Ontario Hydro
TECHNOLOGIES

SUBSTATION GROUNDING CONNECTORS
IEEE STD 837-1989 TEST SERIES

Report No C-95-EST-193-P

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ABSTRACT

A comparative evaluation of three fundamentally different designs of direct burial electrical grounding connectors was performed under contract for Erico® Inc. of Solon Ohio. These tests were performed in accordance with the method and procedures specified in IEEE Std. 837-1989, "*IEEE Standard for Qualifying Permanent Connections Used in Substation Grounding*". The test results indicate that exothermically welded connections appear to be more consistent and uniform in their performance following the series of tests. In the samples tested, some of the bolted and compression connectors have unexplained failures or increase in resistance. It was also observed that bolted and compression connectors appear to be more susceptible to deterioration in a corrosive environment than welded connections. Although these test results show failures of individual connector samples, it does not imply that the connectors fundamental design concept is flawed. It does however indicate that some of these connector/conductor combinations did not meet the IEEE Std 837-1989 series of tests.

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SUBSTATION GROUNDING CONNECTORS
IEEE STD 837-1989 TEST SERIES

INTRODUCTION

A comparative evaluation of three fundamentally different designs from four manufacturers of direct burial, electrical grounding connectors was performed under contract for Erico Inc in accordance with the method and procedures indicated in IEEE Std. 837-1989. The three designs evaluated were bolted wedge, exothermically welded (Cadweld®) and die compression type connections. The performance of each design type was evaluated on 4/0 to 4/0, 19 strands, medium hard drawn copper conductor and on 4/0 to 3/4" copper clad, steel core ground rod.

One hundred and sixty connectors (twenty of each connector/conductor combination) were included in the test program.

- Exothermically welded connection, (Cadweld # XAC2Q2Q) for 4/0 to 4/0
- Exothermically welded connection, (Cadweld # GTC182Q) for 4/0 to 3/4" rod
- Bolted wedge type connectors, (AMP Wrench-lok # 81228-1) for 4/0 to 4/0
- Bolted wedge type connectors, (AMP Wrench-lok # 81229-1) for 4/0 to 3/4" rod
- Die compression type connectors, (Burndy # YGL29C29) for 4/0 to 4/0
- Die compression type connectors, (Burndy # YGLR29C34) for 4/0 to 3/4" rod
- Die compression type connectors, (T&B # GG40250-40250) for 4/0 to 4/0
- Die compression type connectors, (T&B # GG500-40250) for 4/0 to 3/4" rod

The connectors were tested in accordance with the IEEE Std. 837-1989, *"IEEE Standard for Qualifying Permanent Connections Used in Substation Grounding"*. Additional tests were performed at higher than specified levels in certain sections. This was to provide information on the connectors' ability to surpass the performance requirements of IEEE Std. 837-1989.

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TEST SUMMARY

The different tests are described by category and identified as indicated in IEEE Std 837.

- Individual test group mechanical - Mechanical Pullout, Section 7.2
- Individual test group electromagnetic - Electromagnetic Force, Section 7.3
- Sequential test groups-acidic
  - Current-Temperature Cycling, Section 8
  - Freeze-Thaw, Section 9
  - Corrosion-nitric acid, Section 10.2
  - Fault Current, Section 11
- Sequential test groups-alkaline
  - Current-Temperature cycling, Section 8
  - Freeze-thaw, Section 9
  - Corrosion-salt spray, Section 10.3
  - Fault current, Section 11

For each of the above-mentioned test groups, a different connector set (consisting of four connectors) was assembled from each manufacturer. An additional set was prepared for the Electromagnetic force test for the test at higher levels. The connector sets were coded as indicated in Table 1.

Table 1
Connector Set Identification

Test	Conductors	AMP 81228-1	BURNDY YGL29C29	CADWELD XAC2Q2Q	T&B GG40250-40250
Mechanical-pullout	4/0-4/0	1A	1B	1C	1T
Electromagnetic force	4/0-4/0	3A	3B	3C	3T
Electromagnetic force	4/0-4/0	4A	4B	4C	4T
Alkaline Test group	4/0-4/0	7A	7B	7C	7T
Acidic Test group	4/0-4/0	9A	9B	9C	9T
	Conductors	**81229-1**	**YGLR28C34**	**GTC182Q**	**GG500-40250**
Mechanical-pullout	4/0-ROD	2A	2B	2C	2T
Electromagnetic force	4/0-ROD	5A	5B	5C	5T
Electromagnetic force	4/0-ROD	6A	6B	6C	6T
Alkaline Test group	4/0-ROD	8 A	8B	8C	8T
Acidic Test group	4/0-ROD	10 A	10B	10C	10T

SAMPLE PREPARATION

All of the samples were assembled by staff from Ontario Hydro Technologies (OHT) according to the instruction sheets provided with the connectors or obtained from the manufacturer. Conductor lengths were cut and cleaned using a wire brush before assembly. All equalizers on the 4/0 conductors consisted of an exothermic weld using Cadweld mold #SSC2Q and weld metal #90. The terminals on the end of the conductor samples were made using Cadweld mold # LAC2QEE with weld metal #90 and Lug #B102EEOL. The copper conductor used for all these tests was new 4/0 - 19 strands medium hard drawn conductor. The ground rod used were new 3/4" copper clad, steel core rod (ERICO #1034).

The bolted wedge design connector (AMP Wrench-Lok 81228-1 and 81229-1) consists of a wedge driven into the connector body by a shear head bolt. Once the design torque is reached, the bolt head breaks away leaving the wedge and connection securely fastened. No special tooling is required for the installation of this connector.

The die compression type connectors (Burndy YGL29C29 and YGLR29C34 and T&B GG40250-40250 and GG500-40250) were installed using the recommended crimp tool and new dies purchased from the manufacturer. The compression of the tools were verified before use and found to be within manufacturer's specification.

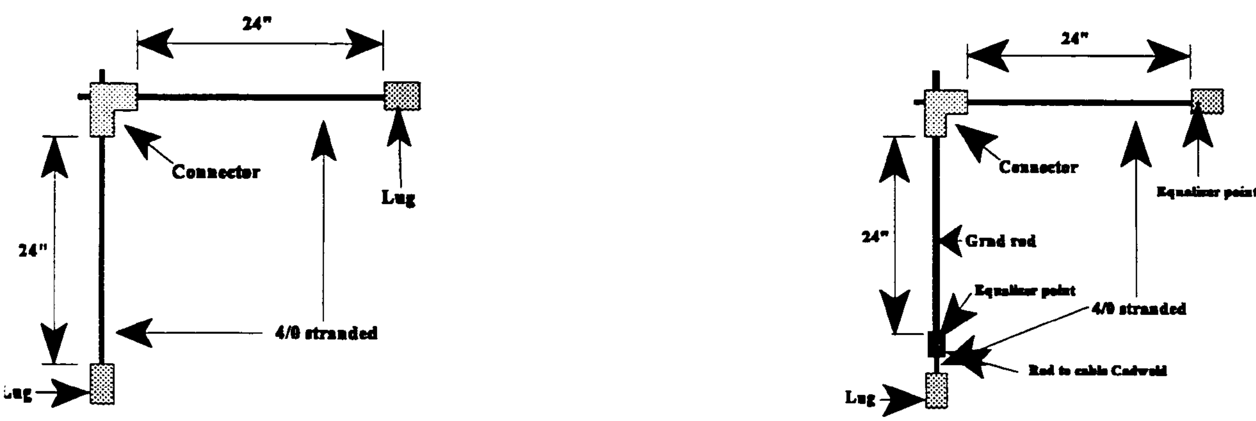
The Burndy connector YGL29C29 was crimped using die #U997, the connector YGLR29C34 was crimped using die #U997 on the 4/0 cable and UPRECRIMP34 and PU998 on the 3/4" rod. A Y35 crimp tool was used for both connectors.

The T&B connector GG40250-40250 was crimped using a TBM14M tool and a #71 die, the connector GG500-40250 was crimped using the same tool with a #71 die for 4/0 cable and #87 die for the 3/4" rod.

The Cadweld connections (# XAC2Q2Q and GTC182Q) were done using Cadweld weld metal #200 for the 4/0 to 4/0 cable connection and Cadweld weld metal #115 for the 4/0 to 3/4" ground rod. New molds were purchased to prepare the samples. All similar connections were made with the same mold.

A typical installation layout followed for the 4/0 to 4/0 conductor and 4/0 to 3/4" ground rod is shown in Figure 1.

Figure 1: Assembly Drawing for Connector Samples



TEST PROGRAM

TEST #1: Mechanical Pullout (Tensile Strength), Ref IEEE Std 837-1989, 7.1

Condensed requirements
Each connector is tested individually. The requirement for 4/0 AWG is 500 lbs (2225N) and 1000 lbs for 3/4" rod (4450N) minimum with no movement of the conductor in relation to the connector. The minimum length of the conductor between the connector and the gripping device shall be 10 inches (254 mm). The gripping device shall load all strands of the conductor simultaneously and in line with the connector. The loading speed of the crosshead shall not exceed 0.25 inches per minute.

Additional tests
Each connector was taken to failure noting slippage and failure mode.

Test Equipment
These tests were performed with a Satec Universal machine model 120WHVL, S/N 1322.

Test Procedure
The samples were prepared with 16 inches of exposed conductor on either side of the connector. An equalizer was formed using Cadweld SSC2Q at the 12-inch mark. Each sample was placed in the Satec Test Machine using a jig fabricated to pull on the shoulder of the connector and the equalizer. Both sides of the connector were pulled except the AMP since the connector comes apart once one conductor is pulled out. A typical sample mounted for the test is shown in Figure 2. The samples were then pulled to the required tension and observed for slip. The tension was then increased to failure. A record of the failure load and mode of failure is given in Table 2. Photographs of typical failures are shown in Figures 3 and 4.

Summary of Test Results for Mechanical-Pullout

Bolted wedge design:	AMP Wrench-Lok #81228-1, 4/0 to 4/0 conductor: No slip at 500 lbs AMP Wrench-Lok #81229-1, 4/0 to 3/4" rod: One rod slip below 1000 lbs
Die compression connectors:	Burndy YGL29C29, 4/0 top 4/0 conductor: No slip at 500 lbs Burndy YGLR29C34, 4/0 to 3/4" rod: No slip at 1000 lbs
Exothermically welded:	Cadweld XAC2Q2Q, 4/0 to 4/0 conductor: No slip at 500 lbs Cadweld GTC182Q, 4/0 to 3/4" rod: No slip at 1000 lbs
Die compression connectors:	T&B GG40250-40250, 4/0 to 4/0 conductor: No slip at 500 lbs T&B GG500-40250, 4/0 to 3/4" rod: Four rods pulled out below 1000 lbs

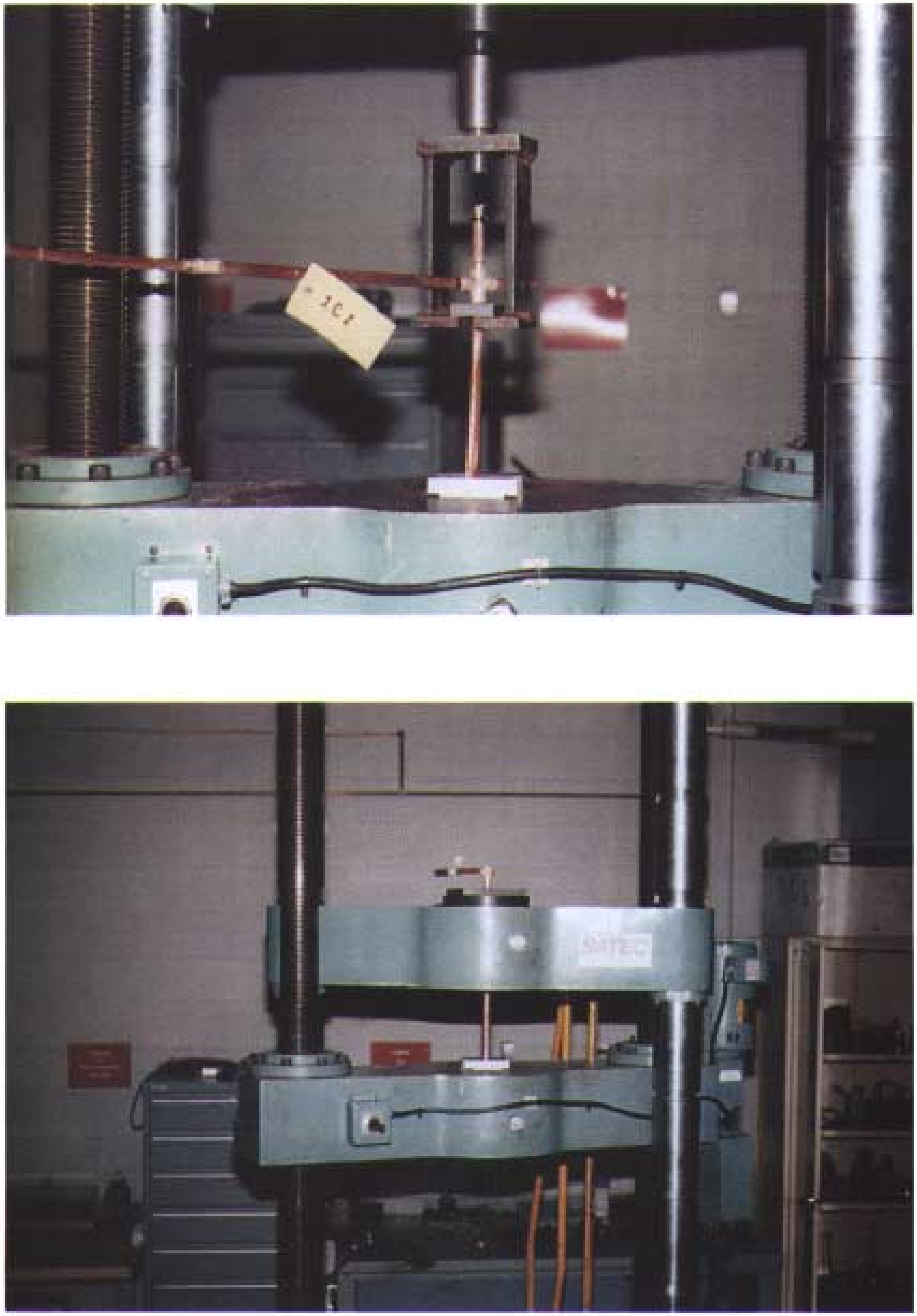


Figure 2: Typical Mounting of Connector for Mechanical Pullout Test

Table 2
Test Result of Mechanical Pullout Test

Connector	Sample ID	Side	Failure Load Lbs	Mode of Failure
AMP: 81228-1	1A1	A	1,888	Conductor pulled out
	1A2	A	2,161	Conductor pulled out
	1A3	A	2,732	Conductor pulled out
	1A4	A	2,903	Conductor pulled out
AMP:81229-1	2A1	A-ROD	970	Rod pulled out
	2A2	A-ROD	1,540	1st slip 1,410 lbs., rod pulled out
	2A3	A-ROD	1,109	Rod pulled out
	2A4	A-ROD	1,124	Rod pulled out
BURNDY: YGL29C29	1B1	A	1,430	Conductor pulled out
		B	1,720	Conductor pulled out
	1B2	A	1,816	Conductor pulled out
		B	2,022	Conductor pulled out
	1B3	A	1,995	Conductor pulled out
		B	1,665	1520 Lbs. Conductor pulled out
	1B4	A	1,780	Conductor pulled out
		B	1,677	Conductor pulled out
BURNDY: YGLR29C34	2B1	A-ROD	3,323	Rod pulled out
		B	828	Conductor pulled out
	2B2	A-ROD	3,571	Rod pulled out
		B	826	Conductor pulled out
	2B3	A-ROD	3,485	Rod pulled out
		B	1,058	Conductor pulled out
	2B4	A-ROD	3,824	Rod pulled out
		B	853	Conductor pulled out

