt, while the fritting voltage for the same thickness of aluminum oxide is 40 volts.

Because of its high fritting voltage, aluminum oxide may interrupt the current path. This potential interruption has resulted in special wire/connector designs, termination techniques, and performance testing for electrical connections terminating aluminum wire.

Virgin metal-to-metal contact should be established and maintained between aluminum wire and other conducting components in the continuous current path of an electrical system if efficient electrical function and safety are to be achieved under required service conditions.

Virgin metal-to-metal contact is reported to be not as important for the fire safety of copper wiring systems because of the low fritting voltage of copper oxide. However, other surface films caused by corrosion might cause overheating in copper wire connections [47].

The significance of an insulating surface layer to the performance of an electrical connection is represented by the curve in Figure 5 [48]. Williamson explains that as long as the resistance of the joint remains small the temperature-dependent processes occur slowly, but when the constriction resistance increases by slow reoxidation at the interface, the temperature rises and this accelerates the reoxidation. The data for Figure 5 were derived by measuring the overall resistance, the current (I), and the temperature of an electrical joint of two aluminum conductors. Williamson then estimates the constriction resistance (R_o) as the difference between the observed resistance and the resistance of an equivalent length of conductor of the same diameter as the joint. Molten aluminum and high temperatures in the electrical joint present the potential for unacceptable fire safety. Williamson concludes: (1) that the interfacial temperature in a well-made joint under normal operating conditions is only a few degrees Celsius above the bulk temperature, and (2) uncertainties about the constriction resistance are due to a lack of knowledge of the way contact spots are distributed over the joint interface.

Figure 5 shows the temperature in a compression joint between two aluminum conductors in an ambient temperature of 20 °C. The abscissa has been plotted in terms of the product of the constriction resistance, measured with a low current at 20 °C and the current through the joint.

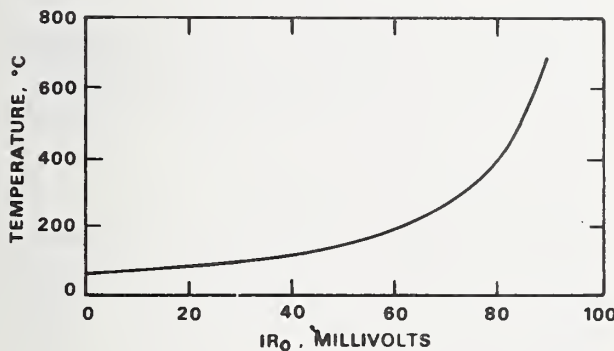


FIGURE 5. Relation between the temperature created at the interface of a joint and the potential difference across the restriction resistance [48].

8.3. Effect of Contact Pressure

Reference 45 describes a continuous current path (metal-to-metal contact) through insulating surface layers in wire-to-connector interfaces. Low contact resistance was achieved by the application of high con-

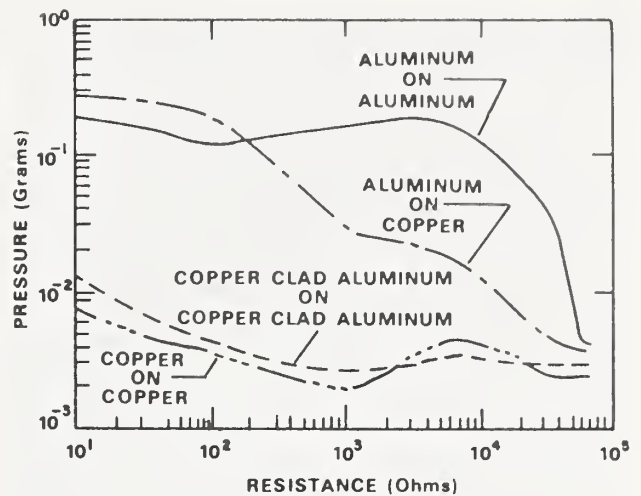


FIGURE 6. Contact resistance versus contact pressure for electrical connections wired with the indicated conductors.

tact pressures as shown in Figure 6. Figure 6 shows that electrical connections wired with copper and copper clad aluminum exhibit low contact resistance at much lower contact pressures than electrical connections wired with aluminum.

8.4. Creep and Stress Relaxation

Once a continuous low resistance current path has been established, it must be maintained under various service conditions.

Creep and stress relaxation present a special problem relative to maintaining a continuous current path over an extended period of time. "Creep" and "stress relaxation" are names for the same property of metals under different conditions. Creep is an increase of strain at a constant stress. Relaxation is a decrease of stress at constant strain. The high contact pressure which is needed to establish metal-to-metal contact applies stress to the wire. Certain metals when under stress in a connector, can flow to reduce the stress. This flow results in a decrease in contact pressure and a possible increase in the oxide surface layer, the contact resistance, and the temperature of the interface. This mechanism is referred to as cold flow, creep, or stress relaxation. Creep occurs at stresses below the yield strength of the metal, and the rate of creep increases with increasing temperature.

Creep of metals such as copper and steel is reported to be not significant at temperatures commonly exhibited by electrical connections.

Some aluminum alloys which were used in electrical systems prior to 1973 exhibit a significant amount of creep or stress relaxation. In conventional electrical connections aluminum wire might exhibit creep to such an extent that the increase in interface temperature is accelerated by the cumulative mechanism of contact pressure decrease, oxide layer increase, and

contact resistance increase. The result is overheating and eventual failure of the connection [45].

8.5. Thermal Expansion and Contraction

Thermal expansion is important in electrical connections when there is a significant difference between the properties of the wire and the connector to an overheating mechanism.

Thermal expansion is also important when wire is improperly installed with a heat-producing gap between the wire and the connector.

The ratio of the coefficients of thermal expansion of the steel connector and the wire is about 2 to 1. If the temperature of the connection increases by some heat-producing mechanism, then differential thermal expansion will lead to increased contact resistance and a further increase in temperature. The wire will tend to expand at a greater rate than the connector while current is flowing, but because of its being confined by the connector it will deform plastically in such a way that on cooling it will have a reduced diameter. During periods of no current flow, the connection cools and the contact pressure at the interface between the wire and the connector decreases as the metals contract. This mechanism may lead to excessive overheating and an accelerated destruction of the connection if the connection is current cycled.

8.6. Diffusion Across Material Boundaries

Diffusion is the spontaneous movement of atoms or molecules within a material or across material boundaries. The importance of diffusion in the long-term performance of electrical connections involving dissimilar metals is the change in properties that may result over an extended period of time. The rate of diffusion increases with the temperature.

Consider a connection with zinc-plated steel connector plates and aluminum wire. Such a connector is common because zinc is applied to steel to impede corrosion of the steel.

If overheating has increased the temperature of the connection, then zinc may diffuse more rapidly into the aluminum wire. The newly-formed alloy of aluminum and zinc would have an increased electrical resistance which might contribute to an accelerated failure through overheating.

8.7. Strength, Ductility, and Hardness

The mechanical properties of copper and aluminum wire are a function of composition and work hardening. Composition and processing variables establish the strength, hardness, and ductility of the wire. Strength and hardness increase and ductility decreases with increasing applied stress. The significance of these properties is that a wire may be so weak that it will fail with a small amount of applied stress or it may be strong and "brittle" so that it will break in bending during installation. The optimum, as-fabricated, properties for aluminum wire as specified by U.L. are a tensile

strength of 15,000 to 22,000 psi and a minimum elongation of 10 percent [8].

These properties are also important after termination in a connector because contact pressure can increase the hardness and decrease the ductility of a wire to such an extent that the wire can break on bending after installation.

8.8. Electrical Conductivity

Electrical conductivity measured in percent IACS (International Annealed Copper Standard) is the property of a conductor which indicates the electrical efficiency of the flow of current. Electrical conductivity is the reciprocal of electrical resistivity. The electrical conductivity of aluminum and copper wires decrease as alloys are modified so as to improve properties such as creep, stress relaxation, and ductility, which are related to durability.

9. Materials Properties Considerations in Electrical Connector Design

The purpose of this section is to show how problems with the performance of electrical connections may be minimized by taking materials properties into account in connector design.

9.1. Surface Layers on Wire

One approach to the establishment of a continuous current path through surface layers in wire to connector interfaces requires a special geometry in connector design. This approach involves the use of indium-plated connector plates which contain small indentations on their surfaces which contact the wire. When pressure is applied to the binding head screw of this design the surface layer on the wire is broken as the wire metal is extruded into the indentations making metal-to-metal contact with the connector plates. It is not known what contact pressure is required to achieve metal-to-metal contact by this method, but an ad hoc committee sponsored by U.L. specifies a torque of 12 pound-inches [7].

The purpose of the indium is twofold, first to flow through the breakage of the surface layer and then to inhibit environmental reaction at the connector interface by acting as a barrier to elements in the atmosphere during subsequent operation of the electrical system.

