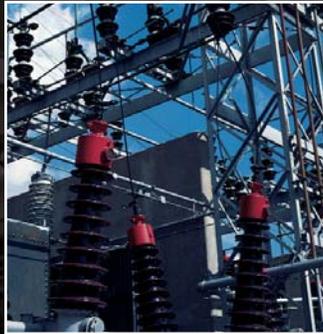


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THE CONNECTABILITY STUDY

Introduction

This study was conducted for the Canadian Copper & Brass Development Association (CCBDA) in Toronto, Ontario by Powertech Labs of Surrey, B.C. The full text of the study is available on request. Limited space allows only the results of the intensive testing to be published here.

Objective

The objective of this project was to compare the connector performance under equivalent severe environmental conditions for the following three configurations:

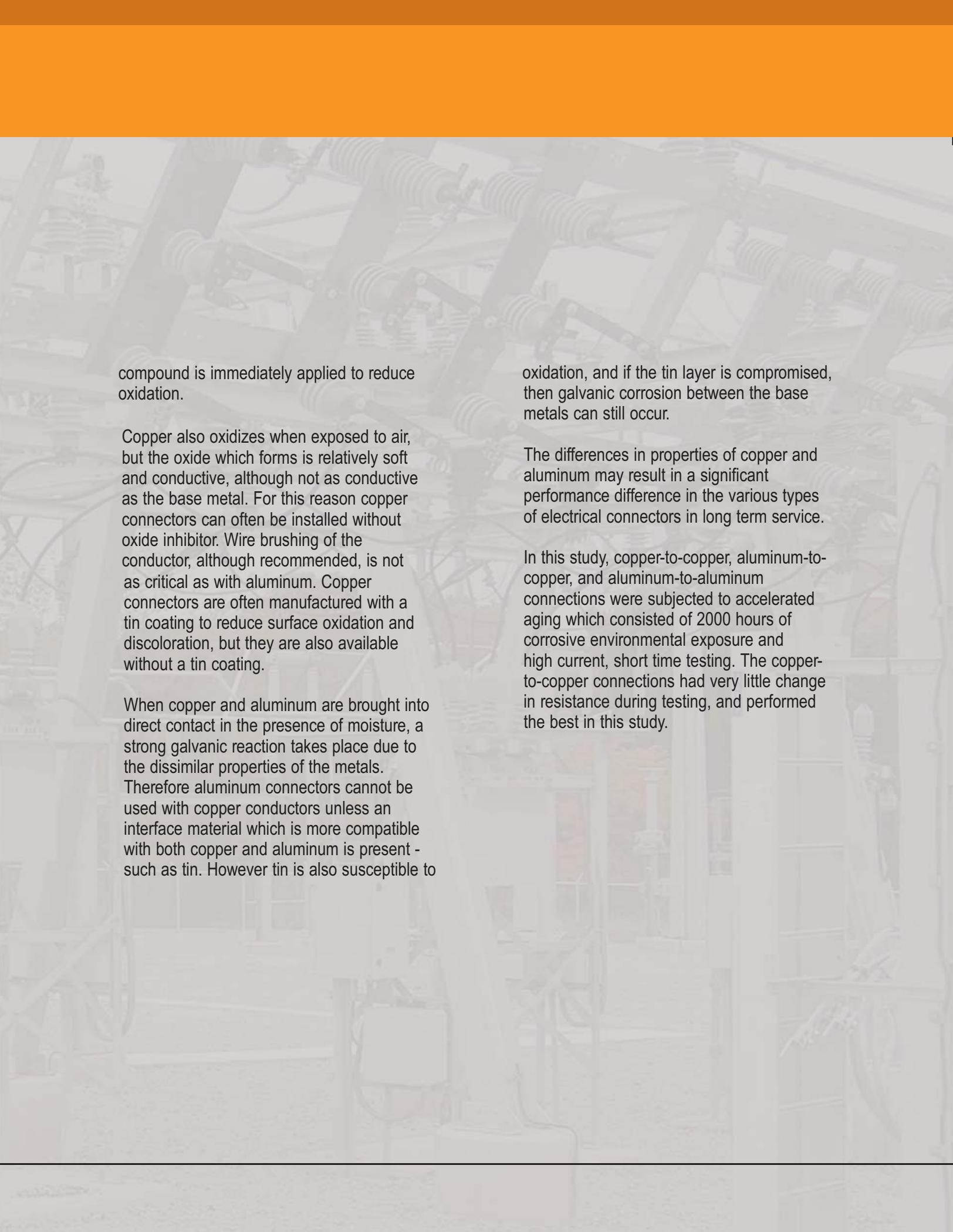
- copper connectors on copper conductor,
- aluminum connectors on copper conductor, and
- aluminum connectors on aluminum conductor.