Table 2: Test Result of Mechanical Pullout Test (Con't)

Connector	Sample ID	Side	Failure Load Lbs.	Mode of Failure
Cadweld: XAC2Q2Q	1C1	A	5,324	Strands fail in connector
		B	5,079	Strands fail in equalizer
	1C2	A	4,834	Strands fail in equalizer
		B	4,910	Strands fail in equalizer
	1C3	A	4,304	Strands fail in equalizer
		B	4,824	Strands fail in equalizer
	1C4	A	4,720	Strands fail in equalizer
		B	5,005	Strands fail in connector
Cadweld: GTC182Q	2C1	A-ROD	13,220	Rod pulled out
		B	5,478	Strands fail in connector
	2C2	A-ROD	13,540	Rod pulled out
		B	5,270	Strands fail in equalizer
	2C3	A-ROD	11,640	Rod pulled out
		B	5,700	Strands fail in equalizer
	2C4	A-ROD	13,800	Rod pulled out
		B	4,720	Strands fail in connector
T&B: GG40250-40250	1T1	A	4,911	Conductor pulled out
		B	4,824	Conductor pulled out
	1T2	A	4,862	Conductor pulled out
		B	5,897	Conductor pulled out
	1T3	A	5,820	Conductor pulled out
		B	5,070	1520 Lbs Conductor pulled out
	1T4	A	5,808	Conductor pulled out
		B	5,064	Conductor pulled out
T&B: GG500-40250	2T1	A-ROD	370	1st Slip at 217 Lbs, Rod pulled out
		B	5,559	Conductor pulled out
	2T2	A-ROD	367	Rod pulled out
		B	5,288	Conductor pulled out
	2T3	A-ROD	327	Rod pulled out
		B	5,951	Conductor pulled out
	2T4	A-ROD	363	1st Slip at 249 Lbs, Rod pulled out
		B	5,497	Conductor pulled out

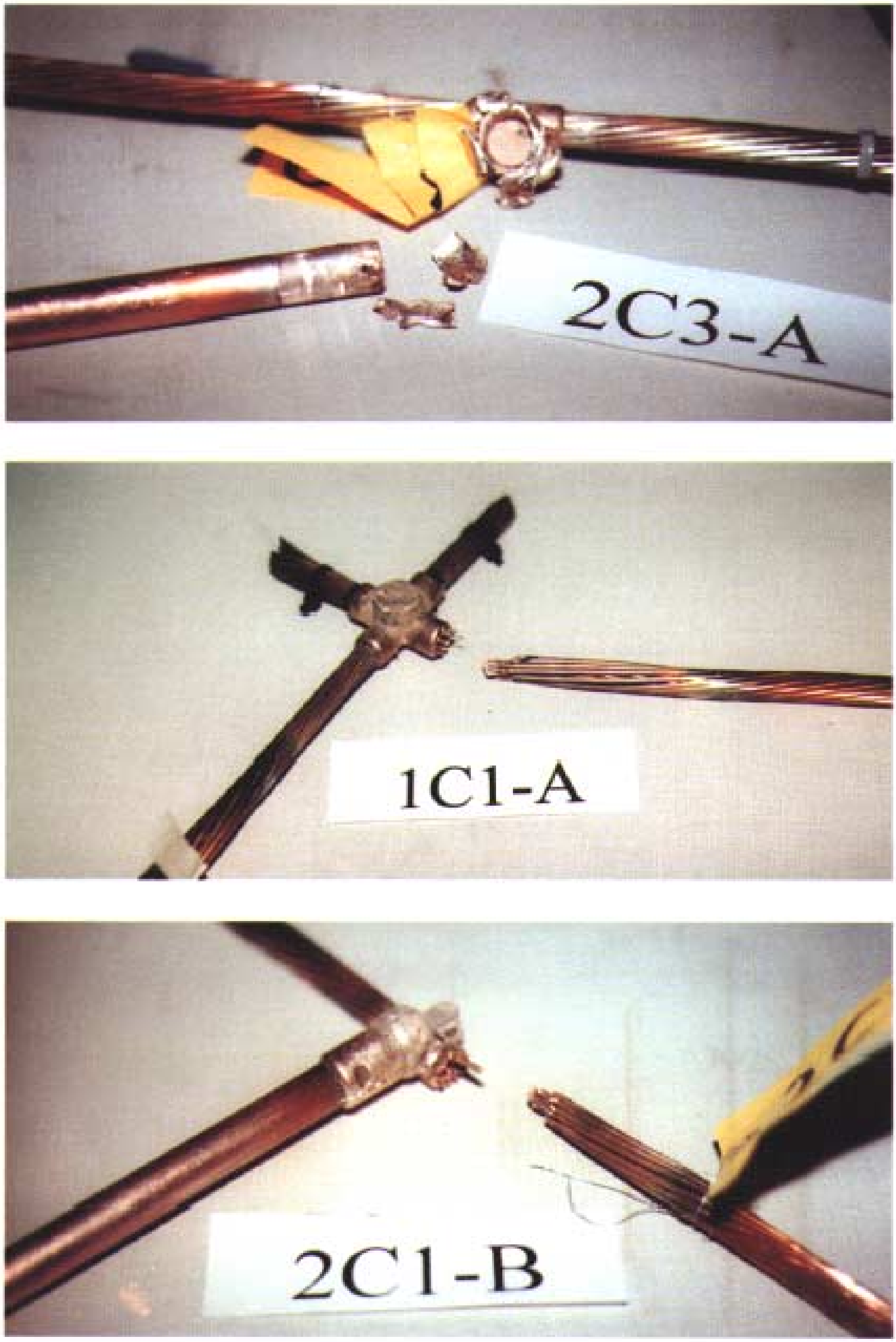


Figure 3: Typical Failure Modes for Cadweld Welded Connections

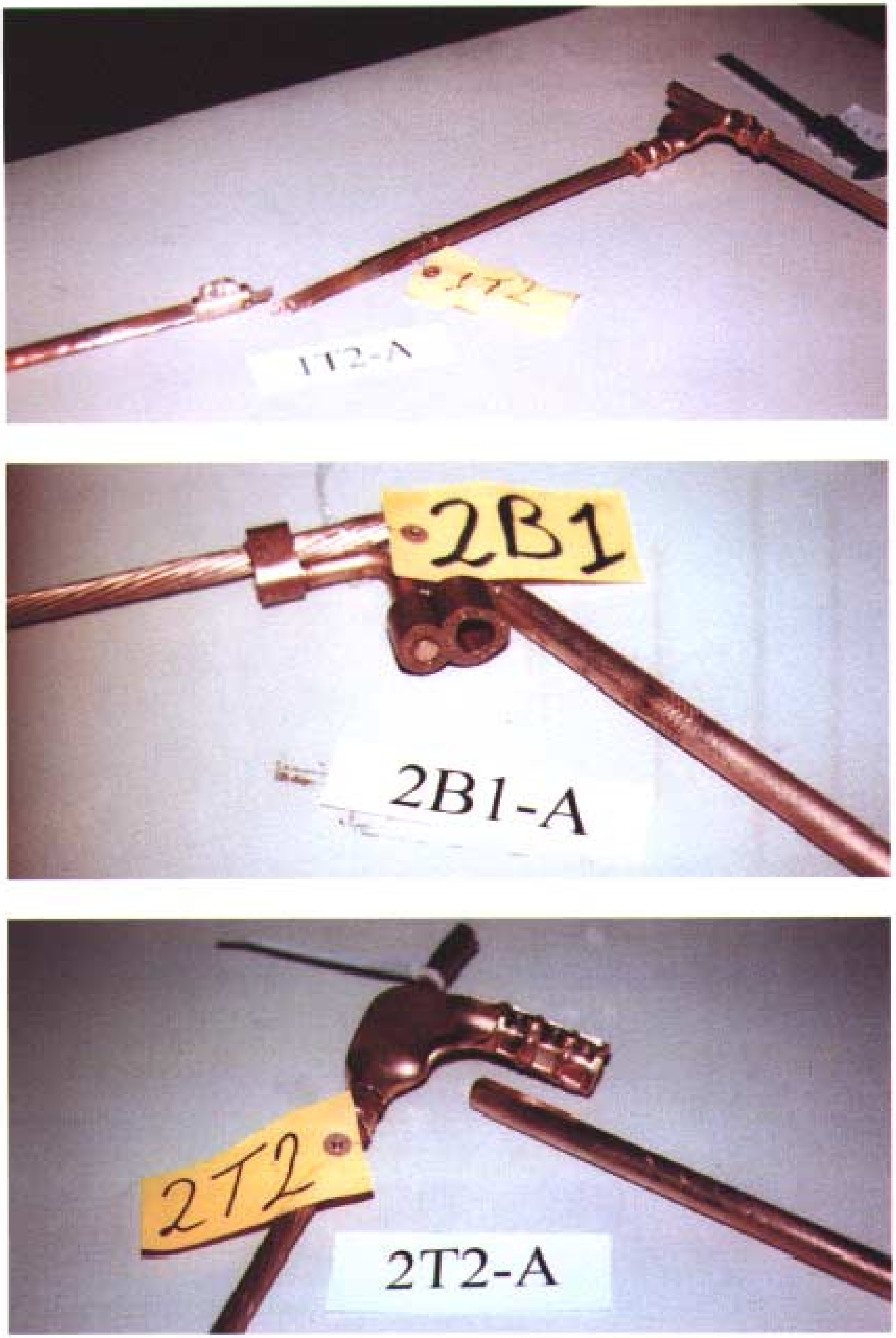


Figure 4: Typical Mode of Failure for Die Compression Type Connectors

TEST #2: **Electromagnetic Force, Ref IEEE Std 837-1989, 7.2**

Condensed Requirements

Four connector samples can be tested individually or can be interconnected in a loop. This test requires equalizers on either side of the connection under test for resistance measurements. The minimum exposed length between connector and equalizer is 24 inches (610 mm). The fault current is specified as the required rms fault current calculated as one-half of 80% of the 0.2 second rms symmetrical value of the conductor fusing current. For 4/0 conductor, fusing current = 67,500 A rms x ½ x 80% = 27,000 A. The peak first half cycle of the test current shall be 2.7 times the calculated rms value. For 4/0 conductor, 2.7 x 27 kA = 72.9 kA.

Before the test, the resistance of each connector and the resistance of the control conductor with exposed conductor length between equalizers equal to the total exposed length of the conductor in the test sample shall be measured. The resistance of each connector shall be calculated by subtracting the resistance of the control conductor from the resistance of each test sample. If the original connector resistance is more than 10% greater than the equal length of the conductor, the connector shall have failed the test without further testing. Three surges as calculated above shall be applied with the conductor allowed to cool to 100°C or less between surges. The connectors shall have passed if the resistance of the connector as calculated above does not increase more than 50% from the original measured resistance.

Additional Tests

The test is to be repeated on new samples as indicated above with a test level corresponding to 1.5 times the previous level. This level is based on ANSI/IEEE C37.32, "*High-Voltage Air Switches, Bus Supports, and Switch Accessories*". This standard was chosen because faults in a substation generally flow through an air switch which is tested to this standard. The momentary asymmetrical rating of 61 kA rms corresponds to a peak withstand of 103 kA. The electromagnetic withstand criteria used in these additional tests were selected to exceed this preferred rating assigned to 1200A switches in ANSI/IEEE C37.32. These switches are generally the smallest used in the majority of substations.