9.2. Creep and Stress Relaxation

There are essentially three approaches to the problem of creep and stress relaxation, which are in the areas of connector design, metallurgical bonding, and materials development.

a. Connector Design Approach

A connector might be designed with spring tension or the equivalent to maintain contact pressure between the connector and the wire.

b. Metallurgical Bonding

The detrimental interfacial surface layer which can form in a mechanical electrical connection could be eliminated by metallurgically bonding the conductor wire to the connectors. Soldering is the only process used in the United States.

Possible improvements in branch circuit electrical connections lies in the fields of welding, cold forming, and explosive bonding. It appears that practical application of these processes could only be done in a factory environment because of equipment requirements.

c. Wire Alloy Development

Nine wiring manufacturers have developed aluminum alloys for electrical wiring which have been accepted by Underwriters' Laboratories as indicated by Reference 8. It should be noted that as of March 29, 1973, this acceptance excludes many of the alloys which are presently installed in homes.

d. Copper Cladding

Aluminum wire can be clad with a metal such as copper to overcome the property changes which result in a thermal failure mechanism. Reference 45 provides the information on copper cladding. Essentially, copper cladding of aluminum wire provides an electrical bond at terminations and prevents the increase in contact resistance initiated by aluminum oxide which triggers creep, overheating, and eventual destruction of an electrical connection. Copper-clad aluminum appears to perform nearly as well as solid copper. A failure mechanism can be postulated for clad aluminum if the coating is perforated and exposed to moisture. Under these conditions the wire would tend to corrode at an accelerated rate and promote overheating and wire breakage.

e. Nickel Plating

The same performance comments that apply to copper-clad aluminum also apply to nickel-plated aluminum. The advantage of nickel-plated aluminum wire is its reported lower cost compared to copper, copper-clad, and the new U.L. listed aluminum alloys.

10. Recent Innovations

The principal developments of innovative electrical connections for branch circuit wiring in housing are described below. Information concerning innovative electrical connections is based on information published by the organizations developing the products described, in engineering or test reports concerning these products, on examination of the products and on discussions with people concerned with their development.

10.1. Electrical Harness

For the Operation BREAKTHROUGH program, an electrical harness for use in branch circuit wiring was developed. The basic idea was the adaptation of the principles of automobile electrical harnesses (12-volt systems) to electrical systems in housing (nominal 115- and 230-volt systems).

Each harness consisted of a central junction box or circuit breaker panel and a network of legs of predetermined length using outlets and switches specifically designed for attachment in controlled, high-volume, factory assembly lines. The junction boxes were located at ceiling fixtures or other convenient access points such as closets, utility or service areas. A housing module electric power distribution system consisted of one or more spider harnesses installed at the housing producer's plant.

The system used conventional materials and components. Conventional non-metallic sheathed cable was used. The switches and outlets were of conventional design insofar as switching actions and face configurations of receptacles are concerned. The unique characteristics of the switches and outlets were the wire was factory terminated and an integral junction box was used. The switch and outlet designs included a back case cover, made of electrical insulation material, which functioned as an integral part of the junction box. The principal waivers of the National Electrical Code provisions which were necessary to permit the use of this harness were those requiring a specific volume of "free space" within the box. (See sec. 3.2.b. of this report.)

In this system all electrical connections were made in the factory producing the electrical harness. In the housing producers' factory, only mechanical connections were necessary. Portions of U.L. Standards 20 (Snap Switches), 498 (Attachment Plugs and Receptacles) and 514 (Outlet Boxes and Fittings) were used as a guide in the acceptance testing of the harness system [24, 25, 23]. The test results, which included sixteen different types of tests, appeared to be satisfactory when compared to criteria established by Underwriters' Laboratories for similar conventional components. The tests were actually of the harness and not specifically of the electrical connections.

The economic justification for this innovative electrical harness was the saving of labor in a housing producer's factory. Estimates were made that the costs of materials, if there were volume production, would be about one-third more than materials in a conventional electrical system. However, it was estimated that installation labor would be cut, possibly by as much as 70 or 80 percent.

The question of replaceability in the event of failure of one of the components such as a switch or receptacle was considered. It was determined that components could be replaced with reasonable effort with corresponding conventional devices as long as sufficient slack was left in the cable. A minimum of 12 inches for each device or for each leg was recommended.

10.2. Split-beam Receptacles

The most successful innovation concerning electrical connections in branch circuit wiring up to the present time has been split-beam receptacles. Non-metallic sheathed cable is prepared by a special tool which cuts the insulation but not the wire, and positions the wire in the proper position for quick placement into one

piece of a two-piece receptacle. The special tool (costing about \$50.00) is then used to clamp the receptacle together making a non-visible electrical connection within the receptacle.

These receptacles have, within the last year, received widespread use in mobile homes and limited use in factory-built and conventionally built homes. National Electrical Code provisions concerning the box (see 3.2.b.) have been the principal reasons for their non-use in housing. Special NEC exceptions for mobile homes and for re-wiring in existing buildings have been taken advantage of for its use in limited applications. (See appendix.)

These receptacles, which do not employ a separate "box," cost more than conventional receptacle assemblies. The economic justification for this device, however, is the saving on installation labor, either in a housing factory or in conventionally-built housing.

Underwriters' Laboratories has issued a fact-finding report on this device. Underwriters' subjected this device to the tests which they believed relevant. Tests used for conventional devices, such as U.L. 498 on Attachment Plugs and Receptacles [25] were, in general, used as a guide. U.L. also subjected these devices to the vibration test outlined in [27] to simulate the vibrations encountered from movement of land transportation vehicles. Tests to simulate time were not made. As a result of the tests, U.L. has listed these devices for applications permitted by the National Electrical Code [5].

The question of replaceability was examined by Underwriters' and it was determined that these devices could be replaced by a conventional receptacle with reasonable effort as long as there was sufficient slack left in the cable during installation. It would be difficult to get less than 18 in of slack if the installation were done in accordance with recommended procedures because of the amount of cable needed to operate the special tool.

Development work is being done on a replacement receptacle which would not require a special tool for its installation. Development of split-beam switches, lighting fixtures, and appliance mountings on the same general principles used in the innovative receptacle is underway. Completion of this work with a satisfactory evaluation by proper authorities would permit the use of this system of electrical connections for nearly all normal applications in branch circuit wiring.

10.3. Quick Splicing Connectors

Quick splicing connectors were developed by at least two manufacturers in response to Operation BREAKTHROUGH opportunities.

The intent was to use these connectors without boxes. Otherwise it was contended that the innovations would not be feasible or competitive. However, for lack of technical knowledge these connectors were permitted to be installed only in accessible enclosures which contained no combustible materials. Because of this and construction schedules, the Operation BREAKTHROUGH housing producers did not use these connectors and installed conventional wiring systems.

10.4. Baseboard Receptacle System

An innovative wiring system was developed on an Operation BREAKTHROUGH Type B contract [49]. This development was concerned primarily with an economical way of providing more electrical receptacles in each room of a building. The principal features of this development concerned the connection of attachment plugs to receptacles and not permanent connections in branch circuit wiring. However, this system would eliminate some connections which would ordinarily be made in branch circuits. Only prototypes of this system have been developed.

11. Research Considerations of Innovative Electrical Connections

Tests have been run (see subsection 10.2. of this report) on innovative concepts which appear to meet or exceed the acceptance requirements of Underwriters' Laboratories.

The principal reason preventing the application of these innovative systems in the field is the potential use of wiring materials other than copper and the lack of durability data.

The technical factors of greatest importance to the durability performance of innovative electrical connections are temperature-increasing mechanisms and materials properties which will result in failures of the continuous current path.

Adequate metal-to-metal contact should be established during installation and maintained during service to minimize temperature increases.

Materials for a mechanical-type electrical connection should be selected with the required strength and ductility to prevent breakage during installation and service.

These materials should also exhibit properties which will not increase the temperature of the electrical connection above an acceptable operating level.

Metal-to-metal contact can be measured directly by destructive examination. However, destructive examination can be useful when related to non-destructive indirect performance measurements.

Contact resistance can be measured electrically and can be related to joint temperatures. More information is needed concerning contact resistance, contact temperature, contact pressure, and metal-to-metal contact with time. A method is needed to measure the contact temperature at the interface between the wire and the connector.

The development of the above measurement techniques would permit the indirect determination of metal-to-metal contact and contact temperatures during the performance testing of electrical connections under cyclic load.

Measurement techniques should be first developed and then applied to the performance testing of innovative electrical connections. The following performance testing is needed:

1. Accelerated tests should be performed to provide data which can be related to the performance of electrical connections under real life conditions. The

basis for acceleration factors, such as cycles, cycle times, current overload, ambient temperature, and aggressive environment, is not presently known.

2. Long-term (10,000 hours) cyclic loading tests at currents typical of household use should be performed to establish data for the performance of electrical connections under real life conditions.

3. Accelerated environmental tests should be performed in aggressive laboratory environments to provide data which can be related to the performance of electrical connections exposed to environments in the field (various geographic locations) such as marine, industrial, et al. The relationship between accelerated environmental results and field environmental results is not known.