The power connectors, conductor, and oxide inhibitor used to make the samples were standard commercially available varieties obtained from several different manufacturers. The sizes are 2/0 AWG copper and 4/0 AWG aluminum.

Background

Copper connectors are available for use with copper conductor, and aluminum connectors are available for use with copper and aluminum conductors. Test standards for power connectors include the CSA C57 or ANSI C119.4 500 cycle current cycling test, which is intended to establish long term performance. There are significant differences in the material and electrical properties of aluminum and copper and their oxides which may affect their long term performance.

Aluminum oxidizes readily when exposed to air, and a strongly attached hard outer layer of electrically insulating oxide quickly forms around the metal. For this reason aluminum connectors are often manufactured with an outer tin coating which is intended to prevent surface oxidation of the connector from occurring. Aluminum crimp connectors are also pre-filled with oxide inhibiting compound to reduce oxidation between the conductor and connector when in service. Aluminum conductors must always be wire brushed to remove the oxide layer, and oxide inhibiting



compound is immediately applied to reduce oxidation.

Copper also oxidizes when exposed to air, but the oxide which forms is relatively soft and conductive, although not as conductive as the base metal. For this reason copper connectors can often be installed without oxide inhibitor. Wire brushing of the conductor, although recommended, is not as critical as with aluminum. Copper connectors are often manufactured with a tin coating to reduce surface oxidation and discoloration, but they are also available without a tin coating.

When copper and aluminum are brought into direct contact in the presence of moisture, a strong galvanic reaction takes place due to the dissimilar properties of the metals. Therefore aluminum connectors cannot be used with copper conductors unless an interface material which is more compatible with both copper and aluminum is present - such as tin. However tin is also susceptible to

oxidation, and if the tin layer is compromised, then galvanic corrosion between the base metals can still occur.

The differences in properties of copper and aluminum may result in a significant performance difference in the various types of electrical connectors in long term service.

In this study, copper-to-copper, aluminum-to-copper, and aluminum-to-aluminum connections were subjected to accelerated aging which consisted of 2000 hours of corrosive environmental exposure and high current, short time testing. The copper-to-copper connections had very little change in resistance during testing, and performed the best in this study.

Connector Samples Used For Testing

Test Samples

The test samples used in the study were combinations of copper and aluminum conductors and connectors, with all components being standard off-the-shelf varieties. Copper conductor was bare 19-strand 2/0 AWG, and aluminum conductor was Alcan NUAL 18-strand compact 4/0 AWG. Conductor sizes were selected to be approximately the same ampacity. Connectors were a combination of compression and mechanical bolted type 1-hole lug connectors. All aluminum compression connectors were tin plated and supplied pre-filled with oxide inhibitor. A complete list of the test samples is provided in Table 1, and a photograph of the samples before installation is shown in Figure 1.