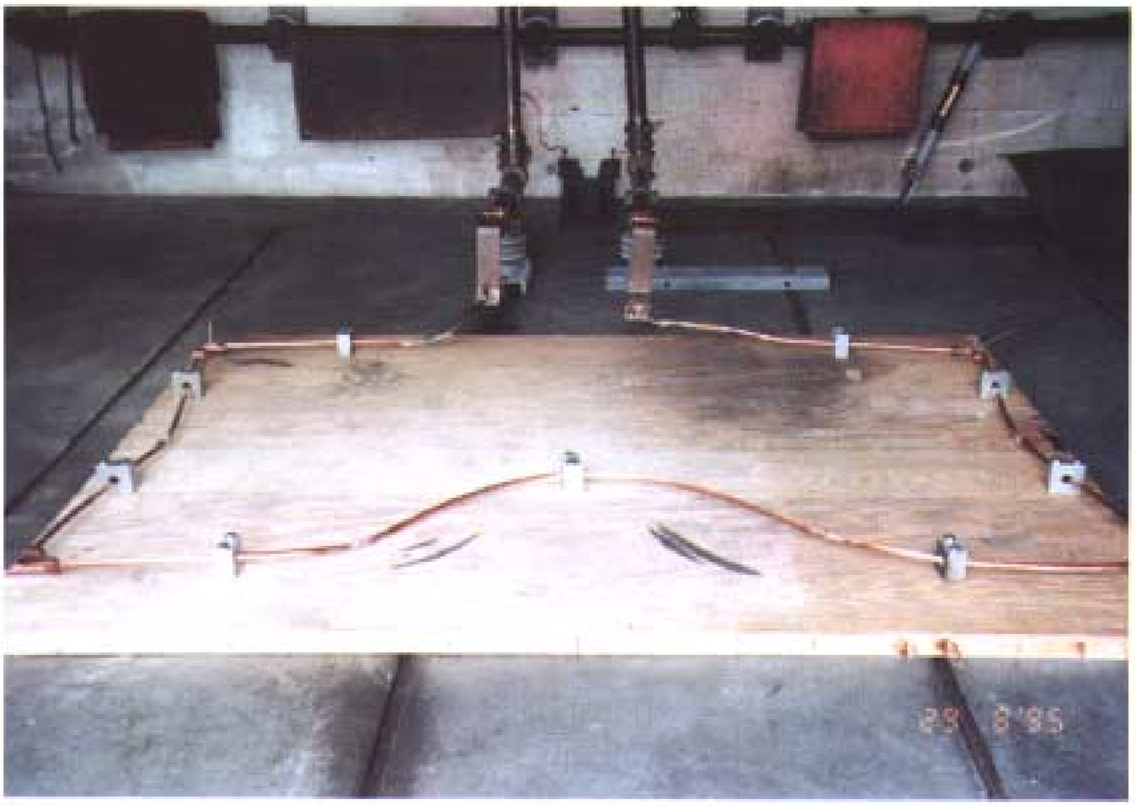
Test Facility

These tests were carried out at OHT's High Current Laboratory. The HCL test facility is a 60-Hz power source supplied from the Ontario Hydro power distribution grid. Three single-phase test transformers are connected in series or parallel combinations to attain the desired test levels. Current limiting reactors are used to control the test current further and obtain a high X/R ratio. A synchronous make-switch is used to control the closing angle and initiate current flow. The closing angle of the make-switch is varied to obtain the desired asymmetrical offset for the peak withstand tests (electromagnetic force). The main laboratory breaker is used to interrupt current flow after the desired test period. A multi-channel synchronous programmer is used to synchronize all the events including the data acquisition system.

Test Procedure

The four connector samples were assembled in a loop with dimensions conforming to the values indicated in IEEE 837-1989. The initial resistance of the connector samples was measured and the connector resistance calculated. The loops were placed on wooden test panels and connected to the power supply bus as shown in Figure 5. Aluminum blocks were used as loosely fitting restraining devices as permitted in the Standard.

The first peak of the asymmetrical test current for 4/0 stranded conductors is 72.9 kA. This is based the formula given in Appendix B of IEEE 837-1989 with an initial starting temperature of 40°C. Each connector loop was given three shots allowing the conductor to cool to approximately 40°C between shots. Between shots, the connectors were examined for slip. Following the three shots, the final resistance was measured and compared with the original values. The test results and observations are given in Tables 3 and 4. The test parameters given are the average of the three shots. The tabulated dc resistance of the connectors is given in Tables 5 and 6. Photographs of selected test samples are given in Figures 6, 7, and 8. Oscilograms of selected shots obtained are given in Appendix B.



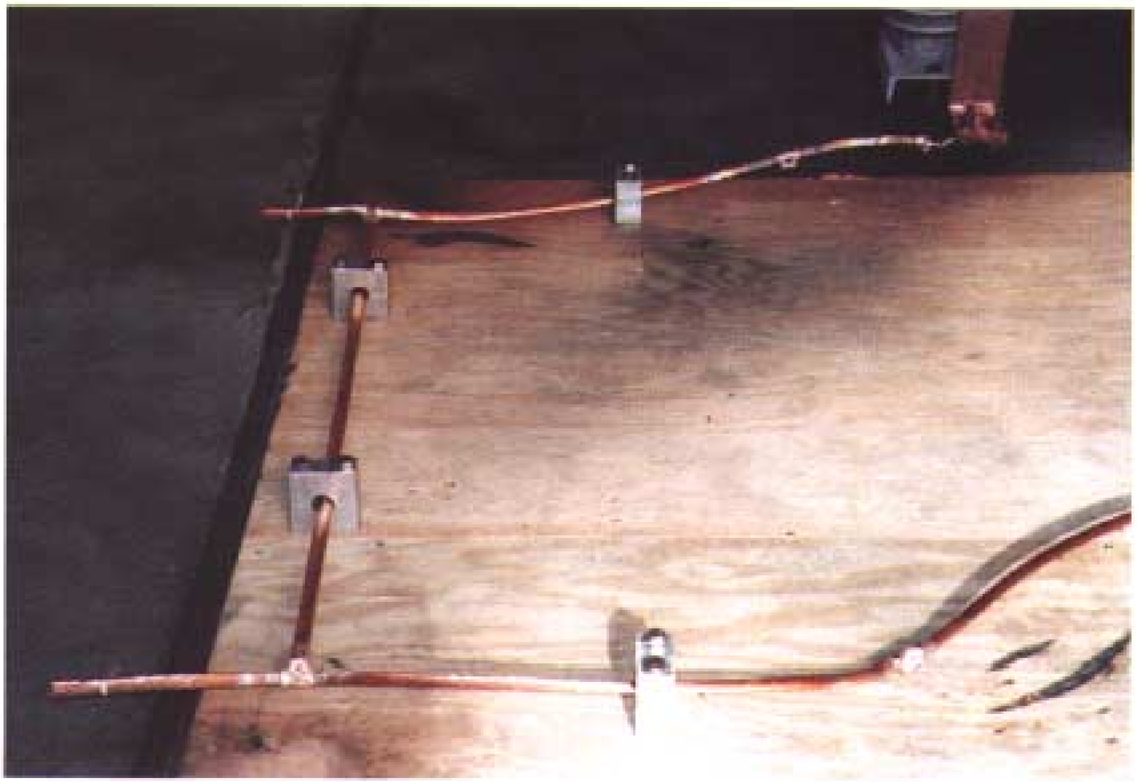


Figure 5: Typical Setup for Electromagnetic Force Withstand Test

Table 3
Test Results for EMF Withstand, IEEE Std 837, Section 7.3

Loop ID Number	Connector Number	Conductor Run/Tap	Test Current		Number of 12 cycle shots	Observation
			Applied Peak (kA)	Applied RMS (kA)		
3B	YGL29C29	4/0-4/0	74.3	32.1	3	No movement
3T	GG40250-40250	4/0-4/0	73.8	31.9	3	No movement
3C	XAC2Q2Q	4/0-4/0	73.0	32.0	3	No movement
3A	81228-1	4/0-4/0	73.6	31.9	3	Movement on 3 connectors (¼")
4B	YGL29C29	4/0-4/0	104.5	45.1	3	No movement
4T	GG40250-40250	4/0-4/0	104.6	45.0	3	No movement
4C	XAC2Q2Q	4/0-4/0	105.5	45.4	3	No movement
4A	81228-1	4/0-4/0	105.8	45.6	3	Movement on 2 connectors (½")

Table 4
Test Results for EMF Withstand, IEEE Std 837, Section 7.3

Loop ID Number	Connector Number	Conductor Run/Tap	Test Current		Number of 12 cycle shots	Observation
			Applied Peak (kA)	Applied RMS (kA)		
5B	YGLR29C34	4/0-rod	74.7	32.5	3	Movement on 3 connectors (1/16")
5T	GG500-40250	4/0-rod	74.9	32.5	2	Movement on connectors (up to 3") Lost connection of one connector on 2nd shot , third shot not done.
5C	GTC182Q	4/0-rod	75.5	32.7	3	No movement
5A	81229-1	4/0-rod	74.2	32.4	3	No movement
6B	YGLR29C34	4/0-rod	105.2	45.6	2	Movement of all 4 connectors, 1"-3" Lost connection of one connector on 2nd shot, third shot not done.
6T	GG500-40250	4/0-rod	105.5	--	1	Movement of all connectors Lost connection on one connector on first shot
6C	GTC182Q	4/0-rod	106.0	45.9	3	No movement
6A	81229-1	4/0-rod	103.5	44.9	3	Movement on 2 connectors (3/8")

Table 5
Dc Resistance Following EMF Withstand, IEEE Std 837, 7.3

Loop ID	Connector Number	Conductor		Resistance ($\mu\Omega$)				Change
		Size	Length	Initial	Conn.	Final	Conn.	
3A1	81228-1	4/0	48	222.4	17.6	227.1	17.9	1.7%
3A2	81228-1	4/0	48	222.4	17.6	226.3	17.1	-2.8%
3A3	81228-1	4/0	48	224.1	19.3	227.6	18.4	-4.7%
3A4	81228-1	4/0	48	225.8	21.0	229.2	20.0	-4.8%
Control		4/0	48	204.8		209.2		2.1%
3B1	YGL29C29	4/0	48	225.2	23.9	232.4	23.2	-2.9%
3B2	YGL29C29	4/0	48	222.2	20.6	229.3	20.1	-2.4%
3B3	YGL29C29	4/0	48	223.3	21.7	230.8	21.6	-0.5%
3B4	YGL29C29	4/0	48	235.0	33.4	237.4	28.2	-15.6%
Control		4/0	48	201.6		209.2		3.8%
3C1	XAC2Q2Q	4/0	48	214.6	10.88	221.0	11.32	4.0%
3C2	XAC2Q2Q	4/0	47	209.2	9.72	215.4	10.08	3.7%
3C3	XAC2Q2Q	4/0	47	211.6	12.12	217.8	12.48	3.0%
3C4	XAC2Q2Q	4/0	48	214.2	10.48	220.7	11.02	5.2%
Control		4/0	47.5	201.6		207.5		2.9%
3T1	GG40250-40250	4/0	48	219.9	18.45	224.7	17.68	-4.2%
3T2	GG40250-40250	4/0	48	226.9	24.4	231.6	23.50	-3.7%
3T3	GG40250-40250	4/0	48	218.2	15.7	224.3	16.2	3.2%
3T4	GG40250-40250	4/0	48	221.2	18.7	225.9	17.8	-4.8%
Control		4/0	48	202.5		208.1		2.8%

Table 5b
Dc Resistance Following EMF Withstand: High Level Faults

Loop ID	Connector Number	Conductor		Resistance($\mu\Omega$)				Change
		Size	Length	Initial	Conn.	Final	Conn.	
4A1	81228-1	4/0	48	225.9	23.0	229.4	23.6	2.6%
4A2	81228-1	4/0	48	223.7	20.8	239.4	33.5	61.1%
4A3	81228-1	4/0	48	228.7	25.8	277.1	71.3	176.4%
4A4	81228-1	4/0	48	228.6	25.7	236.7	30.9	20.2%
Control		4/0	48	202.9		205.8		1.4%
4B1	YGL29C29	4/0	48	233.3	29.0	237.5	30.2	4.1%
4B2	YGL29C29	4/0	48	224.9	20.6	236.2	28.9	40.3%
4B3	YGL29C29	4/0	47.5	225.8	23.7	236.0	30.9	30.4%
4B4	YGL29C29	4/0	47.75	237.6	34.4	237.4	31.2	-9.3%
Control		4/0	47.75	203.2		206.2		1.5%
4C1	XAC2Q2Q	4/0	48	216.5	13.0	218.9	14.4	10.8%
4C2	XAC2Q2Q	4/0	47.5	212.8	11.4	215.2	12.8	12.3%
4C3	XAC2Q2Q	4/0	46.75	209.1	10.9	211.3	12.1	11.0%
4C4	XAC2Q2Q	4/0	48	214.8	11.3	216.0	11.5	1.8%
Control		4/0	48	203.5		204.5		0.5%
4T1	GG40250-40250	4/0	48	224.3	20.7	231.5	24.4	17.9%
4T2	GG40250-40250	4/0	48	221.8	18.2	228.1	21.0	15.4%
4T3	GG40250-40250	4/0	48	221.4	17.8	230.2	23.1	29.8%
4T4	GG40250-40250	4/0	48	221.7	18.1	229.8	22.7	25.4%
Control		4/0	48	203.6		207.1		1.7%

Table 6
Dc Resistance Following EMF Withstand, IEEE Std 837, 7.3

Loop ID	Connector Number	Conductor		Resistance($\mu\Omega$)				Change
		Size	Length	Initial	Conn.	Final	Conn.	
5A1	81229-1	4/0	24	109.1	9.27	105.6	5.58	-39.8%
		3/4" rod	24	331.3	19.20	325.5	11.90	-38.0%
5A2	81229-1	4/0	24	110.4	8.45	107.1	4.95	-41.4%
		3/4" rod	24	332.1	20.00	326.4	12.80	-36.0%
5A3	81229-1	4/0	24	112.6	10.65	108.2	6.05	-43.2%
		3/4" rod	24	334.0	21.90	328.0	14.40	-34.2%
5A4	81229-1	4/0	24	113.0	11.05	107.5	5.35	-51.6%
		3/4" rod	24	324.6	12.50	318.0	4.40	-64.8%
Control		4/0	24	102.0		102.1		0.1%
		3/4" rod	24	312.1		313.6		0.5%
5B1	YGLR39C34	4/0	24	116.5	15.80	117.3	16.00	1.3%
		3/4" rod	24	309.8	15.40	320.5	24.20	57.1%
5B2	YGLR39C34	4/0	24	113.6	12.90	112.6	11.30	-12.4%
		3/4" rod	24	307.7	13.30	310.5	14.20	6.8%
5B3	YGLR39C34	4/0	24	118.0	17.30	116.0	14.70	-15.0%
		3/4" rod	24	301.2	6.80	307.5	11.20	64.7%
5B4	YGLR39C34	4/0	24	113.5	12.80	116.5	15.20	18.8%
		3/4" rod	24	305.3	10.90	319.0	22.70	108.3%
Control		4/0	24	100.7		101.3		0.6%
		3/4" rod	24	294.4		296.3		0.6%