4. Long-term (10,000 hours) exposure of electrical connections to field environments should be performed to provide data which can be related to accelerated environmental test data.

This research is needed to establish the validity of acceleration factors and to enable the prediction of the long-term thermal performance of innovative electrical connections based on the results of accelerated performance tests.

Additional research is needed to develop performance tests which will ensure the structural integrity of electrical connections relative to strength and ductility requirements.

12. Summary

1. In the United States the principal basis for the evaluation and approval of electrical connections in branch circuit wiring is the judgment of local electrical inspectors; these are men with practical experience in conventional electrical construction.

2. The National Electrical Code [5] is the principal guide covering the installation of electrical wire and equipment, including the requirements for and the methods of making field electrical connections; unless an innovation can be installed in accordance with the NEC, it will be unable to attain widespread use in the market place.

3. Underwriters' Laboratories requirements and tests are the principal criteria applying to the components interfacing with branch circuit electrical connections.

4. As a result of the use of aluminum wire, research and proposed performance-test programs concerning the failure and hazard mechanisms of branch circuit electrical connections, including some durability aspects, are now under way at Underwriters' Laboratories and Battelle Memorial Institute (see subsections 6.1. and 6.3. of this report).

5. In the construction of both conventional and factory-built housing the traditional system of installing electrical boxes at switch, outlet and junction points, the mechanical fastening of electrical cable to boxes and the making of electrical connections in boxes, are required by the National Electrical Code and most local jurisdictions. It is the requirements for "boxes" and not specifically the requirements for electrical connections which appear to constrain innovation in branch circuit wiring systems (see subsection 3.2.b.).

6. There are some exceptions in the National Electrical Code to the requirements for "boxes." These exceptions apply to mobile homes, to exposed cable wiring and to concealed work in rewiring existing buildings.

7. Electrical connections have failed under field service conditions and some of the overheating-type failures are believed to have been the cause of fires. Wire breakage failures have occurred as a result of wire being bent during installation.

8. Some failures are believed to have been caused by abnormal temperature increases of wire-connector interfaces. The temperature increases are caused by a variety of short and long-term mechanisms which increase the contact resistance at the wire-connector interfaces.

9. Performance tests are needed which measure the properties of electrical connections as they relate to durability and overheating aspects.

10. Measurement techniques are needed to establish a quantitative relationship between contact resistance, contact temperature, contact pressure, and metal-to-metal contact with time under cyclic loading conditions.

11. Data are needed to establish the validity of acceleration factors and to enable the prediction of the long-term thermal performance of innovative electrical connections based on the results of accelerated performance tests (see section 6 and 11 of this report).

12. Metallurgical bonding represents an innovative approach which may avoid the thermal failure potential problem inherent in mechanical-type electrical connectors.

13. Considerable uncertainty is associated with an evaluation of the durability of electrical connectors, because very few applicable data are available and much of the available information is proprietary.

13. Recommendations

1. Initiate a research program to develop information and tests on the performance of innovative electrical connectors. This program would consist of the following parts:

(a) Establish an interface with organizations conducting on-going electrical connector testing to obtain information and perform routine testing.

(b) Develop techniques for measuring the properties of electrical connectors with time under cyclic loading conditions.

(c) Study the validity of acceleration factors to enable the prediction of the long-term thermal performance based on short- and long-term data.

2. Obtain information on metallurgical bonding to permit an evaluation of this innovative approach.

3. Develop interim performance criteria and tests.

4. Make a study of the technical criteria and parameters concerning the necessity of "box" requirements for branch circuit wiring.

5. Make a study concerning the parameters, the performance criteria and the feasibility of non-accessible electrical connections in housing.

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Appendix. NEC Requirements Which Directly Affect Innovative Electrical Connections

A. NEC Requirements for Electrical Connections (see subsection 3.2.a.)

Article 110 General 70-15

110-14. Electrical Connections. Because of different characteristics of copper and aluminum, devices such as pressure terminal or pressure splicing con-

nectors and soldering lugs shall be suitable for the material of the conductor and shall be properly installed and used. Conductors of dissimilar metals shall not be intermixed in a terminal or splicing connector where physical contact occurs between dissimilar conductors (such as copper and aluminum, copper and copper-clad aluminum, or aluminum and copper-clad aluminum), unless the device is suitable for the purpose and conditions of use. Materials such as solder, fluxes, inhibitors, and compounds, where employed, shall be suitable for the use and shall be of a type which will not adversely affect the conductors, installation, or equipment.

(a) **Terminals.** Connection of conductors to terminal parts shall insure a thoroughly good connection without damaging the conductors and shall be made by means of pressure connectors (including set-screw type), solder lugs or splices to flexible leads except that No. 8 or smaller solid conductors and No. 10 or smaller stranded conductors may be connected by means of wire-binding screws or studs and nuts having upturned lugs, or the equivalent. Terminals for more than one conductor and terminals used to connect aluminum shall be of a type suitable for the purpose.

(b) **Splices.** Conductors shall be spliced or joined with splicing devices suitable for the use or by brazing, welding, or soldering with a fusible metal or alloy. Soldered splices shall first be so spliced or joined as to be mechanically and electrically secure without solder and then soldered. All splices and joints and the free ends of conductors shall be covered with an insulation equivalent to that of the conductors or with an insulating device suitable for the purpose.

B. NEC Requirements for Boxes (see subsection 3.2.b.) Note particularly 300-15(b) below.

Article 300 Wiring Methods—General 70-93

300-15. Boxes or Fittings Where Required.

(a) **Box or Fitting.** A box or fitting shall be installed at each conductor splice connection point, outlet, switch point, junction point or pull point for the connection of conduit, electrical metallic tubing, surface raceways or other raceways.

Exception No. 1: A box or fitting is not required for a conductor splice connection in surface raceways, wireways, header ducts, multi-outlet assemblies and auxiliary gutters having a removable cover which is accessible after installation.

Exception No. 2: As permitted in Section 410-26.

(b) **Box Only.** A box shall be installed at each conductor splice connection point, outlet, switch point, junction point, or pull point for the connection of metal-clad cable, mineral-insulated metal-sheathed cable,

aluminum-sheathed cable, nonmetallic-sheathed cable, or other cables and at each outlet and switch point for concealed knob-and-tube wiring.

Exception No. 1: As permitted by Section 336-11 for insulated outlet devices supplied by nonmetallic-sheathed cable.

Exception No. 2: As permitted by Section 410-60 for rosettes.

Exception No. 3: Where accessible fittings approved for the purpose are used for straight-through splices in mineral-insulated metal-sheathed cable.

C. NEC Requirements Concerning Free Space in Boxes (see subsection 3.2.b.)

Article 370 Boxes and Fittings 70-165

370-6. Number of Conductors in a Box. Boxes shall be of sufficient size to provide free space for all conductors enclosed in the box.

The provisions of this Section shall not apply to terminal housings supplied with motors. See Section 430-12.

Sections 370-6(a) and (b) do not apply to conductors used for rewiring existing raceways as referred to in Table 1, Chapter 9.

(a) The maximum number of conductors, not counting fixture wires, permitted in outlet and junction boxes shall be as in Tables 370-6(a) (1) and (a) (2) with the exceptions noted.

Tables 370-6(a) (1) and (a) (2) apply where no fittings or devices such as fixture studs, cable clamps, hickey, switches or receptacles, are contained in the box and where no grounding conductors are part of the wiring within the box. Where one or more fixture studs, cable clamps or hickey are contained in the box, the number of conductors shall be one less than shown in the Tables; an additional deduction of one conductor shall be made for each strap containing one or more devices; and a further deduction of one conductor shall be made for one or more grounding conductors entering the box. A conductor running through the box is counted as one conductor, and each conductor originating outside of the box and terminating inside the box is counted as one conductor. Conductors, no part of which leaves the box, are not to be counted. The volume of a wiring enclosure (box) shall be the total of the volume of the assembled sections.

(b) For combinations or conductor sizes not shown in Tables 370-6(a) (1) and (a) (2), Table 370-6(b) shall apply.

(c) Boxes, other than those described in Tables 370-6(a) (1) and 370-6(a) (2), shall be durably and legibly marked by the manufacturer with their cubic-inch content. All boxes shall be durably and legibly marked with the manufacturer's name or trademark.