Connector Installation Procedures

Connectors were installed onto 50-cm long conductor segments according to the manufacturer's recommendations, and using the following procedures:

- All conductors were wire brushed immediately before installing the connectors.
- Thomas & Betts Contax® CTB8 Oxide inhibitor was applied to the aluminum conductor for installation of mechanical connectors.
- No oxide inhibitor was applied to any of the copper-to-copper connections.
- Compression connectors were crimped using a Thomas & Betts (Blackburn) model TBM5 crimping tool.
- Mechanical connectors were installed using torque levels as shown in Table 2.
- A brazed or welded equalizer was installed on the other end of each conductor segment to provide good current distribution to the conductor for current testing and resistance measurements.

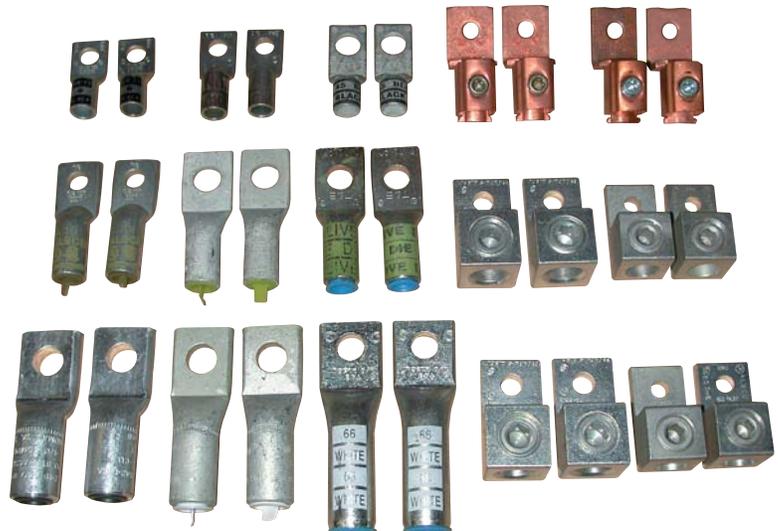
TABLE 1: Connectors and conductors used

Sample No.	Connector Material	Conductor Material	Connector				
			Type	Manufacturer	Size	Plating	Model
A1/A2	Aluminum	Aluminum	Mechanical	A	#6-250	Tin	ADR 25
A3/A4	Aluminum	Aluminum	Compression	A	4/0	Tin	ATL40-12
A5/A6	Aluminum	Aluminum	Compression	B	4/0	Tin	5A-3/0-48
A7/A8	Aluminum	Aluminum	Mechanical	C	#6-250	Tin	TA 350
A9/A10	Aluminum	Aluminum	Compression	D	4/0	Tin	YA28A3
B1/B2	Aluminum	Copper	Compression	D	2/0	Tin	YA26AL
B3/B4	Aluminum	Copper	Compression	C	2/0	Tin	IACL-2/0
B5/B6	Aluminum	Copper	Compression	A	2/0	Tin	ATL20-12
B7/B8	Aluminum	Copper	Mechanical	C	#6-250	Tin	TA 350
B9/B10	Aluminum	Copper	Mechanical	A	#6-250	Tin	ADR 25
C1/C2	Copper	Copper	Compression	D	2/0	Tin	YA1-26T38
C3/C4	Copper	Copper	Compression	C	2/0	Tin	CRA 2/0
C5/C6	Copper	Copper	Compression	A	2/0	Tin	CTL-20-12
C7/C8	Copper	Copper	Mechanical	C	#6-250	None	SLU 300
C9/C10	Copper	Copper	Mechanical	A	#2-4/0	None	BTC 4102

TABLE 2: Mechanical connector torque levels for installation

Conductor Size AWG	Screw Size In.	Torque	
		In. lb	N.m
2/0	7/16	120	13.6
2/0-4/0	11/16	275	31.1
2/0-4/0	3/4	375	42.4

FIGURE 1: Connector samples used for burst testing



Copper on Copper

Test Procedures

The testing consisted of periods of corrosive environmental exposure, followed by application of high current. This was intended to produce conditions in which connectors that are susceptible to corrosion show an increase in contact resistance as the testing progresses.