Table 6
Dc Resistance Following EMF Withstand, IEEE 837, 7.3 (Con't)

Loop ID	Connector Number	Conductor		Resistance($\mu\Omega$)				Change
		Size	Length	Initial	Conn.	Final	Conn.	
5C1	GTC182Q	4/0	24	106.0	5.80	107.1	6.50	12.1%
		3/4" rod 1	24	287.7	14.90	291.5	14.80	-0.7%
5C2	GTC182Q	4/0	24	104.2	4.00	105.1	4.50	12.5%
		3/4" rod 1	24	288.7	15.90	293.2	16.50	3.8%
5C3	GTC182Q	4/0	24	107.0	6.80	108.1	7.50	10.3%
		3/4" rod 2	24	319.5	12.10	324.7	12.80	5.8%
5C4	GTC182Q	4/0	24	104.2	4.00	105.0	4.40	10.0%
		3/4" rod 2	24	318.2	10.80	323.5	11.60	7.4%
Control		4/0	24	100.2		100.6		0.4%
		3/4" rod 1	24	272.8		276.7		1.4%
		3/4" rod 2	24	307.4		311.9		1.5%
5T1	GG500-40250	4/0	24	112.6	12.30	116.9	14.00	13.8%
		3/4" rod 1	24	307.4	18.10	319.4	18.40	1.7%
5T2	GG500-40250	4/0	24	110.0	9.70	113.8	10.90	12.4%
		3/4" rod 1	24	307.8	18.50	322.0	21.00	13.5%
5T3	GG500-40250	4/0	24	111.8	11.50	115.3	12.40	7.8%
		3/4" rod 2	24	322.8	33.50	n.a.	-301.00	n.a.
5T4	GG500-40250	4/0	24	110.3	10.00	118.3	15.40	54.0%
		3/4" rod 2	24	321.1	31.80	337.0	36.00	13.2%
Control		4/0	24	100.3		102.9		2.6%
		3/4" rod 1	24	289.3		301.0		4.0%
		3/4" rod 2	24	308.1		319.7		3.8%

n.a. indicates that the reading was not available because of a connector failure.

Table 6b
Dc Resistance Following EMF Withstand: High Level Fault

Loop ID	Connector Number	Conductor		Resistance($\mu\Omega$)				Change
		Size	Length	Initial	Conn.	Final	Conn.	
6A1	81229-1	4/0	24	112.0	8.80	111.8	8.70	-1.1%
		3/4" rod	24	333.1	19.60	345.2	26.20	33.7%
6A2	81229-1	4/0	24	111.6	8.40	112.7	9.60	14.3%
		3/4" rod	24	333.4	19.90	346.0	27.00	35.7%
6A3	81229-1	4/0	24	109.6	6.40	110.1	7.00	9.4%
		3/4" rod	24	323.9	10.40	333.0	14.00	34.6%
6A4	81229-1	4/0	24	112.7	9.50	113.9	10.80	13.7%
		3/4" rod	24	325.0	11.50	352.0	33.00	187.0%
Control		4/0	24	103.2		103.1		-0.1%
		3/4" rod	24	313.5		319.0		1.8%
6B1	YGLR29C34	4/0	24	115.5	9.80	n.a.	n.a.	n.a.
		3/4" rod	24	313.8	16.60	n.a.	n.a.	n.a.
6B2	YGLR29C34	4/0	24	121.5	15.80	n.a.	n.a.	n.a.
		3/4" rod	24	314.4	17.20	n.a.	n.a.	n.a.
6B3	YGLR29C34	4/0	24	117.4	11.70	n.a.	n.a.	n.a.
		3/4" rod	24	319.5	22.30	n.a.	n.a.	n.a.
6B4	YGLR29C34	4/0	24	114.7	9.00	n.a.	n.a.	n.a.
		3/4" rod	24	318.2	21.00	n.a.	n.a.	n.a.
Control		4/0	24	105.7				
		3/4" rod	24	297.2				

n.a. indicates that the reading was not available because of a connector failure.

Table 6b (Con't)
Dc Resistance Following EMF Withstand: High Level Faults

Loop ID	Connector Number	Conductor		Resistance($\mu\Omega$)				Change
		Size	Length	Initial	Conn.	Final	Conn.	
6C1	GTC182Q	4/0	24	109.2	6.60	106.8	8.60	30.3%
		3/4" rod1	24	286.7	10.20	277.5	11.70	14.7%
6C2	GTC182Q	4/0	24	108.8	6.20	106.2	8.00	29.0%
		3/4" rod1	24	286.2	9.70	277.6	11.80	21.6%
6C3	GTC182Q	4/0	24	109.6	7.00	106.9	8.70	24.3%
		3/4" rod2	24	320.0	10.30	312.6	13.00	26.2%
6C4	GTC182Q	4/0	24	109.2	6.60	107.4	9.20	39.4%
		3/4" rod2	24	320.0	10.30	312.2	12.60	22.3%
Control		4/0	24	102.6		98.2		-4.3%
		3/4" rod1	24	276.5		265.8		-3.9%
		3/4" rod2	24	309.7		299.6		-3.3%
6T1	GG500-40250	4/0	24	114.2	10.40	n.a.	n.a.	n.a.
		3/4" rod	24	322.7	13.50	n.a.	n.a.	n.a.
6T2	GG500-40250	4/0	24	110.0	6.20	n.a.	n.a.	n.a.
		3/4" rod	24	324.5	15.30	n.a.	n.a.	n.a.
6T3	GG500-40250	4/0	24	113.9	10.10	n.a.	n.a.	n.a.
		3/4" rod	24	333.4	24.20	n.a.	n.a.	n.a.
6T4	GG500-40250	4/0	24	112.1	8.30	n.a.	n.a.	n.a.
		3/4" rod	24	328.3	19.10	n.a.	n.a.	n.a.
Control		4/0	24	103.8		n.a.	n.a.	n.a.
		3/4" rod	24	309.2		n.a.	n.a.	n.a.

n.a. indicates that the reading was not available because of a connector failure.

Summary of Electromagnetic Force Test

Bolted wedge design connector for 4/0 to 4/0 conductor (AMP Wrench-Lok # 81228-1):

At current levels specified in IEEE-837-1989 (set 3A)
- Movement up to 1/4" observed on three of four connectors.
- No apparent increase in connector resistance.

At current levels approximately 50% higher than specified in Standard IEEE 837-1989 (set 4A)
- Movement up to 1/2" observed on two of four connectors.
- Increase in connector resistance up to 176%.

Die compression type connector for 4/0 to 4/0 conductor (Burndy #YGL29C29):

At current levels specified in IEEE-837-1989 (set 3B)
- No movement observed in any connector
- No apparent increase in connector resistance.

At current levels approximately 50% higher than specified in Standard IEEE 837-1989 (set 4B)
- No movement observed in any connector
- Increase in connector resistance of30%-40% in two connectors.

Exothermically welded connection for 4/0 to 4/0 conductor (Cadweld # XAC2Q2Q):

At current levels specified in IEEE-837-1989 (set 3C)
- No movement observed in any connector
- No apparent increase in connector resistance.

At current levels approximately 50% higher than specified in Standard IEEE 837-1989 (set 4C)
- No movement observed in any connector
- Increases in connector resistance of 10%-12% in three connectors.

Die compression type connector for 4/0 to 4/0 conductor (T&B # GG40250-40250):

At current levels specified in IEEE-837-1989 (set 3T)
- No movement observed in any connector
- No apparent increase in connector resistance.

At current levels approximately 50% higher than specified in Standard IEEE 837-1989 (set 4T)
- No movement observed in any connector
- Increase in connector resistance of 15%-30%.

Bolted wedge design connector for 4/0 conductor to 3/4" rod (AMP Wrench-Lok # 81229-1):

At current levels specified in IEEE-837-1989 (set 5A)
- ♦ No movement observed on any connectors.
- ♦ No apparent increase in connector resistance.

At current levels approximately 50% higher than specified in Standard IEEE 837-1989 (set 6A)
- ♦ Movement up to 3/8" observed on two of four connectors
- ♦ Increase in connector resistance up to 187%.

Die compression type connector for 4/0 conductor to 3/4" rod (Burndy #YGLR29C34):

At current levels specified in IEEE-837-1989 (set 5B)
- ♦ Movement up to 1/16" observed on three connectors.
- ♦ Increase in the rod side of connector resistance of up to 108%.

At current levels approximately 50% higher than specified in Standard IEEE 837-1989 (set 6B)
- ♦ Movement of 1" to 3" on all four connectors after first shot.
- ♦ Loss connection on 2nd shot, incomplete test sequence.
- ♦ Final resistance not possible.

Exothermically welded connection for 4/0 conductor to 3/4" rod (Cadweld # GTC182Q):

At current levels specified in IEEE-837-1989 (set 5C)
- ♦ No movement observed in any connector.
- ♦ Increases in connector resistance of up to 12%.

At current levels approximately 50% higher than specified in Standard IEEE 837-1989 (set 6C).
- ♦ No movement observed in any connector.
- ♦ Increase in connector resistance of up to 40%.

Die compression type connector for 4/0 conductor to 3/4" rod (T&B # GG500-40250):

At current levels specified in IEEE-837-1989 (set 5T)
- ♦ Movement of 3" on one connector, some movement (1/16") on two others.
- ♦ Loss connection on 3rd shot
- ♦ Increase in connector resistance of remaining three up to 54%.

At current levels approximately 50% higher than specified in Standard IEEE 837-1989 (set 6T)
- ♦ Loss connection on first shot, several inches of slip on remaining connectors.
- ♦ Final resistance not possible.

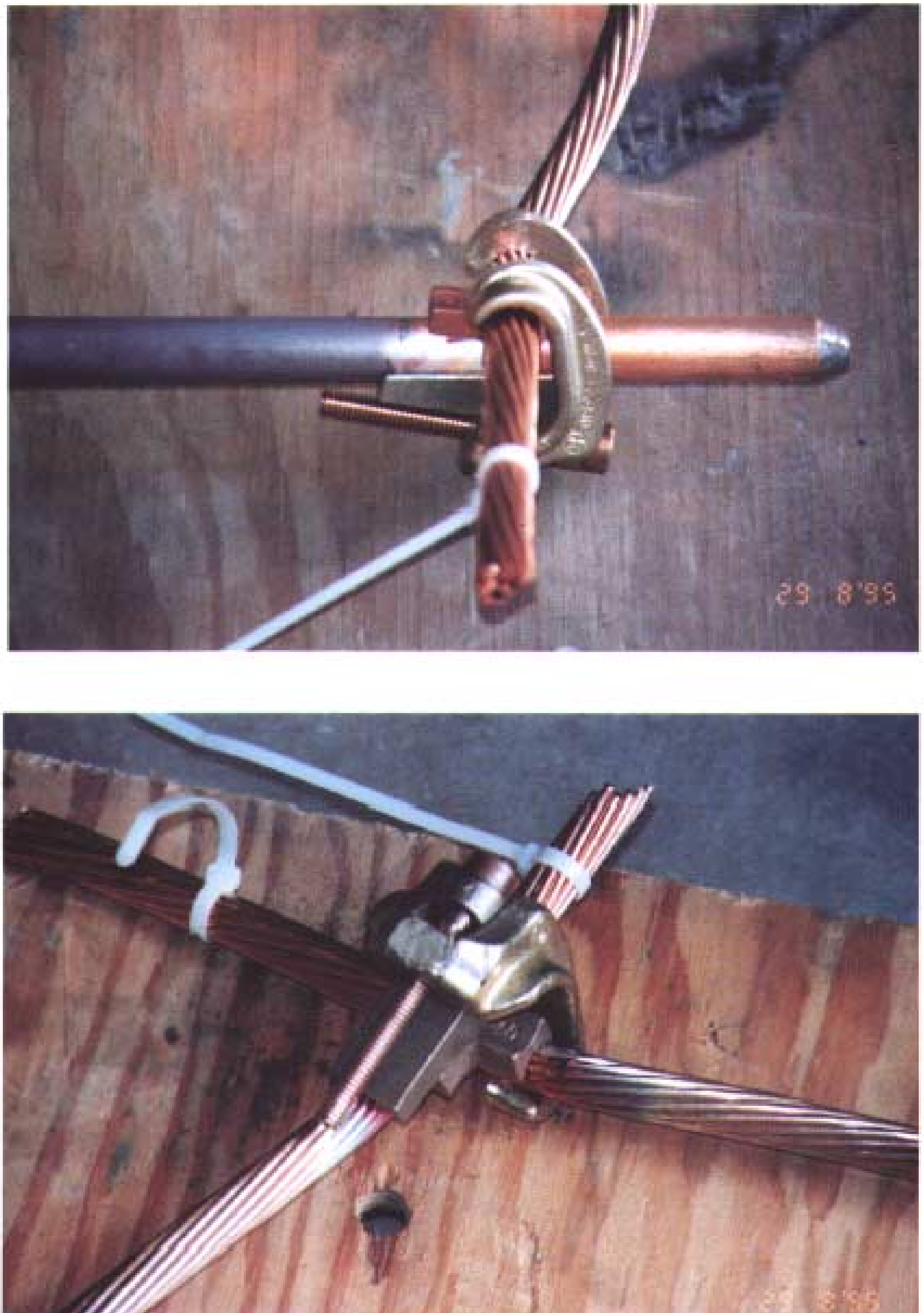


Figure 6: After Test Appearance of Wedge Type Connector - Connectors from Loop 6A and 3A