NATIONAL ELECTRICAL CODE

TABLE 370-6(a) (1). *Deep Boxes*

Box Dimensions, Inches Trade Size	Cubic Inch Cap.	Maximum No. of Conductors			
		No. 14	No. 12	No. 10	No. 8
3¼ x 1½ Octagonal	10.9	5	4	4	3
3½ x 1½ Octagonal	11.9	5	5	5	3
4 x 1½ Octagonal	17.1	8	7	6	5
4 x 2½ Octagonal	23.6	11	10	9	7
4 x 1½ Square	22.6	11	10	9	7
4 x 2½ Square	31.9	15	14	12	10
4 11/16 x 1½ Square	32.2	16	14	12	10
4 11/16 x 2½ Square	46.4	23	20	18	15
3 x 2 x 1½ Device	7.9	3	3	3	2
3 x 2 x 2 Device	10.7	5	4	4	3
3 x 2 x 2¼ Device	11.3	5	5	4	3
3 x 2 x 2½ Device	13	6	5	5	4
3 x 2 x 2¾ Device	14.6	7	6	5	4
3 x 2 x 3½ Device	18.3	9	8	7	6
4 x 2½ x 1½ Device	11.1	5	4	4	3
4 x 2½ x 1¾ Device	13.9	6	6	5	4
4 x 2½ x 2½ Device	15.6	7	6	6	5

See Section 370-18 where boxes are used as pull and junction boxes

TABLE 370-6(a) (2). *Shallow Boxes*

Box Dimensions, In Trade Size	Maximum Number of Conductors		
	No. 14	No. 12	No. 10
3¼	4	4	3
4	6	6	4
1¼ x 4 Square	9	7	6
4 11/16	8	6	6

Any box less than 1½-in deep is considered to be a shallow box.

TABLE 370-6(b). *Volume Required Per Conductor*

Size of Conductor	Free Space Within Box for Each Conductor
No. 14	2. in ³
No. 12	2.25 in ³
No. 10	2.5 in ³
No. 8	3. in ³
No. 6	5. in ³

D. Exceptions to Box Requirements in Mobile Homes (see 550-8(j) below).

Article 550 Mobile Homes and Parks 70-369

550-8. Wiring Methods and Materials. Except as specifically limited in this Section the wiring methods and materials included in this Code shall be used in mobile homes.

(a) Nonmetallic outlet boxes are acceptable only with nonmetallic cable.

(b) Nonmetallic cable located 15 in or less above the floor, if exposed, shall be protected from physical damage by covering boards, guard strips, or conduit. Cable likely to be damaged by stowage shall be so protected in all cases.

(c) Metal-clad and nonmetallic cables may be passed through the centers of the wide side of 2-in by 4-in studs. However, they shall be protected where they pass through 2-in by 2-in studs or at other studs or frames where the cable or armor would be less than

1½ in from the inside or outside surface. Steel plates on each side of the cable, or a tube, with not less than No. 16 MSG wall thickness, are required to protect the cable. These plates or tubes shall be securely held in place.

(d) Where metallic faceplates are used they shall be effectively grounded.

(e) If the range, clothes dryer, or similar appliance is connected by metal-clad cable or flexible conduit, a length of free cable or conduit should be provided to permit moving the appliance. The cable or flexible conduit should be adequately secured to the wall. Clearance space behind a range may provide the required protection when a range is connected by Type SE cable. When used, Type SE cable shall have an identified and insulated neutral plus an equipment grounding conductor. Nonmetallic-sheathed cable (Type NM) shall not be used to connect a range or dryer.

This does not prohibit the use of Type NM cable between the branch-circuit overcurrent protective device and a range or dryer receptacle.

(f) Rigid metal conduit shall be provided with a locknut inside and outside the box, and a conduit bushing shall be used on the inside. Inside ends of the conduit shall be reamed.

(g) Switches shall be rated as follows:

(1) For lighting circuits, switches shall have a 10-ampere 125-volt rating; or higher, if needed for the connected load.

(2) For motors or other loads, switches shall have ampere or horsepower ratings or both adequate for loads controlled. (An "AC general-use" snap switch may control a motor 2 horsepower or less with full-load current not over 80 percent of the switch ampere rating.)

(h) At least 4 in of free conductor shall be left at each outlet box except where conductors are intended to loop without joints.

(i) **Under-Chassis Wiring.** (Exposed to Weather).

(1) When outdoor or under-chassis line-voltage wiring is exposed to moisture or physical damage, it shall be protected by rigid metal conduit. The conductors shall be suitable for wet locations.

Exception: Electrical metallic tubing may be used when closely routed against frames and equipment enclosures.

(2) The cables or conductors shall be Type NMC, TW, or equivalent.

(j) Outlet boxes of dimensions less than those required in Tables 370-6(a) (1) and 370-6(a) (2) may be used provided the box has been tested and approved for the purpose.

(k) Boxes, fittings and cabinets shall be securely fastened in place.

Exception: Snap-in type boxes or boxes provided with special wall or ceiling brackets that securely fasten boxes in walls or ceilings may be used.

E. Exceptions to Box Requirements in Exposed Cable Wiring and for Concealed Work for Rewiring in Existing Buildings

Article 336 Nonmetallic-Sheathed Cable 70-135

336-11. Devices of Insulating Material. Switch, outlet, and tap devices of insulating material may be used without boxes in exposed cable wiring, and for concealed work for rewiring in existing buildings where the cable is concealed and fished. Openings in such devices shall form a close fit around the outer covering of the cable and the device shall fully enclose that part of the cable from which any part of the covering has been removed.

Where connections to conductors are by binding-screw terminals, there shall be available as many terminals as conductors, unless cables are clamped within the structure and terminals are of a type approved for multiple conductors.

F. Splices—Concealed Knob-and-Tube Work

Article 324 Concealed Knob-and-Tube Work 70-127

324-11. Splices. Splices shall be made only where close to knobs or tubes using solder or specially approved splicing devices. In line or strain splices shall not be used.

G. NEC Requirements for Accessible Electrical Connections (see subsection 3.2.3).

Article 370 Boxes and Fittings 70-169

370-19. Junction, Pull and Outlet Boxes to Be Accessible. Junction, pull and outlet boxes shall be so installed that the wiring contained in them may be rendered accessible without removing any part of the building, sidewalks or paving.

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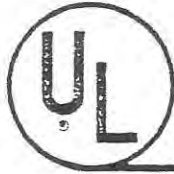
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Subjects 4, 44, 83, 115, 133, 493,
719, and 854

Melville, New York
April 2, 1971

To: Electrical Council of Underwriters' Laboratories, Inc.,
and
Manufacturers of Listed Wires and Cables

Subject: Recognition of Copper-Clad Aluminum Conductor For Use
In Terminals Suitable For Copper Conductor

Underwriters' Laboratories, Inc., after conducting progressive heat cycling tests to evaluate the performance of No. 12 AWG copper-clad aluminum conductor as compared to No. 14 AWG copper conductor, finds it appropriate to extend recognition to copper-clad aluminum conductors for use in all terminations suitable for copper conductor.

As a result of this conductor evaluation program, the restriction on the use of copper-clad aluminum "Must be used with pressure wire connectors or with terminals suitable for copper and aluminum wire" is being revised as follows: "May be used with pressure wire connectors and terminals suitable for copper wire or for copper and aluminum wires". This change is effective immediately and is being made on the guide cards for the following classifications. Appropriate changes will be made in the affected standards as the opportunity arises.

- Armored Cable (UL 4)
- Rubber-Insulated Wire and Cable (UL 44)
- Thermoplastic-Insulated Wire (UL 83)
- Asbestos-and Asbestos-Varnished-Cloth Insulated Cloth Wires (UL 115)
- Varnished-Cloth Wires (UL 133)
- Underground Feeder and Branch-Circuit Cables (UL 493)
- Nonmetallic-Sheathed Cable (UL 719)
- Service-Entrance Cable (UL 854)

An outline of the test approach used in this program is attached for reference as Appendix A, and the results obtained which provide the basis of this announcement are summarized in Appendix B.

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Although this program utilized only back-wired devices with the pressure plate and push-in connecting mechanisms, it is the opinion of the Laboratories that the performance of copper or copper-clad aluminum conductor terminated in either of these mechanisms represents of all the possible termination - conductor combinations available, worst case conditions.

For the push-in and pressure-plate type devices, the data shows that copper and copper-clad aluminum conductors have similar performance characteristics.

If you have any questions concerning this announcement, please send them to the writer at the Laboratories' Melville office (1285 Walt Whitman Road, Melville, Long Island, New York 11746) within two weeks of the date of the bulletin.

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APPENDIX A

TEST PROGRAM FOR DETERMINING THE SUITABILITY OF COPPER-CLAD ALUMINUM CONDUCTORS TERMINATING IN STANDARD PUSH-IN AND PRESSURE-PLATE TYPE CONNECTORS

Scope

This program was devised to yield comparative information to evaluate copper-clad aluminum conductors, No. 12 AWG, terminating in standard connectors provided integral with receptacles, lampholders, and switches rated 15 amperes maximum for use in Code recognized wiring systems, Dry Locations Only. Such wiring devices have conventional binding-screw terminals (now recognized for all wiring without investigation), push-in (screwless) terminals and pressure-plate (back or side wired) terminals (now listed for copper only).