The cyclic testing was conducted in the following sequence.

- Salt fog corrosion cycling was carried out for 500-hour blocks of time.
- Current burst tests were carried out following each 500-hour salt fog period.
- DC resistance readings of each connector were made approximately every 170-hours during the corrosion testing, and before and after each set of current burst tests.
- A total of four sets of salt fog and current burst tests were conducted, for a total of approximately 2000-hours of salt fog testing.

Corrosion Cycling

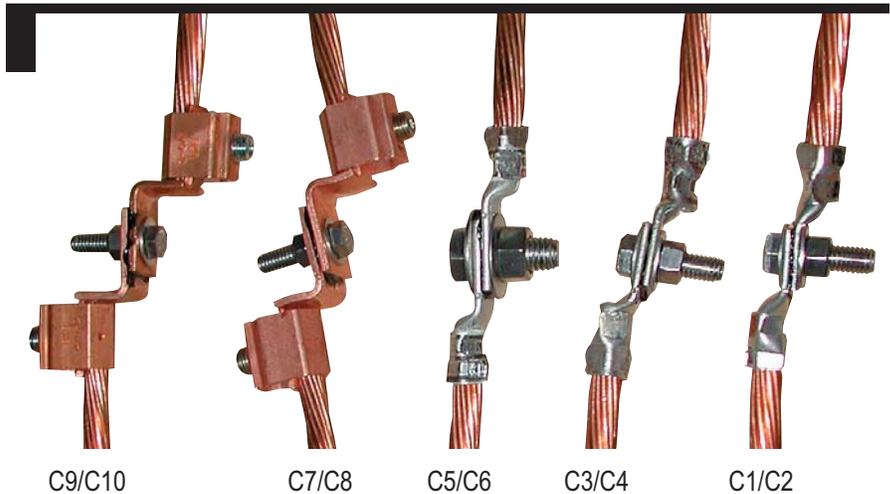
Connector sample groups were arranged on a three tier PVC rack in an environmental chamber with the conductors and connectors oriented horizontally, and the connectors suspended in clear air. The positions of the connector sets were exchanged periodically so that more consistent environmental exposure from sample to sample was achieved over the testing period.

Each 4-hour corrosion testing cycle consisted of the following steps:

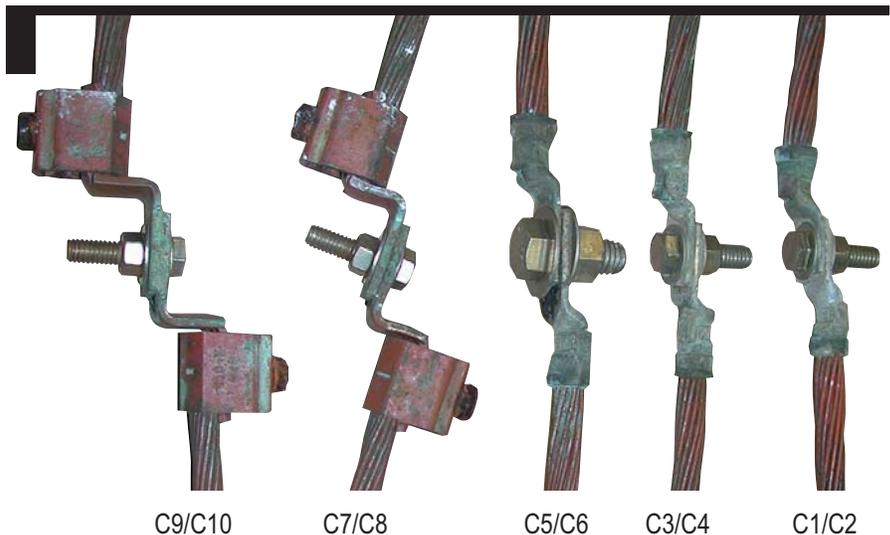
1. Salt fog spray for a period of 1-hour 45-minutes, consisting of a fine mist of aerated 3% NaCl solution buffered to a pH of 5.5 using nitric acid.
2. Dry heat for a period of 2-hours, reaching a maximum of 70 °C during the 2-hour period.
3. Clear water rinse for a period of 15-minutes.