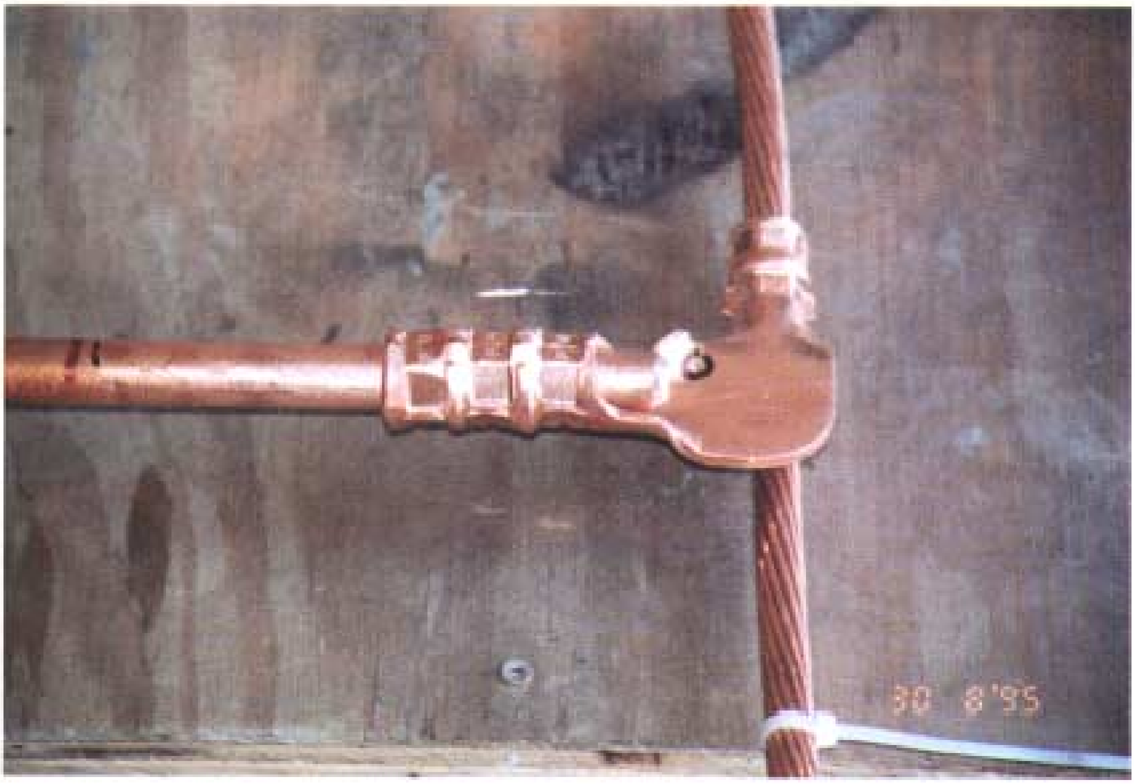


Figure 7: After Test Appearance of Die Compression Connector
- Connectors from Loop 5B and 5T

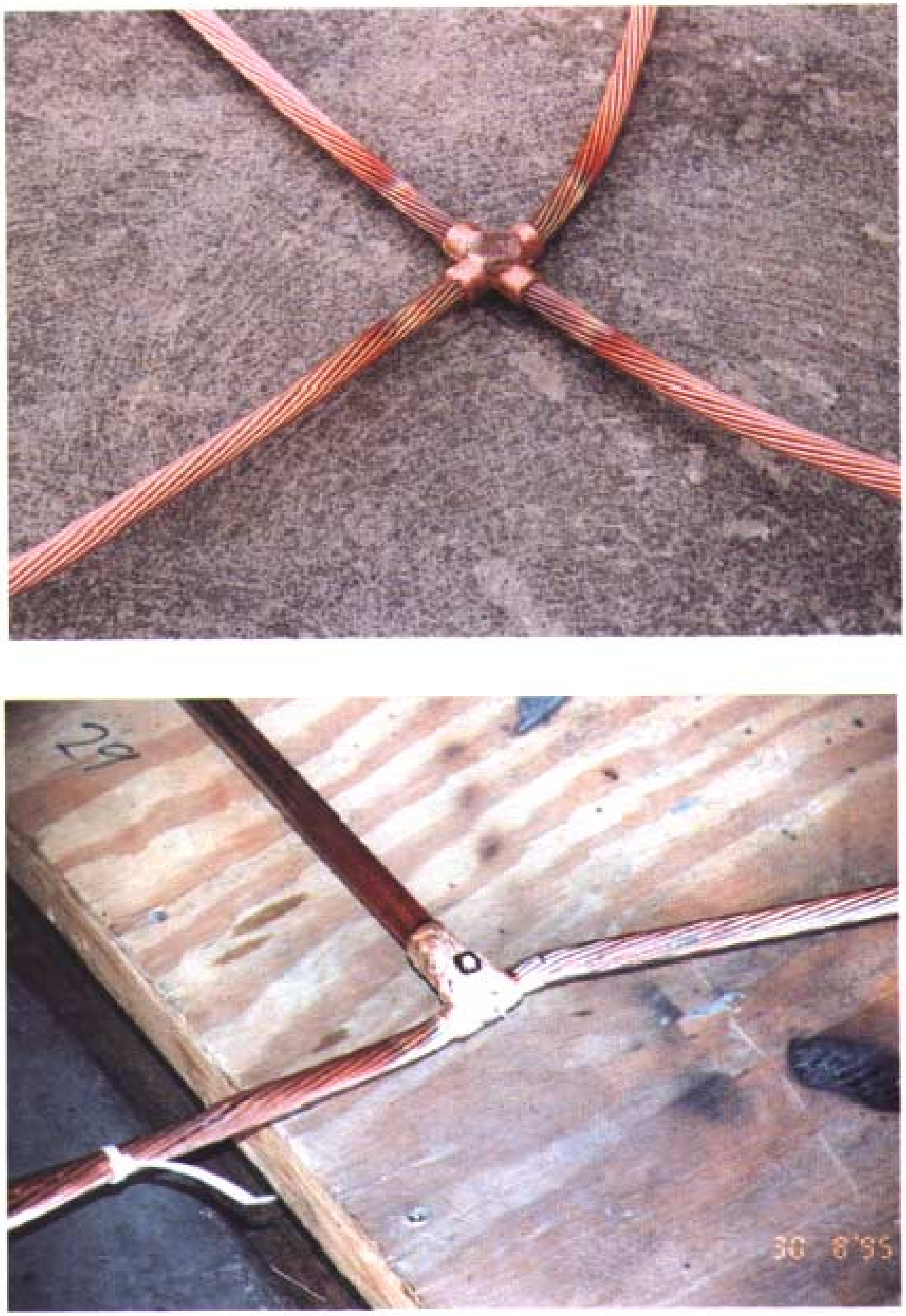


Figure 8: After Test Appearance of Cadweld Welded Connections
- From Loops 3C and 5C

SEQUENTIAL TEST SERIES ALKALINE AND ACIDIC

These are a series of tests performed sequentially on a connector set. Current-temperature cycling, freeze-thaw, corrosion and fault-current tests are performed. Separate samples were used for the sequential acidic series of tests and a separate set for the alkaline series of tests.

In the two test series, three of the four sequential tests are performed in an identical manner. The current-temperature cycling, freeze-thaw and fault current tests described in the following sections of this report apply to both test groups.

Measuring Connector Resistance

In accordance with the IEEE Std 837-1989, the connector resistance is to be determined by subtracting the resistance of the control conductor from the resistance of the connection sample tested. In performing this calculation from the readings obtained it was evident that minor variations in conductor lengths and the variation in the conductor uniformity is of concern.

In preparing the samples, the exposed conductor lengths were carefully controlled. The exposed conductor lengths were measured following the assembly, all samples were within 1/4" of the prescribed length (24" for samples, 48" for control conductors). No correction in the resistance reading was made to compensate for the variation in lengths. The connectors shall have passed if the resistance of the connector does not increase more than 150% from the original measured resistance.

Variation in conductor uniformity was found to introduce anomalies in the calculated connector resistance. This problem was only apparent in the copper-clad steel core ground rod samples. The problem became evident once all the samples were prepared and resistance reading was obtained. It was found that the resistance per unit length of the ground rods varies significantly between samples. Because the control conductor lengths of ground rods were taken from separate rod lengths it was not possible to subtract the control rod resistance from the connector sample resistance and obtain a meaningful connector resistance. In many cases the connector resistance was a negative value. It was then decided to continue to record the sample resistance and control conductor resistance but not perform the calculation for the connector resistance. The performance of the connector based on the resistance criterion would be decided on the overall sample stability and compared with the change in control conductor resistance.

Since the criterion for connector resistance stability defined in IEEE Std 837-1989, Section 5.3.2, was not directly applicable to our readings, another criterion for assessing connector performance was necessary. Measurements and calculations were made to approximate the expected variation in the overall sample resistance (from 4/0 conductor to 3/4" ground rod) given a 150% change in connector resistance. Based on the investigative measurements taken, 150% change in connector resistance would correspond to an 8% to 10% change in overall sample resistance.

For the 4/0 stranded conductor to 3/4" ground rod samples, sets #8 and #10, in the following sections, the criterion for allowable resistance variation is less than 10% increase over the change in control conductor. For example, if the control conductor has a 4% change in overall resistance, the connector sample would be allowed up to 14% change in resistance. This analysis method was developed to overcome difficulties encountered during the test program. The precision and bias of this method have not been determined.

Because of the difficulties in establishing a precise connector resistance and to obtain more informative test results, no samples were removed from the test program based on connector resistance.

TEST #3A: - Sequential Test Groups-Acidic, Current Temperature Cycling - Ref IEEE 837-1989, 8

Condensed Requirement

This is the first test conducted in a series of sequential tests. Four connectors connected in a loop were subjected to 25 current cycles of one hour on and cooling back to room temperature between cycles. The current shall be such that the control conductor is heated to 350°C. When different conductors are combined, the lower ampacity conductor shall be used as the control sample. Equalizers were placed on each side of the connector leaving 24 inches of exposed conductor. The dc resistance measurements shall be recorded at the beginning and after every five cycles.

Test Equipment

These tests were performed in a connector test room having a low-voltage/ high current source. An HP3497A data acquisition system controlled by a personal computer was used to control the experiment. The resistance of the connector samples was measured with a Valhalla micro-ohmeter model 4300B.

Test Procedure

The samples were joined using the bolted terminal lugs. The samples were kept elevated from ground using wooden stands with high temperature spacers at the support location. The samples were kept at the same elevation approximately three feet above the floor. The samples were laid out in a loop with approximately two feet between samples. A total of sixteen connector sets (four connectors per set) were tested in the same fashion. These included eight 4/0 to 4/0 connector sets (#7 and #9) and eight 4/0 to 3/4" rod connector sets (#8 and #10). To minimize the test period required to complete all the tests, two connector sets were tested at the same time.

Once the connector samples were placed in a loop, thermocouples were attached and the resistance of each sample was measured. Thermocouples were also used to monitor the control conductor temperature and the room ambient. Sufficient current was then circulated through the loop to attain a temperature of 350°C of the control conductor. The 4/0 connector samples were tested at a nominal current of 1010 A and the 3/4" rod connector samples were tested at 540 A. The test controller was set to complete 25 cycles consisting of one hour on and one hour off. During this period, the samples were monitored for thermal stability and overheating. The resistance measurement of all samples was repeated at the end of the 25 cycles. The detailed connector resistance is given in Appendix C.

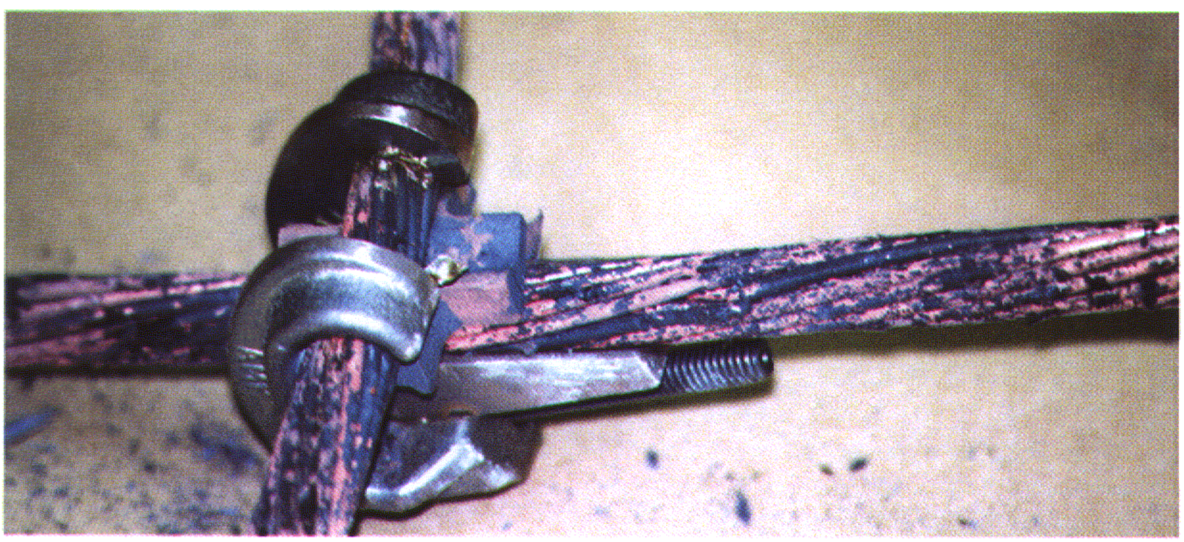


Figure 9: Failed Connector During Temperature Cycling

TEST #3B: - Sequential Test Groups-Acidic, Freeze-Thaw, Ref IEEE 837-1989, 9

Condensed Requirement
This is the second test conducted in a series of sequential tests. The test samples for the Acidic and Alkaline Groups were tested in the same fashion. Four connectors connected in a loop or as individual samples are placed in a container and submerged with a minimum of 1 inch of water. The samples are then subjected to 10 freeze thaw cycles. Each cycle consists of lowering the temperature of the samples to -10°C or lower and raising the temperature to 20°C or higher. The samples are to remain at both the low and high temperature for at least two hours.

Resistance measurements shall be recorded before the initial freeze-thaw cycle and after the final freeze-thaw cycle. The samples are to be thoroughly dried before the final resistance by heating the samples to 100°C for one hour.

No performance criteria are indicated for this section. This test is to provide conditioning of the connectors for the fault-current test.

Test Equipment
These tests were performed in a large walk-in environmental test room having a controlled temperature range of -50°C to +50°C.