Samples

Duplex receptacles with the following terminal designs were used for this investigation:

Type of Terminal	Manufacturer
Pressure plate (flat, serrated)	A
Pressure plate (concave)	B
Push-in (spring actuated)	C
Push-in (spring actuated)	D
Push-in (spring actuated)	E
Push-in (spring actuated)	F
Push-in (spring actuated)	G

Heat Cycling (Accelerated Performance)

1. Objective

The objective of this test was to determine the relative performance of copper-clad aluminum as compared to copper conductor (control). This was accomplished by measuring the temperature of various terminations during a heat cycling test and recording the time at which each termination failed. Failure criteria were specified as an attained temperature of 175°C.

The temperature of 175°C was chosen, since at this value the polyvinyl chloride, widely used as conductor insulation, starts to melt and the EC grade aluminum under the copper cladding tends to lose its physical properties.

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2. Test Schedule

In order to obtain this data, specimens of terminations, described in Section 3 of this heat cycling procedure were subjected to the following tests:

Test No.	Test Current, Amperes	Conductors (Solid)	
		AWG	Material
1	40	14	Copper
		12	Copper-clad aluminum
2	30	14	Copper
		12	Copper-clad aluminum
3	25	14	Copper
		12	Copper-clad aluminum

3. Test Procedure

For each of the tests listed in Section 2 of this heat cycling procedure, the following procedure was used:

- Five specimens of each sample described above were connected by means of the specified conductor to form a series circuit.
- So that only one conductor could be placed in each terminal of the duplex receptacle, the circuit was continued by making connection to both terminals on one side of the receptacle thus including the through-connection shunt in the circuit. The circuit was designed to include both the plated and unplated terminals.
- A thermocouple was placed on the through-connection shunt on both sides of the receptacle prior to torquing down each terminal screw.
- While making the pressure-plate conductor connections, a torque of six inch-pounds was used.
- There were no special preparations for either the copper-clad aluminum or copper conductors.
- The conductor insulation was stripped off the required length immediately prior to making the termination.
- There was no movement of connections once established.

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A test current of a specified value was caused to flow through the test circuit using a cycle of 3-1/2 hours on, 1/2 hour off.

During the test, the temperature of each termination was observed. When a termination reached a temperature of 175°C, it was removed from the circuit and the total time the circuit was on to cause failure was recorded.

The temperature measurements were made using No. 30 AWG iron-constantan thermocouple wires with potentiometer-type indicating equipment.

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APPENDIX B

TEMPERATURE DATA RECORDED THROUGH
MARCH 30, 1971 FOR THE 40A, 30A, AND 25A
HEAT CYCLING TESTS

The average time to failure (ATTF) associated with each connector-conductor termination at each of the specified current levels was determined and is summarized below:

BACKWIRED RECEPTACLE		AVERAGE TIME-TO-FAILURE (ATTF) (HRS)					
Type Terminal	Manufacturer Code	CONDUCTOR TYPE					
		CU/AL-12			CU-14		
		40A	30A	25A	40A	30A	25A
Pressure Plate, Flat Serrated	A	-	-	-	-	-	-
Pressure Plate, Concave	B	78 ₂	-	-	-	-	-
Push-in	C	18.5 ₆	250 ₅	349 ₂	17 ₄	122.5 ₁	-
Push-in	D	52.5 ₁	324 ₁	-	45.5 ₁	-	-
Push-in	E	20 ₅	-	-	17.5 ₃	-	-
Push-in	F	34.5 ₄	-	-	21 ₄	-	-
Push-in	G	-	-	-	-	-	-

- Notes: 1) ATTF - Equal to summation of current on time of each failed sample divided by number of failures.
- 2) Subscript indicates the number of failed samples.

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The following tabulation is a summary of the initial and latest temperatures recorded with the associated number of cycles completed for each of the samples which have not reached the failure criteria of 175°C.

Sample Number	Mfr. Code	Conductor Type	Current Level	Initial Temperature	Final Temperature	Temperature Change	Number of Cycles Completed
				Push-In Type			
5	C	CU #14	40A	96 95	98 110	+ 2 +15	34 34
2	D	CU #14	40A	90 90	120 133	+30 +43	58 58
3	D	CU #14	40A	118 115	130 121	+12 + 6	23 23
4	D	CU #14	40A	111 114	118 117	+ 7 + 3	23 23
2	D	CU AL #12	40A	100 99	98 98	- 2 - 1	50 50
3	D	CU AL #12	40A	107 103	123 119	+16 +16	50 50
4	D	CU AL #12	40A	104 102	140 123	+36 +21	26 26
4	E	CU #14	40A	121 127	151 147	+30 +20	23 23
1	G	CU #14	40A	113 129	119 168	+ 6 +39	23 23
2	G	CU #14	40A	112 115	117 128	+ 5 +13	23 23
3	G	CU #14	40A	104 113	125 126	+21 +13	23 23
4	G	CU #14	40A	107 111	110 128	+ 3 +17	23 23
1	G	CU AL #12	40A	90 90	99 96	+ 9 + 6	23 23
2	G	CU AL #12	40A	90 98	92 114	+ 2 +16	23 23
3	G	CU AL #12	40A	100 97	108 99	+ 8 + 2	23 23

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Sample Number	Mfr. Code	Conductor Type	Current Level	Initial Temperature	Final Temperature	Temperature Change	Number of Cycles Completed
				<u>Push-In Type</u>			
4	G	CU AL #12	40A	97	153	+56	23
				80	100	+20	23
5	G	CU AL #12	40A	94	99	+ 5	23
				98	138	+40	23
				<u>Pressure Plate</u>			
1	A	CU #14	40A	90	81	- 9	58
				90	88	- 2	58
1	A	CU AL #12	40A	87	83	- 4	58
				92	92	0	58
2	A	CU AL #12	40A	90	77	-13	58
				89	88	- 1	58
1	B	CU #14	40A	94	98	+ 4	58
				97	103	+ 6	58
3	B	CU AL #12	40A	87	90	+ 3	58
				92	125	+33	58
4	B	CU AL #12	40A	78	91	+13	26
				86	106	+20	26
				<u>Push-In Type</u>			
2	C	CU #14	30A	90	81	- 9	130
				97	140	+43	130
3	C	CU #14	30A	86	93	+ 7	73
				103	126	+23	73
4	C	CU #14	30A	85	92	+ 7	73
				118	148	+30	73
6	C	CU AL #12	30A	70	106	+36	106
				80	94	+14	106
1	D	CU #14	30A	100	82	-18	167
				83	94	+11	167
2	D	CU #14	30A	65	62	- 3	73
				71	70	- 1	73
3	D	CU #14	30A	74	71	- 3	73
				82	76	- 6	73
4	D	CU #14	30A	75	75	0	73
				77	75	- 2	73

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<u>Sample Number</u>	<u>Mfr. Code</u>	<u>Conductor Type</u>	<u>Current Level</u>	<u>Initial Temperature</u>	<u>Final Temperature</u>	<u>Temperature Change</u>	<u>Number of Cycles Completed</u>
<u>Push-In Type</u>							
2	D	CU AL #12	30A	71	77	+ 6	167
				86	76	-10	167
3	D	CU AL #12	30A	80	80	0	167
				72	79	+ 7	167
4	D	CU AL #12	30A	70	86	+16	72
				73	82	+ 9	72
5	D	CU AL #12	30A	72	74	+ 2	73
				72	73	+ 1	73
6	D	CU AL #12	30A	77	78	+ 1	73
				78	81	+ 3	73
1	E	CU #14	30A	92	92	0	73
				96	103	+ 7	73
2	E	CU #14	30A	80	90	+10	73
				83	93	+10	73
3	E	CU #14	30A	65	75	+10	73
				64	135	+71	73
4	E	CU #14	30A	86	94	+ 8	73
				85	92	+ 7	73
1	E	CU AL #12	30A	88	97	+ 9	73
				84	99	+15	73
2	E	CU AL #12	30A	83	94	+11	73
				83	100	+17	73
3	E	CU AL #12	30A	81	89	+ 8	73
				74	83	+ 9	73
4	E	CU AL #12	30A	95	101	+ 6	73
				85	95	+10	73
1	F	CU #14	30A	86	82	- 4	73
				87	88	+ 1	73
2	F	CU #14	30A	82	78	- 4	73
				97	90	- 7	73
3	F	CU #14	30A	80	79	- 1	73
				95	110	+15	73
4	F	CU #14	30A	100	99	- 1	73
				97	100	+ 3	73