The cycle was repeated continuously during the corrosion testing.

Copper-to-copper samples before testing



Copper-to-copper samples after 2000 hours of testing



Aluminum on Aluminum

Current Burst Testing

The reason for conducting current burst testing was to encourage accelerated degradation at the connector contact with the conductor. For the test, current levels of 1750 A_{rms} for 4/0 aluminum conductor, and 1800 A_{rms} for 2/0 copper conductor were determined to be sufficient to produce the desired effect. For each test, the current was held at these levels long enough to raise the temperature of the control conductor to 250°C, as determined by thermocouple measurement at the center of the control conductor span. Typically, this required an application of current for approximately 50 seconds, starting with a conductor at near room temperature.

Samples were subjected to current burst testing as follows:

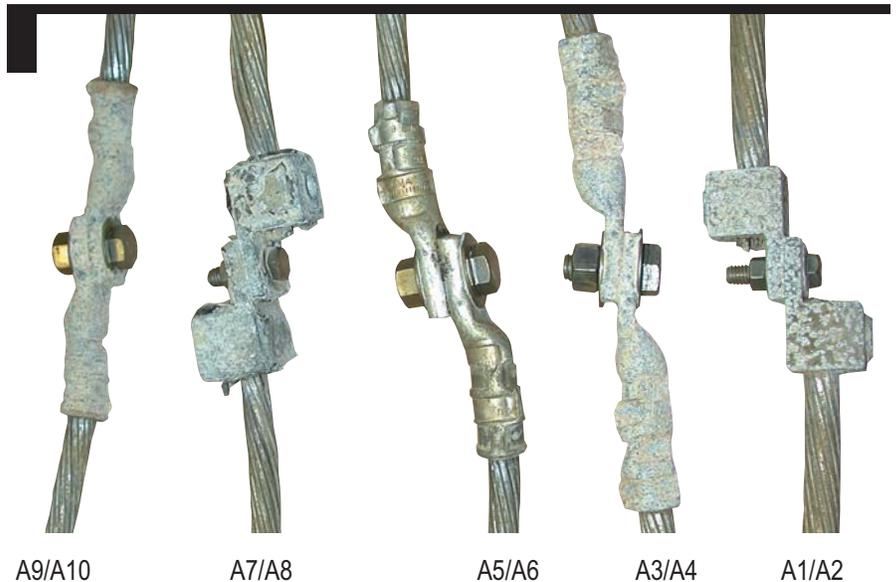
- Each set of 10 connectors, which were joined together in series, were subjected to current burst testing simultaneously.
- The control conductor was placed in series with the connector assembly. A thermocouple was attached to the center of the length of each control conductor to measure the conductor temperature during current burst testing.
- Five short duration bursts of high current were applied in succession. The control sample was allowed to cool to 40°C or less between each current burst.

The resistance of each sample (from each equalizer to each connector) was measured at room temperature using a micro-ohmmeter before and after each set of five current burst tests.

Aluminum-to-aluminum samples before testing



Aluminum-to-aluminum samples after 2000 hours of testing



Aluminum on Copper

Final Results

The final results of the corrosion and current burst testing are given below, which shows the number of samples of each type listed by percent change in resistance over the entire testing period. It was determined that a resistance increase of greater than 5% for the whole sample (equalizer, conductor segment and connector) was equivalent to an increase of more than 100% for the contact from the conductor to the connector. Therefore an increase in sample resistance of greater than 5% was considered to be significant.

Aluminum Connectors on Aluminum Conductor:

- 40% of the connector samples could be considered to have failed.
- 10% of the samples showed a significant increase in resistance.
- 20% of the samples showed a moderate increase in resistance.
- 30% of the samples showed a decrease in resistance.