Test Procedure
The samples were placed in plastic containers with the connector completely submersed in water. These included the eight 4/0 to 4/0 connector sets (#7 and #8) and the eight 4/0 to 3/4" rod connector sets (#9 & #10) previously temperature cycled. The containers were placed in the environmental chamber. A thermocouple was connected to a connector sample in one of the containers. This was to monitor a typical connector to determine when the samples attained the required temperatures. Another thermocouple was used to measure the chamber air temperature. The chamber was cooled to -50°C and then heated to +50°C while monitoring the connector temperature. The chamber controller was then programmed to assure the connectors were cooled to less than -10°C then thawed and soaked at 20°C or higher for at least two hours at each level.

Before the first freeze-thaw cycle, the resistance of the samples was measured (final resistance after Temperature Cycling, test #3A). The resistance of each connector was measured following the completion of the 10 freeze-thaw cycles.

The detailed connector resistance given in Appendix C.

Observations following Freeze-Thaw Cycling Test
The connector samples did not appear to have been adversely affected by the freeze-thaw cycles. Several connectors however have significant increase in resistance following the test some as high as 2590% (see Appendix C for details).

TEST #3C: - Sequential Test Groups-Acidic, Corrosion-Nitric Acid Test, Ref IEEE 837-1989, 10.2

Condensed Requirement

This is the third test conducted in a series of sequential tests. The samples are to be the same ones as those previously tested in Temperature-Cycle and Freeze-Thaw. The connectors are to be submerged in a bath containing a 10% solution by volume of Nitric Acid and distilled water. The connector shall be centrally located on a conductor length and with a minimum of 80% of the distance between equalizers of exposed conductors shall be submerged in the acid solution. A control conductor having the same length and shape with equalizers shall be used to monitor the required submersion time.

The test sample shall be submerged in the 10% acid solution for a time, which will reduce the control conductor to 80% of its original cross-sectional area. The reduction shall be determined by the weight reduction per unit length or resistance increase of the control conductor. For copper-clad steel core ground rods, the test samples shall be submerged in the 10% acid solution for a time that will increase the resistance of the control conductor by 25% above the initial resistance before testing. Before taking resistance, the samples are to be washed and dried at 100°C for 1 hour to assure dryness.

No performance criteria are indicated for this section. This test is to provide conditioning of the connectors for the fault-current test.

Test Equipment

These tests were performed in a large walk-in environmental test room having a suitable ventilating system to vent the fumes and maintain the room temperature at 25°C.

Test Procedure

The control conductors for each connector set were individually weighed and their resistance was measured before the test. The samples were placed in an "L" shaped PVC trough having enough acid solution to submerse the connector fully. The ends of the conductors were turned up to prevent the equalizers from being attacked by the acid, approximately 80% of the 24 inches of exposed conductor were submerged. The control conductor samples were taken out of the bath periodically, the resistance and weight of the samples were measured. When the control conductor attained the required reduction in cross-sectional area, all the samples were removed from the bath and thoroughly washed in fresh water. The samples were then dried and the final resistance on the connector samples was measured. A fresh 10% acid solution was mixed for each connector set submerged.

A summary of the resistance measurement obtained on the samples following the Nitric Acid bath is given in Appendix C.

Observations following Nitric-Acid bath Test

The connector samples did not appear to have abnormal or excessive corrosion on any part. Although some loss of material was noticeable, the connections appeared to be undamaged. The conductors were more adversely affected by the corrosion. The conductor samples were not uniform in the loss of cross sectional area. This was more apparent at the point where the conductor came out of the bath (dip line). This could be avoided in future tests by protecting the equalizer and end connection and submerge the entire sample. The copper-clad ground rod appears to be more susceptible to uneven corrosion. Due to the thin copper cladding on the rods, a minor variation in copper thickness (after the acid bath) causes a great variation in resistance. This caused some difficulties in determining the connector resistance.

TEST #4C: - Sequential Test Groups-Alkaline, Corrosion-Salt Spray Test, Ref IEEE 837-1989, 10.3

Condensed Requirement
This is the third test conducted in a series of sequential tests. The samples are to be the same ones as those previously tested in Temperature-Cycle and Freeze-Thaw. The connectors are to be subjected to the corrosive effects of 500 hrs of salt spray. The tests shall be performed in accordance with ANSI/ASTM B117-85 except that Sections 5 and 6 shall be modified to accommodate conductor and connector design combinations.

Resistance of the connectors is measured before and after completion of the test. Before the final resistance is taken, the samples are to be washed and dried at 100°C for 1 hour to assure dryness. No performance criteria are indicated for this section. Although the samples will be inspected for unusual corrosion or pitting, this test is to provide conditioning of the connectors for the fault-current test.

Test Equipment
These tests were performed in an *Industrial Filter & Pump Mfg Co* salt-fog corrosion test chamber. The chamber meets the requirements of ANSI/ASTM B117-85.

Test Procedure
The connector samples and control conductors were placed in the corrosion chamber. The cover was closed and the salt spray cabinet was turned on. The chamber was set to produce continuous salt fog and maintain a temperature of 30°C. The chamber was inspected daily (except weekends) during the 500-hour test period (approx 21 days).

At the end of the test period, the samples were removed from the chamber and washed with fresh running water. The samples were dried and their resistance was measured. A summary of the resistance measurement obtained on the samples is given in Appendix C.

Observations following the Salt-Spray Test
The connector samples did not appear abnormally corroded following the 500 hr spray period. The conductors had signs of being in a corrosive environment (a greenish residue) but were not excessively affected. The connector resistance indicated some connector instability in certain samples as some connectors were found to increase in resistance as much as 1570% while others decreased.

A summary of the resistance measurement obtained on the samples following the Salt Spray is given in Appendix C.

TEST #5: - Sequential Test Groups-Fault Current Test, Ref IEEE 837-1989, 11

Condensed Requirement
The purpose of this test is to determine if connections conditioned in previous tests will withstand fault-current surges. This is the fourth in the series of sequential tests. The samples shall be mounted in a loop or tested individually. The symmetrical fault current shall be 90% of the fusing current for the remaining cross-sectional area and maintained for a 10-second duration. Three surges shall be performed after allowing the conductors to cool to below 100°C. Resistance readings shall be recorded initially and after the three fault current surges.

Test Facility
These tests were carried out at OHT's High Current Laboratory. The HCL test facility is a 60-Hz power source supplied from the Ontario Hydro power distribution grid. Three single-phase test transformers are connected in series or parallel combinations to attain the desired test levels. Current limiting reactors are used to control the test current further and obtain a high X/R ratio. A synchronous make-switch is used to control the closing angle and initiate current flow. The closing angle of the make-switch is varied to obtain the desired asymmetrical offset. The main laboratory breaker is used to interrupt current flow after the desired test period. A multi-channel synchronous programmer is used to synchronize all the events including the data acquisition system.

Test Procedure
The connector samples were bolted in a loop and connected to the supply bus. The samples were placed on wooden panels. Temperature resistant panels were placed under the conductor to prevent burning of the wood. The connectors were subjected to three 10 second current surges as described above. The samples were allowed to return to near ambient between shots. The test current magnitude was calculated with the equations provided in the IEEE Standard 837-1989 based on the remaining cross-sectional area of the control conductor. The calculated and attained test levels for each test loop is given in Tables 7 and 8.

Summarized Test Results
The photograph in Figure 10 shows conductor damage as a result of a reduced cross section at the acid bath dip line. This problem occurred on several samples and resulted in fusing of some strands or the complete conductor. The loss of conductor prevented the final resistance from being obtained.

A summary of the resistance measurement obtained on the samples following the fault current test is given in Appendix C. Photographs taken of each of the connector sets following the fault current test are shown in Appendix A.

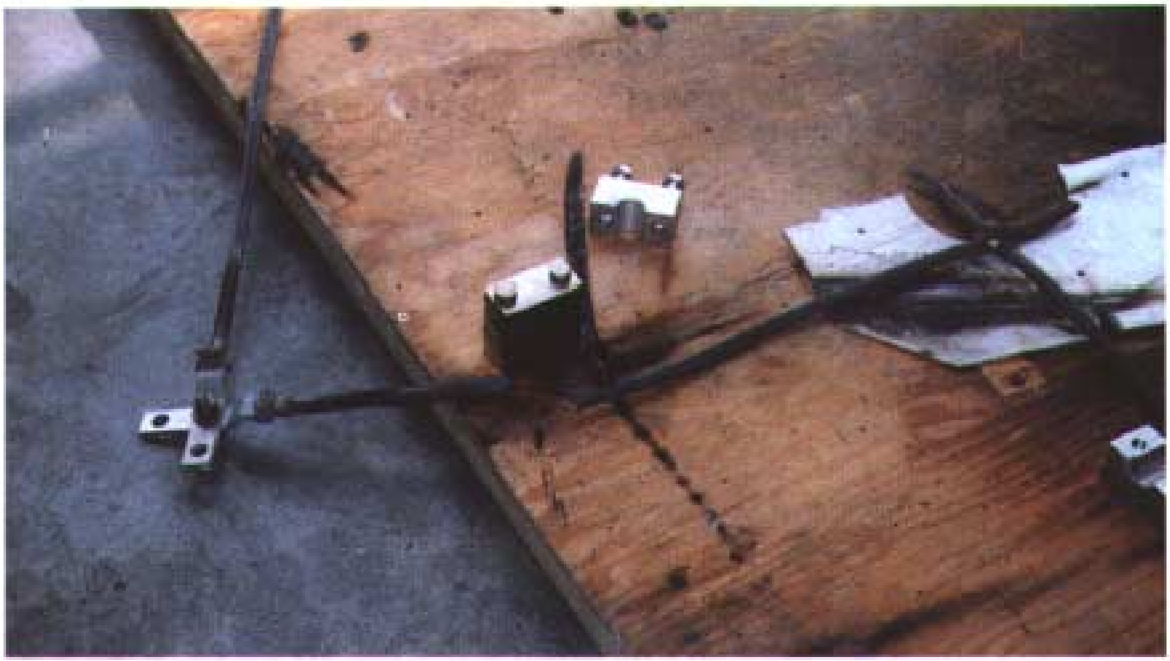


Figure 10: Example of Damaged Conductor Due to Reduced Cross-Section at Acid Dip-Line

Table 7
Test Results for Fault Current Test, IEEE Std 837, 11

Loop ID	Connector Number	Group	Test Current		Number of Shots	Observations
			Calculated Level (kA)	Applied Level (kA)		
7A	81228-1	Alkaline	8.6	8.7 8.7 8.6	10 sec 10 sec 9.7 sec	Arcing visible from connectors Arcing visible from connectors Failure of one connector at 9.7 sec
7B	YGL29C29	Alkaline	8.6	8.7 8.7	2 x 10 sec 1 x 9.7 sec	In same loop as 7A, Connectors OK
7C	XAC2Q2Q	Alkaline	8.6	8.8 8.8	1 x 6.6 sec 2 x 10 sec	In same loop as 7T, Connectors OK
7T	GG40250-40250	Alkaline	8.6	8.8 8.8	1 x 6.6 sec 2 x 10 sec	Failure of one connector on first shot Other two shots OK
8A	81229-1	Alkaline	8.6	8.5	3 x 10 sec	Connectors OK
8B	YGLR28C34	Alkaline	8.6	8.5	3 x 10 sec	Arcing on one connector, first shot
8C	GTC182Q	Alkaline	8.6	8.5	3 x 10 sec	Connectors OK
8T	GG500-40250	Alkaline	8.6	8.5	3 x 10 sec	Connectors OK

Table 8
Test Results for Fault Current Test, IEEE Std 837, 11

Loop ID	Connector Number	Group	Test Current		Number of Shots	Observations
			Calculated Level (kA)	Applied Level (kA)		
9A	81228-1	Acidic	7.0	6.9	3 x 10 sec	Connector OK
9B	YGL29C29	Acidic	6.0	6.3	2 x 10 sec 1 x 9.5 sec	Fusing of conductor at dip line, connectors OK
9C	XAC2Q2Q	Acidic	6.8	6.7	2 x 10 sec 1 x 9.9 sec	Fusing of conductors at dip line, connectors OK
9T	GG40250-40250	Acidic	6.8	6.7	2 x 10 sec 1 x 9.9 sec	Tested in same loop as 9C connectors OK
10A	81229-1	Acidic	4.5	4.4	3 x 10 sec	Connectors OK
10B	YGLR28C34	Acidic	5.4	5.3	3 x 10 sec	Connectors OK
10C	GTC182Q	Acidic	4.7	4.4	3 x 10 sec	Connectors OK
10T	GG500-40250	Acidic	5.0	5.3	3 x 10 sec	Connectors OK

Summary of Alkaline Sequential Test Series

Bolted wedge design connector for 4/0 to 4/0 conductor (AMP Wrench-Lok # 81228-1): set 7A
- ♦ Loss of one connector during temperature cycling.
- ♦ Fusing of conductor at one connector on third shot.
- ♦ Other connectors having greater than 150% increase in resistance.

Die compression type connector for 4/0 to 4/0 conductor (Burndy #YGL29C29): set 7B
- ♦ All connectors complete test series.
- ♦ All four connectors having greater than 150% increase in resistance.

Exothermically welded connection for 4/0 to 4/0 conductor (Cadweld # XAC2Q2Q):set 7C
- ♦ All connectors completed cycling test
- ♦ All four connectors having resistance increase less than 150%.

Die compression type connector for 4/0 to 4/0 conductor (T&B # GG40250-40250):set 7T
- ♦ All connectors completed cycling test
- ♦ Fusing of conductor at one connector on first shot.
- ♦ Other connectors having greater than 150% increase in resistance

Bolted wedge connector for 4/0 conductor to 3/4" rod (AMP Wrench-Lok # 81229-1): set 8A
- ♦ All connectors completed cycling tests
- ♦ Acceptable change in resistance of one connector, other three having high or unstable resistance

Die compression type connector for 4/0 conductor to 3/4" rod (Burndy #YGLR29C34): set 8B
- ♦ All connectors completed cycling tests
- ♦ Acceptable change in resistance of one connector, other three having high resistance

Exothermically welded connection for 4/0 conductor to 3/4" rod (Cadweld # GTC182Q): set 8C
- ♦ All connectors completed cycling test
- ♦ Acceptable change in resistance of all samples

Die compression type connector for 4/0 conductor to 3/4" rod (T&B # GG500-40250): set 8T
- ♦ All connectors completed cycling test
- ♦ All connectors having high or unstable resistance readings.