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Sample Number	Mfr. Code	Conductor Type	Current Level	Initial Temperature	Final Temperature	Temperature Change	Number of Cycles Completed
<u>Push-In Type</u>							
1	F	CU AL #12	30A	79	86	+ 7	73
				81	82	+ 1	73
2	F	CU AL #12	30A	81	127	+46	73
				75	80	+ 5	73
3	F	CU AL #12	30A	81	95	+14	73
				79	88	+ 9	73
4	F	CU AL #12	30A	90	108	+18	73
				87	138	+51	73
1	G	CU #14	30A	67	68	+ 1	73
				62	61	- 1	73
2	G	CU #14	30A	64	61	- 3	73
				69	68	- 1	73
3	G	CU #14	30A	73	73	0	73
				81	80	- 1	73
4	G	CU #14	30A	74	73	- 1	73
				71	70	- 1	73
5	G	CU #14	30A	67	66	- 1	73
				64	62	- 2	73
1	G	CU AL #12	30A	64	63	- 1	73
				65	66	+ 1	73
2	G	CU AL #12	30A	71	78	+ 7	73
				68	71	+ 3	73
3	G	CU AL #12	30A	62	62	0	73
				61	59	- 2	73
4	G	CU AL#12	30A	60	58	- 2	73
				58	59	+ 1	73
5	G	CU AL#12	30A	67	71	+ 4	73
				68	114	+46	73
<u>Pressure Plate</u>							
1	A	CU #14	30A	67	64	- 3	16
				63	59	- 4	16
1	A	CU AL#12	30A	65	61	- 4	16
				63	68	+ 5	16
2	A	CU AL #12	30A	56	65	+ 9	16
				58	61	+ 3	16
3	A	CU AL #12	30A	71	62	- 9	16

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Sample Number	Mfr. Code	Conductor Type	Current Level	Initial Temperature	Final Temperature	Temperature Change	Number of Cycles Completed
<u>Pressure Plate</u>							
1	B	CU #14	30A	74 81	67 80	- 7 - 1	167 167
1	B	CU AL #12	30A	73 71	95 70	+22 - 1	167 167
2	B	CU AL #12	30A	68 64	63 68	- 5 + 4	167 167
3	B	CU AL #12	30A	66 61	67 66	+ 1 + 5	167 167
4	B	CU AL #12	30A	48 50	65 86	+17 +36	106 106
<u>Push-In Type</u>							
1	C	CU #14	25A	66 82	87 172	+21 +90	166 166
3	C	CU AL #12	25A	83 66	80 72	- 3 + 6	166 166
4	C	CU AL #12	25A	84 75	90 75	+ 6 0	72 72
1	D	CU #14	25A	66 58	62 63	- 4 + 5	166 166
1	D	CU AL #12	25A	52 55	50 67	- 2 +12	166 166
2	D	CU AL #12	25A	62 60	74 65	+12 + 5	166 166
3	D	CU AL #12	25A	46 57	58 57	+12 0	166 166
<u>Pressure Plate Type</u>							
1	A	CU #14	25A	49 50	49 52	0 + 2	166 166
1	A	CU AL #12	25A	46 44	67 55	+21 +11	166 166
2	A	CU AL #12	25A	48 39	57 53	+ 9 +14	166 166
3	A	CU AL #12	25A	48 42	59 69	+11 +17	166 166

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<u>Sample Number</u>	<u>Mfr. Code</u>	<u>Conductor Type.</u>	<u>Current Level</u>	<u>Initial Temperature</u>	<u>Final Temperature</u>	<u>Temperature Change</u>	<u>Number of Cycles Completed</u>
<u>Pressure Plate Type</u>							
1	B	CU #14	25A	51 58	51 59	0 + 1	166 166
1	B	CU AL #12	25A	49 50	50 55	+ 1 + 5	166 166
2	B	CU AL #12	25A	53 51	56 52	+ 3 + 1	166 166
3	B	CU AL #12	25A	53 54	56 55	+ 3 + 1	166 166

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A Texas Instruments Engineering Report

An examination of
copper clad aluminum
conductor for
circuit size wiring



MECHANISMS OF BUILDING WIRE CONNECTION FAILURE

AN EXAMINATION OF COPPER CLAD ALUMINUM CONDUCTOR FOR CIRCUIT SIZE WIRING

John C. Fan Project Manager, Technical Center

Introduction

Because it consumes 60% of all copper used in the United States, the electrical industry is critically affected by copper's fluctuating, spiraling cost and uncertain supply. Until recently, however, aluminum represented the only alternative to copper.

Aluminum, in the more than twenty years since its introduction as an electrical conductor, has made significant penetration into such areas as electric power transmission lines, transformer windings and telephone communications cable. On the other hand, it has received relatively limited acceptance in nonmetallic sheath and other small gauge building wire. The reason has been lack of an acceptable means of connecting or terminating aluminum conductors of #6AWG or smaller cross sectional area. Connector manufacturers, NEMA, inspectors, Underwriters' Laboratories, and aluminum companies are devoting much attention to this connection problem.

Now there is a new conductor available to counter the problems of price, availability and connection reliability: copper clad aluminum. It is a product of a metallurgical materials system; that is, two or more metals inseparably bonded together in a design which utilizes the benefits of each component metal while minimizing their deficiencies. In the case of copper clad aluminum conductor, the electrical reliability of copper is combined with the abundant supply, stable price and light weight of aluminum. Already copper clad aluminum is being used for building wire, battery cable, magnet wire and R.F. coaxial cable. The United Kingdom is in the process of converting entirely to copper clad aluminum for its nonmetallic sheath cable, and European Economic Community countries are actively evaluating it for the same application.

Because of the obvious importance and increasing interest in connection reliability, this paper will review in detail the technical characteristics of electrical connections made with the three conductor materials available today: copper, aluminum, and copper clad aluminum. Special attention will be given to the failure mechanism of a connection. To understand these mechanisms it is necessary to understand the significance of oxide film, contact pressure, and creep. From this discussion it will be shown that copper clad aluminum performs as a copper conductor.

Significance of Oxide Film

In wiring connections, the virgin metal surface of the wire is always covered with a layer of oxide film. On copper we see this oxide as a discoloration which turns copper progressively darker; or it may be invisible, as the transparent oxide on aluminum.

Visible or not, the nature of the oxide surface is critical to the quality of the connection. Since oxide layers of these metals have higher resistivity than their base metals, conduction paths must be created through the oxide.

The mechanism which permits current conduction through the oxide layer on copper is a very interesting one. Dr. Ragnar Holm defined the phenomenon in his contact handbook and called it "fritting." Fritting is a mild electrical breakdown of surface film during current flow. Fritting voltage is directly related to resistivity of the oxide film. In laboratory tests for a layer of film with an average thickness of 100 angstroms, fritting voltage of copper oxide turns out to be less than 0.001 volt, while fritting voltage of aluminum oxide of the same thickness is 40 volts. (Figure 1)

COPPER



VOLTAGE STEADY STATE RANGE 0.015 - 0.018 V
FRITTING VOLTAGE LESS THAN .001 V
FRITTED SPOT MEASURES .002 IN.

ALUMINUM



VOLTAGE STEADY STATE RANGE 0.030 - 0.080 V
MAXIMUM FRITTING VOLTAGE RANGE 35 - 40 V
FRITTED SPOT MEASURES .013 IN.

Figure 1: Fritting Conduction in Metal Oxides

The high fritting voltage of aluminum oxide explains why special procedures are required to connect aluminum conductors. Conduction across a connection can only be achieved by high voltages or by mechanically breaking the aluminum oxide layer. Copper oxide, on the other hand, does not inhibit conduction. Its film is a semiconductive layer which produces multiple conductive fritting paths quickly during conduction. For that reason, electrical connection between two copper surfaces does not require complete virgin metal-to-metal contact.

Oxide forms on the surface of aluminum conductor within a matter of seconds after the bare metal is exposed to the atmosphere, and will attain a thickness of from 60 to 100 angstroms in this short time. The thickness of the film may increase to thousands of angstroms under such environmental conditions as changes in temperature and humidity.

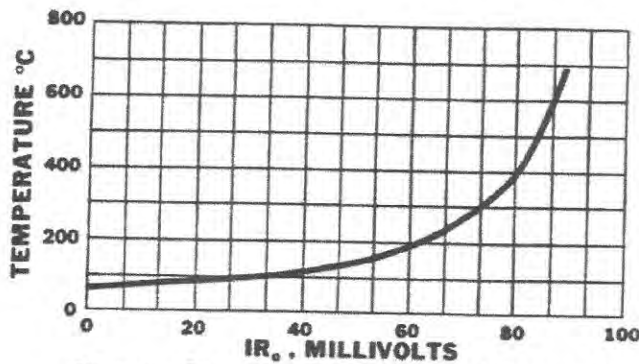


Figure 2: Temperature vs Potential Difference in Connection Interface (Williamson)

Obviously, before a good electrical connection can be made on an aluminum conductor, the oxide film must be removed or penetrated mechanically so that bare metal surfaces, essentially free of oxide, are in intimate contact with one another. Moreover, reoxidation of the aluminum must be prevented. When an aluminum oxide barrier is present, electrical connections will always run hot, because of the high voltage required to penetrate the oxide film.(Figure 2)

Significance of Contact Pressure

Today the only practical way of achieving good aluminum connections is high pressure. This can be seen in Figure 3 which shows the contact resistance observed between the various metals as a function of pressure. Contact resistances for copper-copper contacts are always low, even at very low pressures. Aluminum-aluminum contacts, however, exhibit high contact resistance at low and medium pressure and only begin to approach copper's low contact resistance at high pressure. At these high pressure levels, deformation of the aluminum takes place, which breaks the oxide film achieving direct metal-to-metal contact. Copper clad aluminum contacted to copper clad aluminum performs like solid copper in this test.