Aluminum Connectors on Copper Conductor:

- 40% of the samples showed a significant increase in resistance.
- 30% of the samples showed a moderate increase in resistance.
- 30% of the samples showed a small increase in resistance.

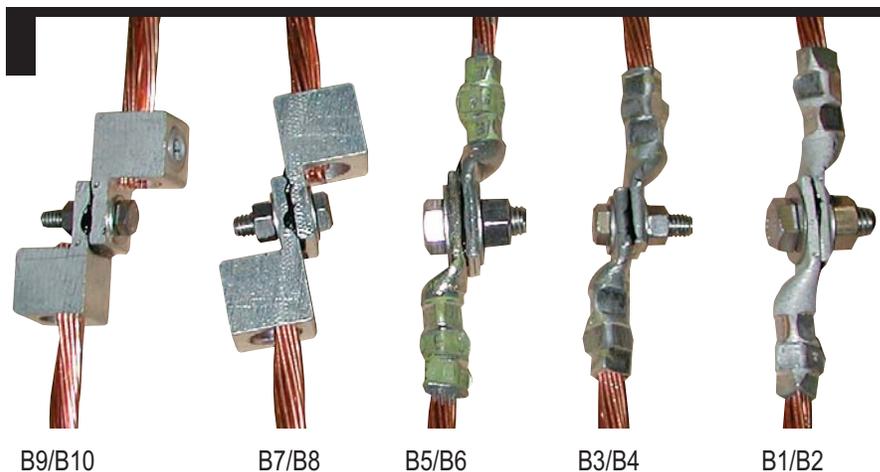
Copper Connectors on Copper Conductor:

- 70% of the samples showed a small increase in resistance.
- 30% of the samples showed a decrease in resistance.

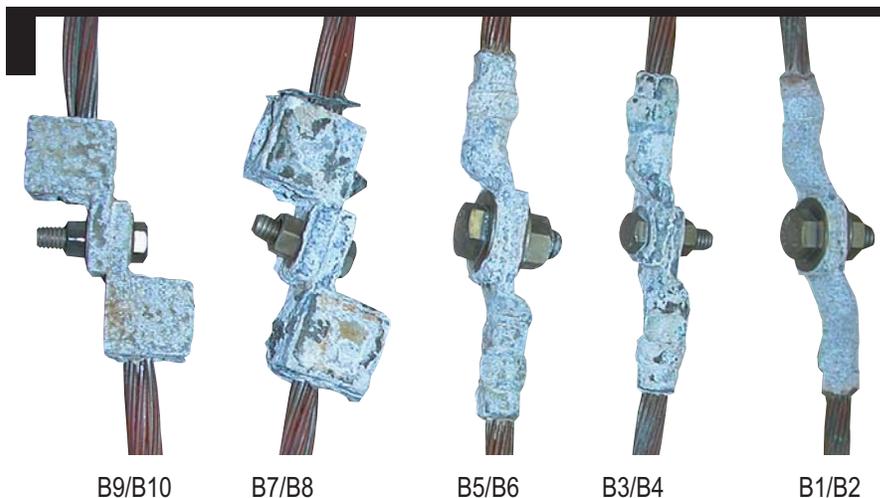
Overall the best performance in this 2000-hour corrosion and current burst test was obtained by all-copper connectors, the all-copper system.

Connector Type	Conductor Type	Overall resistance increase compared to starting resistance:				
		decrease (<0%)	small Increase (0%-1%)	moderate Increase (1%-5%)	significant Increase (5%-10%)	failure (>10%)
Aluminum	Aluminum	3	0	2	1	4
Aluminum	Copper	0	3	3	4	0
Copper	Copper	3	7	0	0	0

Aluminum-to-copper samples before testing



Aluminum-to-copper samples after 2000 hours of testing





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