Summary of Acidic Sequential Test Series

Bolted wedge design connector for 4/0 to 4/0 conductor (AMP Wrench-Lok # 81228-1): set 9A

- All connectors completed test series.
- All four connectors having greater than 150% increase in resistance.

Die compression type connector for 4/0 to 4/0 conductor (Burndy #YGL29C29):set 9B

- All connectors completed test series.
- Three connectors having less than 150% increase in resistance, one connector could not be verified because of a damaged conductor at acid bath dip line.

Exothermically welded connection for 4/0 to 4/0 conductor (Cadweld # XAC2Q2Q): set 9C

- All connectors completed test series
- Two connectors having resistance increases less than 150%, other two could not be verified because of damaged conductors at acid bath dip line.

Die compression type connector for 4/0 to 4/0 conductor (T&B # GG40250-40250): set 9T

- All connectors completed test series
- All four connectors unstable or having greater than 150% increase in resistance

Bolted wedge connector for 4/0 conductor to 3/4" rod (AMP Wrench-Lok # 81229-1): set 10A

- All connectors completed cycling tests
- All four connector samples having acceptable resistance increase.

Die compression type connector for 4/0 conductor to 3/4" rod (Burndy #YGLR29C34): set 10B

- All connectors completed cycling tests
- Acceptable change in resistance of two connectors, other two having high resistance.

Exothermically welded connection for 4/0 conductor to 3/4" rod (Cadweld # GTC182Q): set 10C

- All connectors completed cycling test
- Acceptable change in resistance of all samples

Die compression type connector for 4/0 conductor to 3/4" rod (T&B # GG500-40250): set 10T

- All connectors completed cycling test
- Acceptable changes in resistance in three connectors, one connector having high resistance.

CONCLUSION

Based on the test results obtained and documented in this report, the following observations and comments are based on the test criteria in IEEE Std 837-1989. The test results in Table 9 do not include the results obtained on the EMF tests performed at levels above IEEE Std 837-1989. It must also be noted that some of these products are multi-range conductors, the tests and results obtained on a single conductor size may not be sufficient to fully assess the performance of the connector. In accordance with IEEE Std 837-1989, multi-range connectors must be evaluated with the minimum and maximum conductor sizes as specified.

Table 9: Summary of Comparative Evaluation

Connector	Mechanical-Pullout	Electromagnetic Force	Acid Test Series	Alkaline Test Series
AMP Wrench-Lok #81228-1 4/0 to 4/0	Pass	Slip on 3 connectors, ¼ in. No significant change in resistance	Four connectors with resistance increase over 150%	One connector fail during current-temperature cycling. Fusing of conductor at one connector. Other connectors with resistance increase over 150%
AMP Wrench-Lok #81229-1 4/0 to 3/4" rod.	One rod pull out below 1000 lbs.	Pass No significant change in resistance	Pass	Three connectors with resistance increase over 150%
Burndy #YGL29C29 4/0 to 4/0	Pass	Pass No significant change in resistance	Pass	Four connectors with resistance increase over 150%
Burndy #YGLR29C34 4/0 to 3/4" rod	Pass	Slip on 3 connectors Increase in resistance over 50% in 2 connectors	Two connectors with resistance increase over 150%	Three connectors with resistance increase over 150%
Cadweld #XAC2Q2Q 4/0 to 4/0	Pass	Pass No significant change in resistance	Pass	Pass
Cadweld #GTC182Q 4/0 to 3/4" rod	Pass	Pass No significant change in resistance	Pass	Pass
Thomas & Betts #GG40250-40250 4/0 to 4/0	Pass	Pass No significant change in resistance	Four connectors with resistance increase over 150%	Fusing of conductor at one connector. Other connectors with resistance increase over 150%
Thomas & Betts #GG500-40250 4/0 to 3/4" rod	Four rods pull out below 1000 lbs	Slip on 3 connectors. Complete pull-out on one. Other connector having resistance increase of 54%	One connector with resistance increase over 150%	Four connectors with resistance increase over 150%