Several characteristics of aluminum oxide contribute to the high pressure required to achieve good aluminum electrical contacts. First we are faced with the oxide's inherent high electrical resistivity and dielectric strength which make it necessary to break through the oxide layer to make effective contact. But mechanical properties of the oxide make it difficult to achieve this contact. The oxide is extremely hard -- more than ten times harder than copper oxide. Also, the crystal lattice of aluminum oxide closely fits the crystal lattice of the base metal. This results in a very tight, adherent layer.

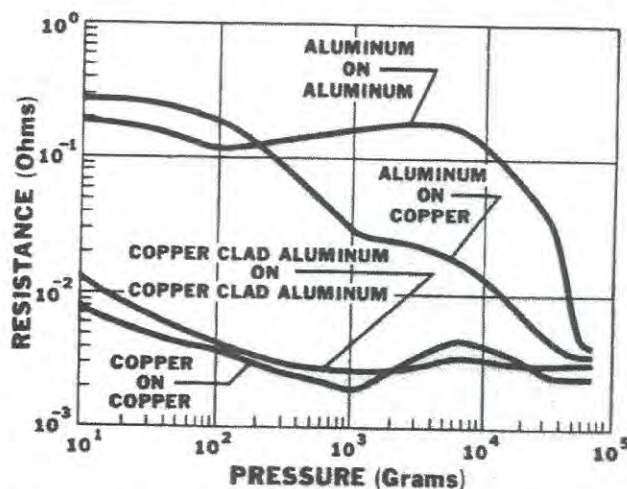


Figure 3: Contact Resistance vs Pressure (Two Conductors Cross Under Load)

	ALUMINUM OXIDE	COPPER OXIDE
CHEMICAL NOTATION	Al ₂ O ₃	Cu ₂ O
POROSITY	PROTECTIVE	POROUS
CONDUCTIVITY RATING	INSULATOR	SEMICONDUCTOR
HARDNESS (DPN)	1800	160
BASE METAL HARDNESS (DPN)	40	100
HARDNESS RATIO	45	1.6
THICKNESS Å (2 HRS.)	60	175
FRITTING VOLTAGE (VOLTS/100 Å)	40	0.01

Figure 4: Properties of Oxides

Overall, the tenacity, mechanical strength, inertness and particularly the dielectric strength of this oxide converts aluminum into a poor electrical connecting material. (Figure 4)

So as a start, we see that making good electrical connections with aluminum requires special care by the installer to make sure high contact pressures are achieved, and maintained.

Significance of Creep

High contact pressure leads to the second cause of failure -- creep -- sometimes called "cold flow." Creep is the slow deformation of a metal under stress. It takes place at stresses well below the nominal yield strength of the metal. It is time dependent and its mechanism is entirely different from plastic flow of metals. All metals creep, but creep rates at room temperature for most are negligible -- the problem only becomes significant at high temperatures for metals such as steel and copper. Aluminum, however, creeps at temperatures and stresses that commonly occur at electrical terminations.

In a conventional connection, creep will take place until the stress is reduced. After all, most connections are made by simply tightening screws or clamps. Unless there is some method to maintain stress -- such as weight or a spring -- the metal will creep away from the stressing point. This phenomena is called "relaxation."

Its effect in a circuit, of course, is profound. Ultimately the pressure can be reduced to the point where good electrical contact no longer exists. The result is high resistivity of the connection, overheating and eventual failure.

Actually, a sequence of events takes place. After initial loading, the material begins to creep, but because the gap is constant, relaxation takes place. This reduces the contact area between the metal surfaces generated by elastic deformation.

In turn, this causes higher resistance both by constricting the current through less contact area and by allowing buildup of oxide in the areas exposed. Temperature of the joint is increased so creep continues despite the fact that stresses are lower. And so it goes until arcing takes place at the joint. In other cases, the connection is completely broken when current is shut off, the connection cools and the metal surfaces contract away from each other.

We should add at this point that solid copper exhibits only negligible creep under these conditions. Also, we have investigated the creep properties of copper clad aluminum wire which turn out to be very close to those of copper.

The mechanism of creep is complex. Creep is essentially a result of thermally-activated cross slip and movement of crystal dislocations. Increased temperature increases the rate of cross slip and dislocation movement, thus increasing the rate of creep. Cladding aluminum with copper, however, inhibits dislocation movement. What happens is the dislocations in the aluminum crystal lattice move to the clad interface. They will not penetrate into the copper because copper's lattice is tighter than that of aluminum. So the dislocations pile up against the copper clad aluminum interface and generate a stress field which retards further dislocation movement and creep in the aluminum core. (Fig 5)

The graph shows current in amperes plotted against the time in hours to reach a point of failure. The first series of tests was conducted with commonly used ring main circuit connectors. The first part of this graph was obtained from high current testing to failure after at least ten hours service and up to well over 10,000 hours. The dotted portion of this graph is an extrapolation to 30,000 hours which is generally accepted as being a reasonable simulation of at least twenty years' life for a wiring cable. (Figure 6)

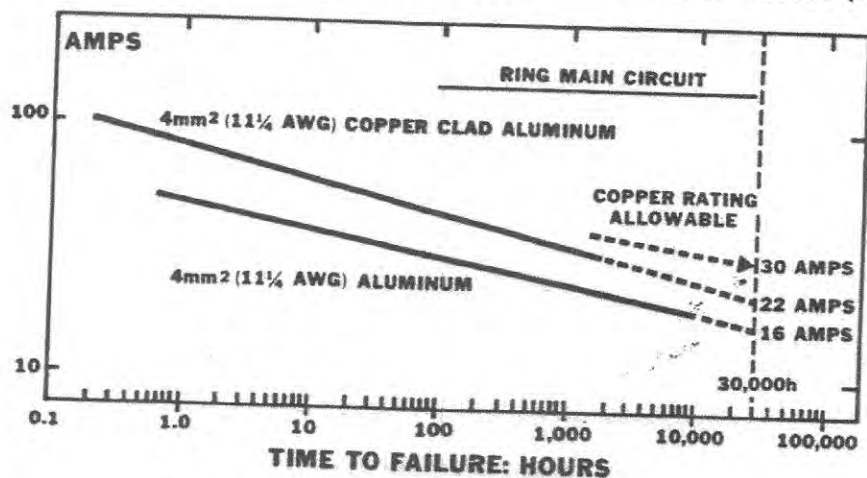


Figure 6: 20-Year Circuit Ampacity

In the case of 4 mm² (11¼ AWG) copper clad aluminum, a 30,000 hour life is reached at a loading of 22 amps, the rating of an equivalent copper conductor cable with full fuse protection. The lower line is for 4 mm² (11¼ AWG) aluminum conductor. It shows that aluminum can carry only 16 amps to reach a life of 30,000 hours. Notice that aluminum would require more than a two gauge increase over copper to have the same current rating with this terminal design. Similar tests were undertaken for lighting circuit connectors. In this case, the results are 10 amps for 1.5 mm² (15½ AWG) aluminum and 12 amps for 1.5 mm² (15½ AWG) copper clad aluminum conductors. 1.5 mm² (15½ AWG) copper conductor will give a figure of 12.5 amps. (Figure 7)

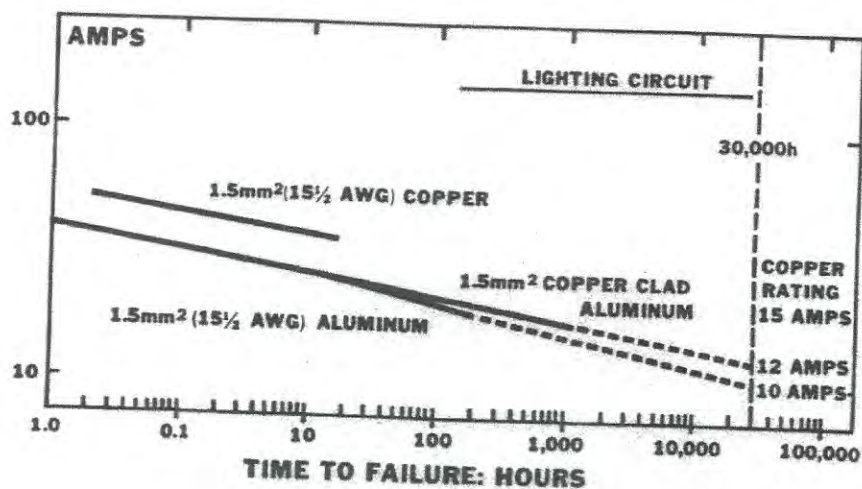


Figure 7: 20-Year Circuit Ampacity

Results of circuit reliability trials were even more conclusive. These tests studied the time taken to cause failure of various kinds of connectors under current cyclic loading conditions. Test procedure was to wire groups of standard connectors as a ring main circuit with a terminal box between connectors so that these could be isolated and replaced. The load cycle was five hours on and one hour off. A daily check was made on temperature rise and, again, a connector was deemed to fail when it reached a temperature of 175°C.

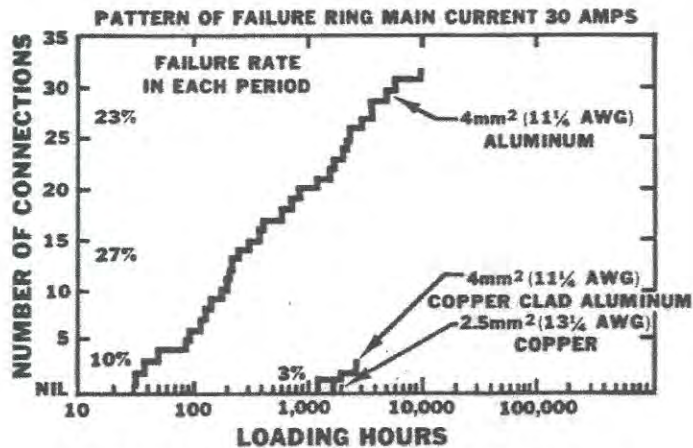


Figure 8: Service Reliability Test

This graph illustrates the pattern of failure in a ring main circuit with 30 amps supplied. It shows the number of connections failed plotted against hours energized. With 4 mm² (11½ AWG) solid aluminum conductors, 10 percent failed after one hundred hours, a further 27 percent after one thousand hours, and a further 23 percent after 10,000 hours. This pattern of failure with 60 percent of the connections failing by 10,000 hours is clearly not acceptable for practical conditions. (Figure 8)

In the case of 2.5 mm² (13½ AWG) copper and 4 mm² (11½ AWG) copper clad aluminum the rate of failure is as low as 3 percent. Also note that initial failure occurs much later.

The next graph illustrates the most practical situation with a ring main current of 22 amps, normal maximum loading for this conductor. Once again solid aluminum conductors have an unacceptable rate of failure. By comparison neither solid copper nor copper clad aluminum recorded a single failure. (Fig 9)

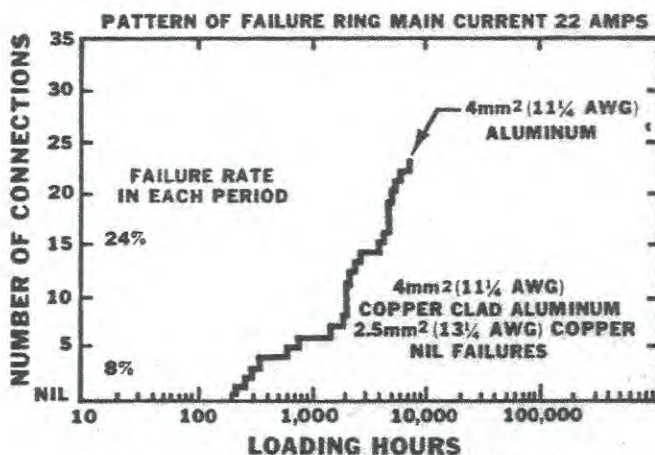


Figure 9: Service Reliability Test

Overall, the testing program undertaken by BICC in relation to ring main connector applications amounts to nearly 10 million fitting hours of test experience. It is important to stress again that in all of these tests wiring of the aluminum was carried out to give the best possible results, and wiring of copper and copper clad aluminum was done under normal conditions.

This cyclic loading test is extremely important because it simulates actual conditions that

wiring systems face with users turning power on and off. It shows cyclic loading is a more severe test condition than continuous loading. Even under cyclical loading copper clad aluminum performed as reliably as copper, a conclusion

verified by historical data on copper clad aluminum in actual use. Recent inspection of Texas Instruments industrial buildings wired with copper clad aluminum conductor since 1967 revealed no indication of termination problems. The installation includes 200,000 feet of copper clad aluminum conductor in sizes from 350 MCM to #12 AWG, and more than 10,000 connections. This constitutes a successful history of more than 262 million fitting hours, two-thirds of which consists of load time. Most importantly, this conductor was installed using the same connections and installation procedures used for copper. Previously, this kind of reliability using this installation procedure could be achieved only with copper building wire. It is also interesting to note that in a recent inspection of bus connections copper clad aluminum cables required one-half turn less than copper cables of the same gauge.

Circuit Ampacity

Connection reliability is important because it is a controlling factor in the actual capacity of circuits. The relative ability of a conductor to carry current is called "ampacity" and is expressed in amperes. Circuit ampacity is the current carrying and current transferring capacity of a conductor or cable and all its connectors as an operating unit. Good terminations are essential to good circuit ampacity. Terminations must have the capacity to transfer current without exceeding conductor or connector temperature ratings. If the conductor can carry 15 amps but the connection can only carry 5 amps, system ampacity is limited by the current carrying capacity of the connection which is 5 amps.

The BICC data reveals that copper clad aluminum's connection reliability -- and circuit ampacity -- is comparable to that of copper.

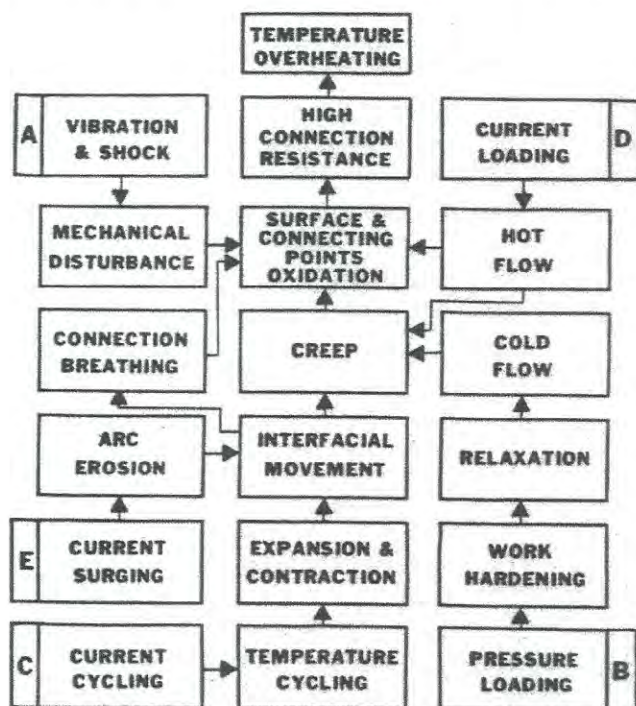


Figure 10: Connection Failure Mechanisms

Review of Failure Mechanisms

Let us examine the various possible failure mechanisms involved with aluminum (Figure 10). One simple method of failure is the result of vibration. With aluminum the failure sequence would follow a pattern starting at block (A).

Failure can occur in constant loading conditions because of creep. It would follow a pattern starting at (B).

Current cycling can cause failure because of expansion and contraction of joints leading to loosening of the joints which allows further buildup of insulating oxide, leading to more overheating and final failure. It would follow a pattern from (C). (Note that in one path creep hastens failure).

Two other failure mechanisms are possible involving high current loading (D) and current surging (E).

Altogether, these various failure modes add up to a complex situation. With aluminum, creep is a contributing factor, but the most important consideration always is its highly resistive and quick forming oxide film.

Possible Solutions

Copper clad aluminum solves this problem by presenting a layer of copper to make the electrical contact. The copper cladding results in surface properties identical to solid copper conductor.

What other alternatives are there to solving aluminum termination problems? Two approaches are under investigation: One is to develop improved connector techniques to overcome aluminum's creep and oxide formation characteristics; the other is to develop better alloys.

Connector manufacturers have, in fact, solved the connector problem for large size aluminum conductors in various ways:

- By modifying base metal to match degree of thermal expansion;
- By plating metal surfaces to avoid oxide formation;
- By adding features to penetrate the hard aluminum oxide layer and by sustaining pressure to maintain metal-to-metal contact.

The increased cost of these connectors and the added installation costs which they entail are easily absorbed by the savings resulting from use of large size aluminum conductor.

In the case of small size building wire, a widely accepted solution has yet to be demonstrated. But regardless of the connector design finally established, it is likely that either special handling procedures will be required or connectors will be relatively more costly.

What about New Alloys?

Many aluminum companies have responded to the need for high strength and low creep rate in aluminum building wire. Some of these new aluminum alloys show improved properties, particularly higher creep resistance, without dramatically sacrificing conductivity.

Alloying could possibly increase mechanical strength and reduce creep, which is one part of the problem; but the problem of aluminum's insulating oxide film would remain. Therefore, the ultimate solution will be a combination of better alloys and improved connectors.

Until that possible eventuality, copper clad aluminum offers an economic and technically-sound solution.

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