Approved

J. Kuffel
Supervising Engineer
Electrical Systems Technology

Submitted

C.G. Maurice
Lead Technologist
Electrical Systems Technology
Technical Resources

CGM:ABA

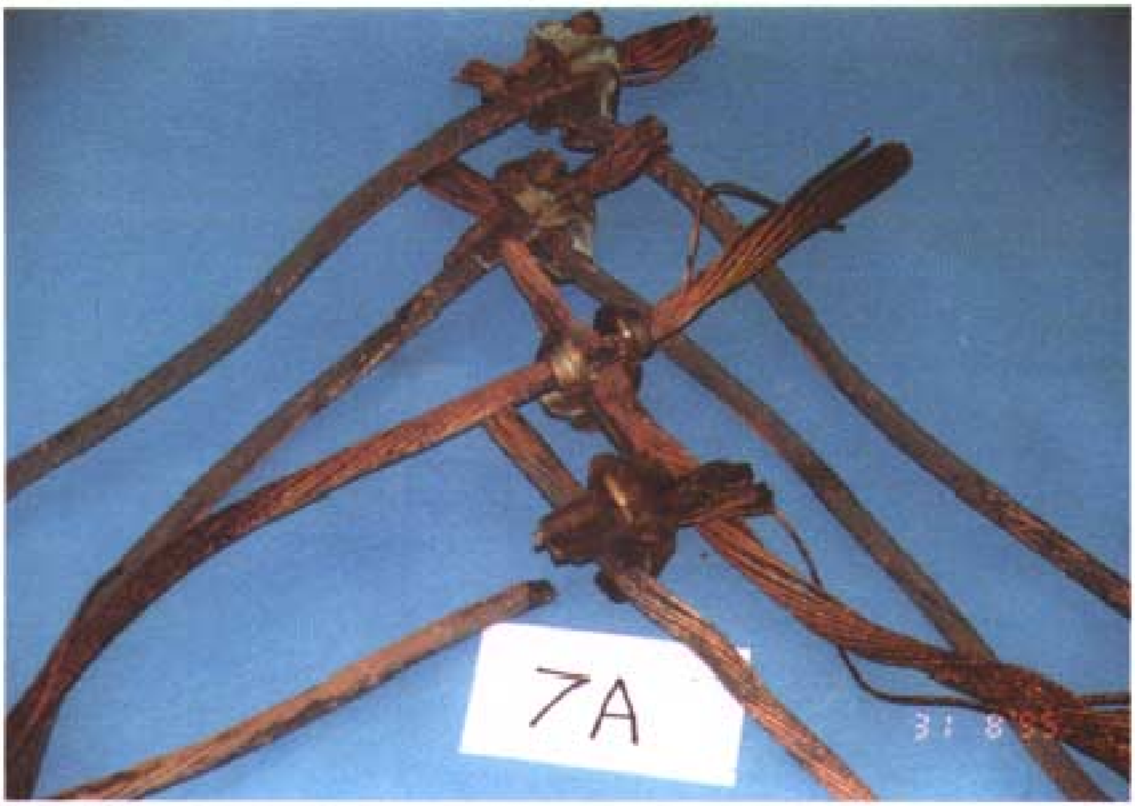
APPENDIX A

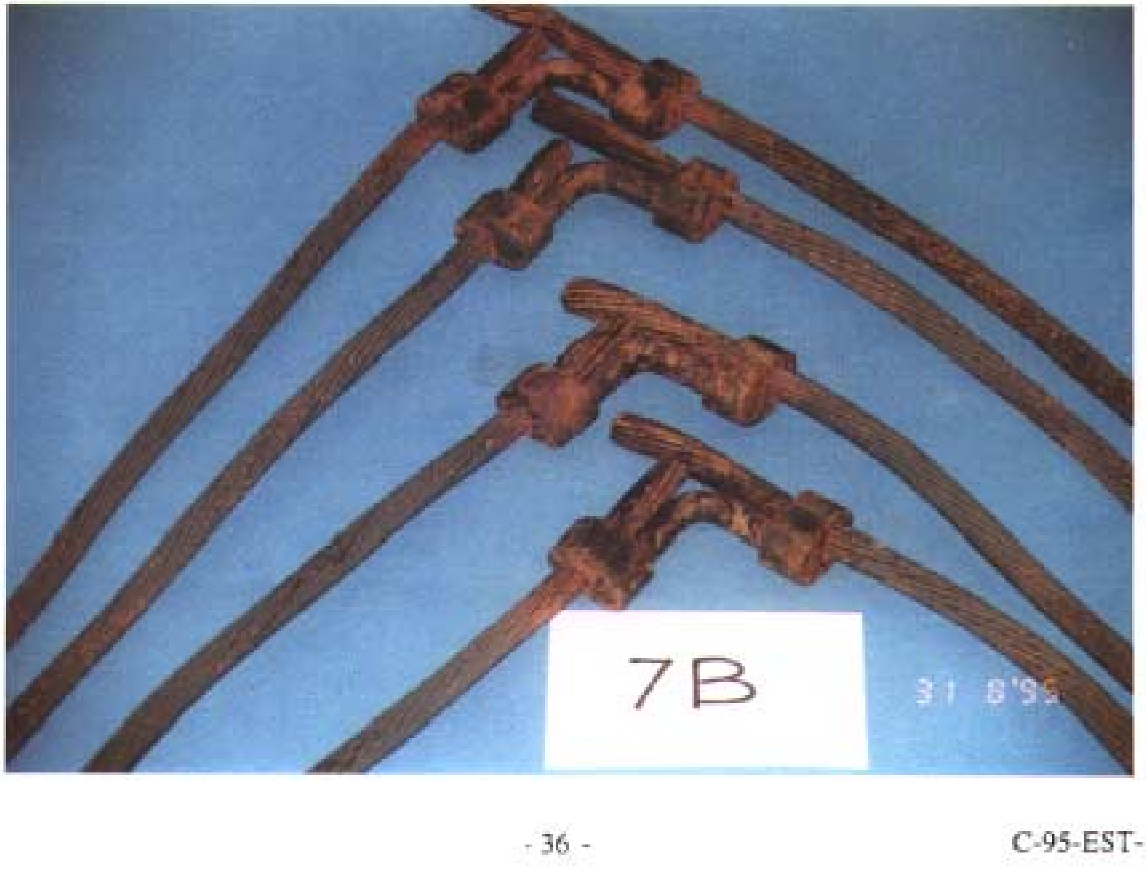
PHOTOGRAPHS OF TESTS SAMPLES FOLLOWING TEST SERIES

APPENDIX A

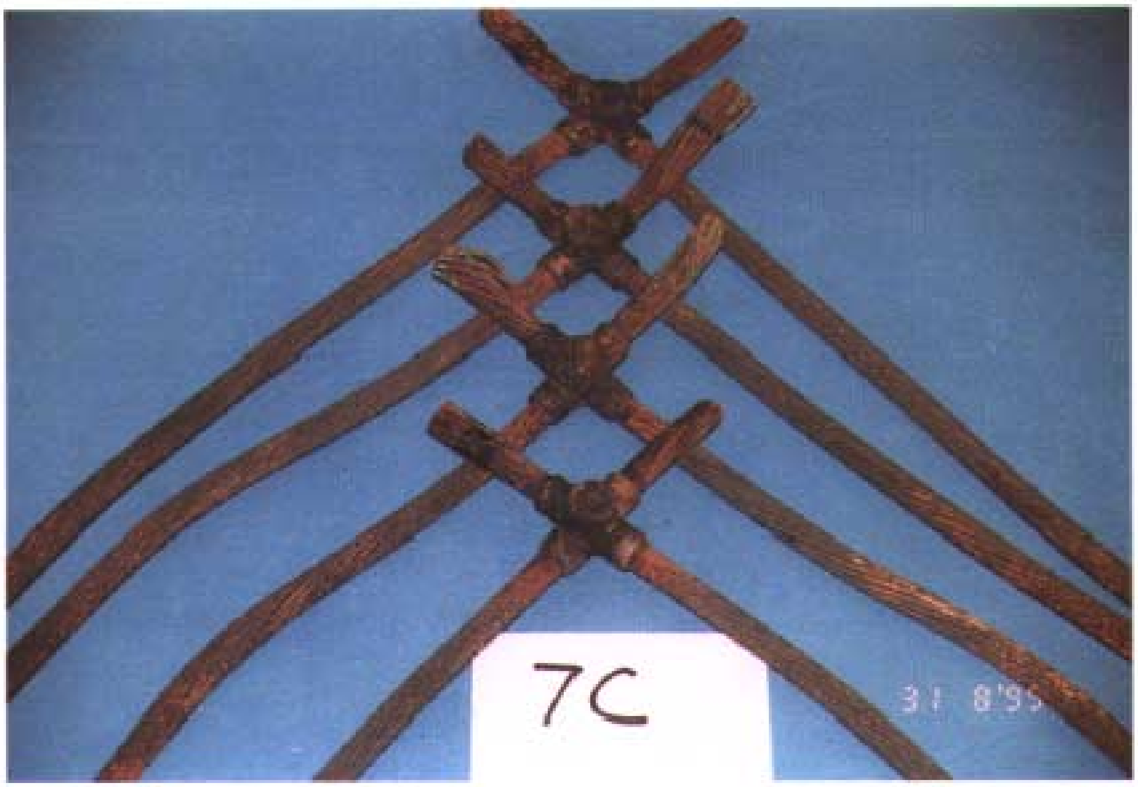
PHOTOGRAPHS OF TESTS SAMPLES FOLLOWING TEST SERIES

Connector Set 7: Alkaline Test Group





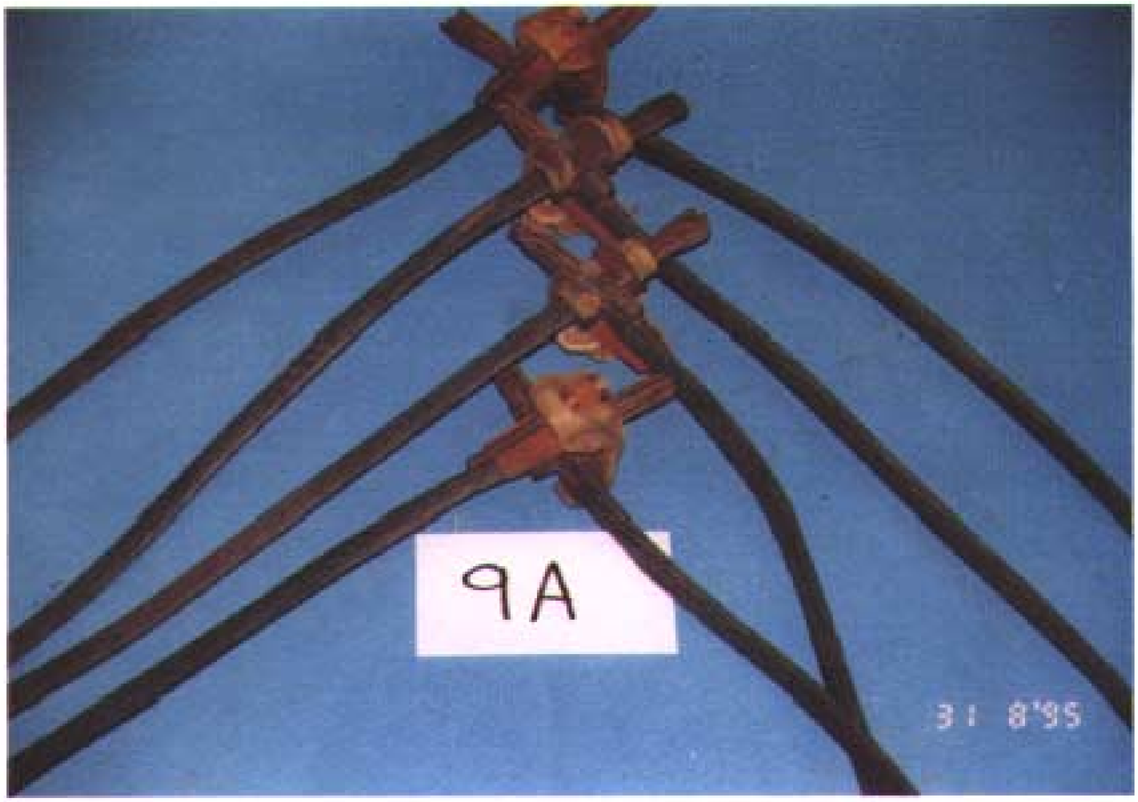
Connector Set 7: Alkaline Test Group

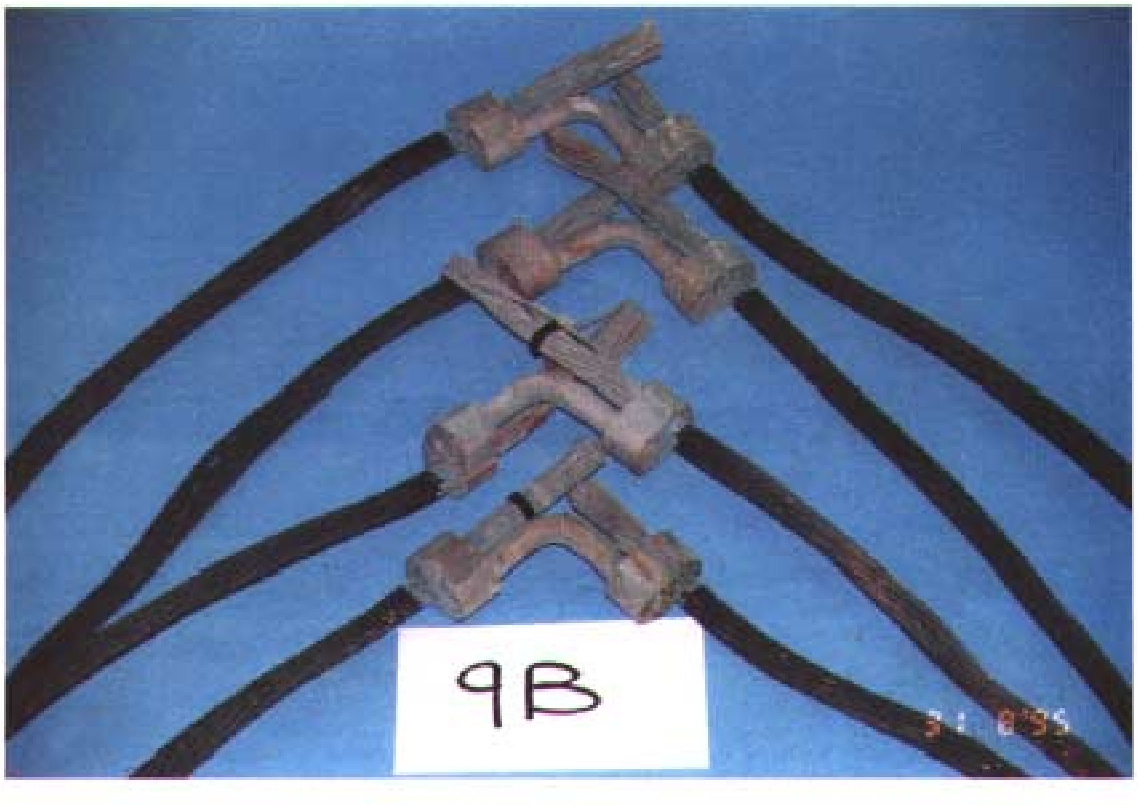


Connector Set 8: Alkaline Test Group

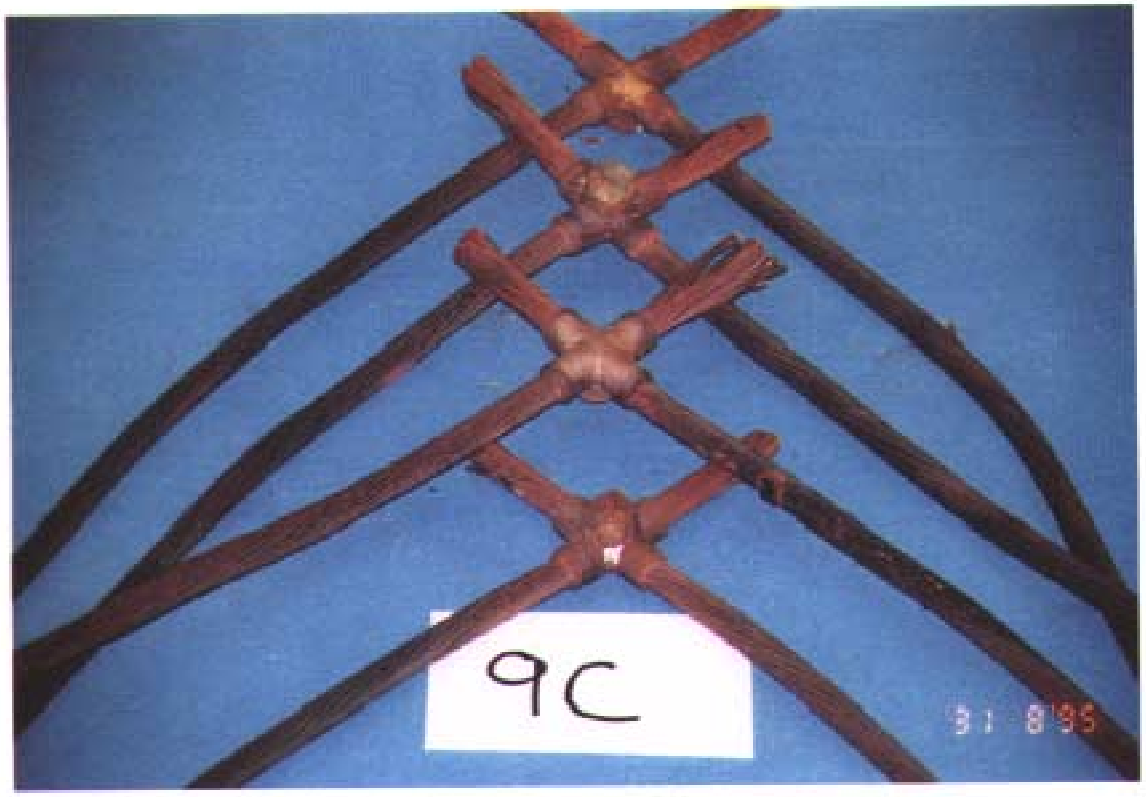
Connector Set 8: Alkaline Test Group

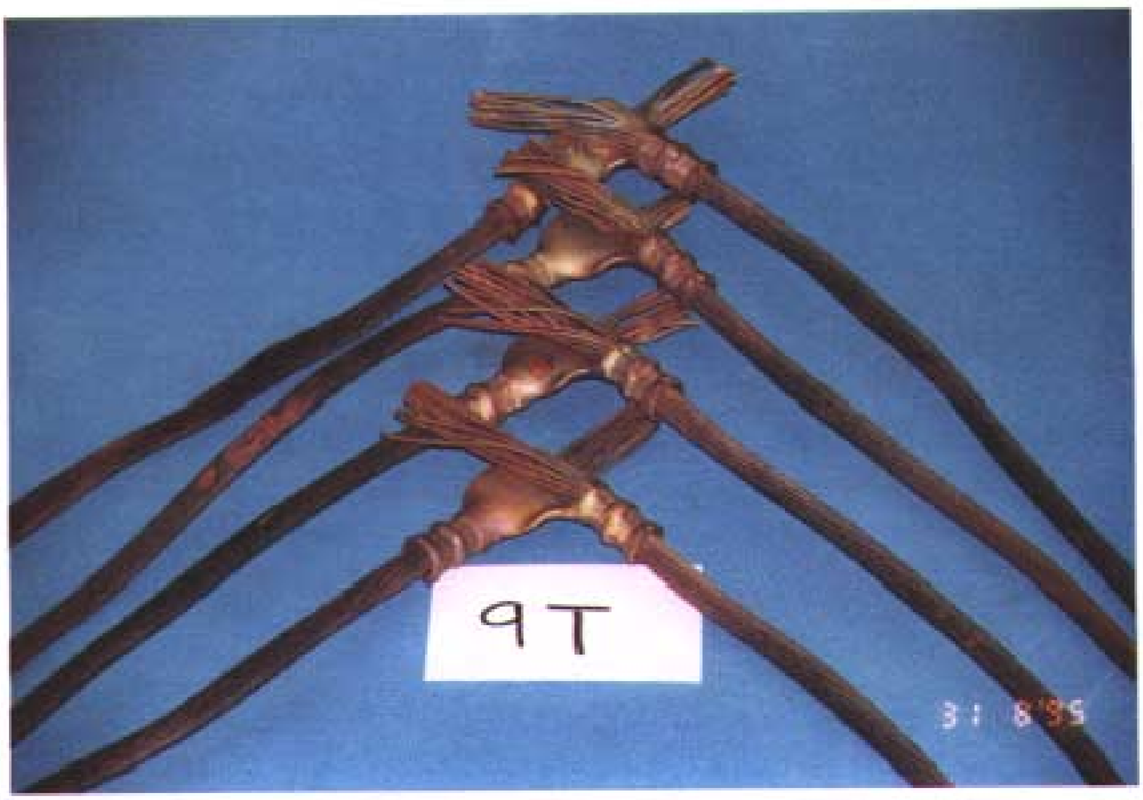
Connector Set 9: Acidic Test Group



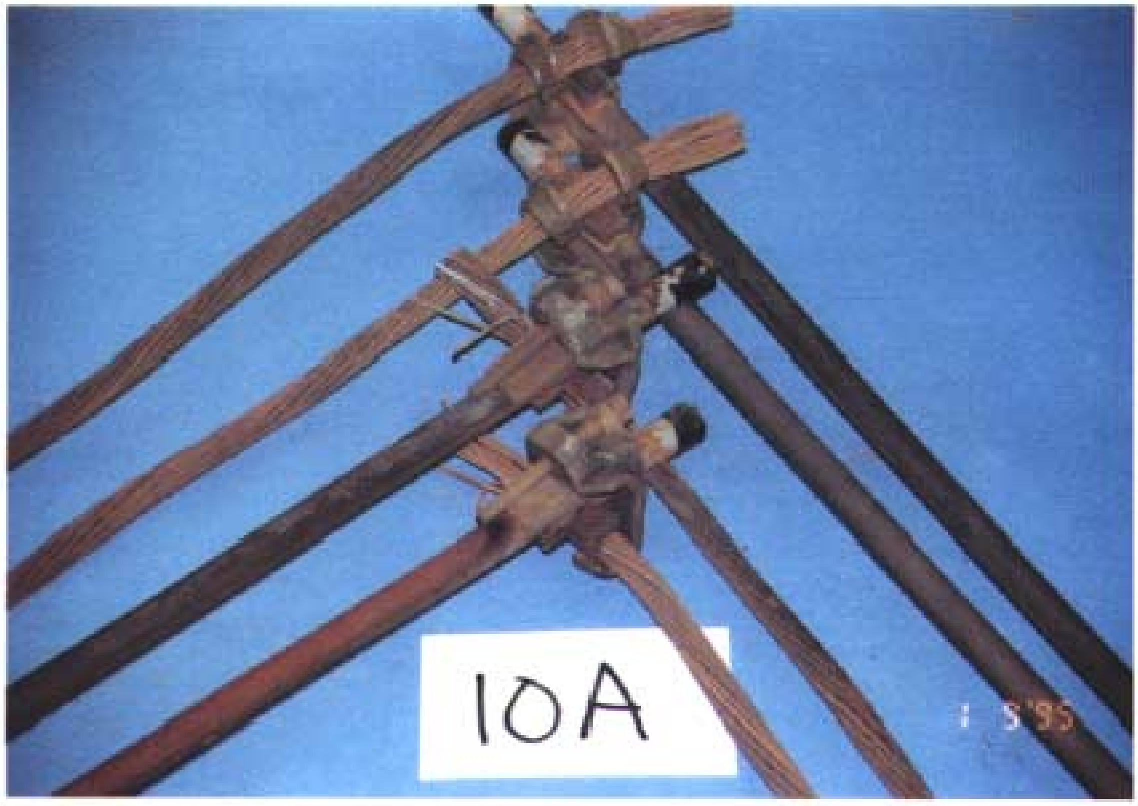


Connector Set 9: Acidic Test Group





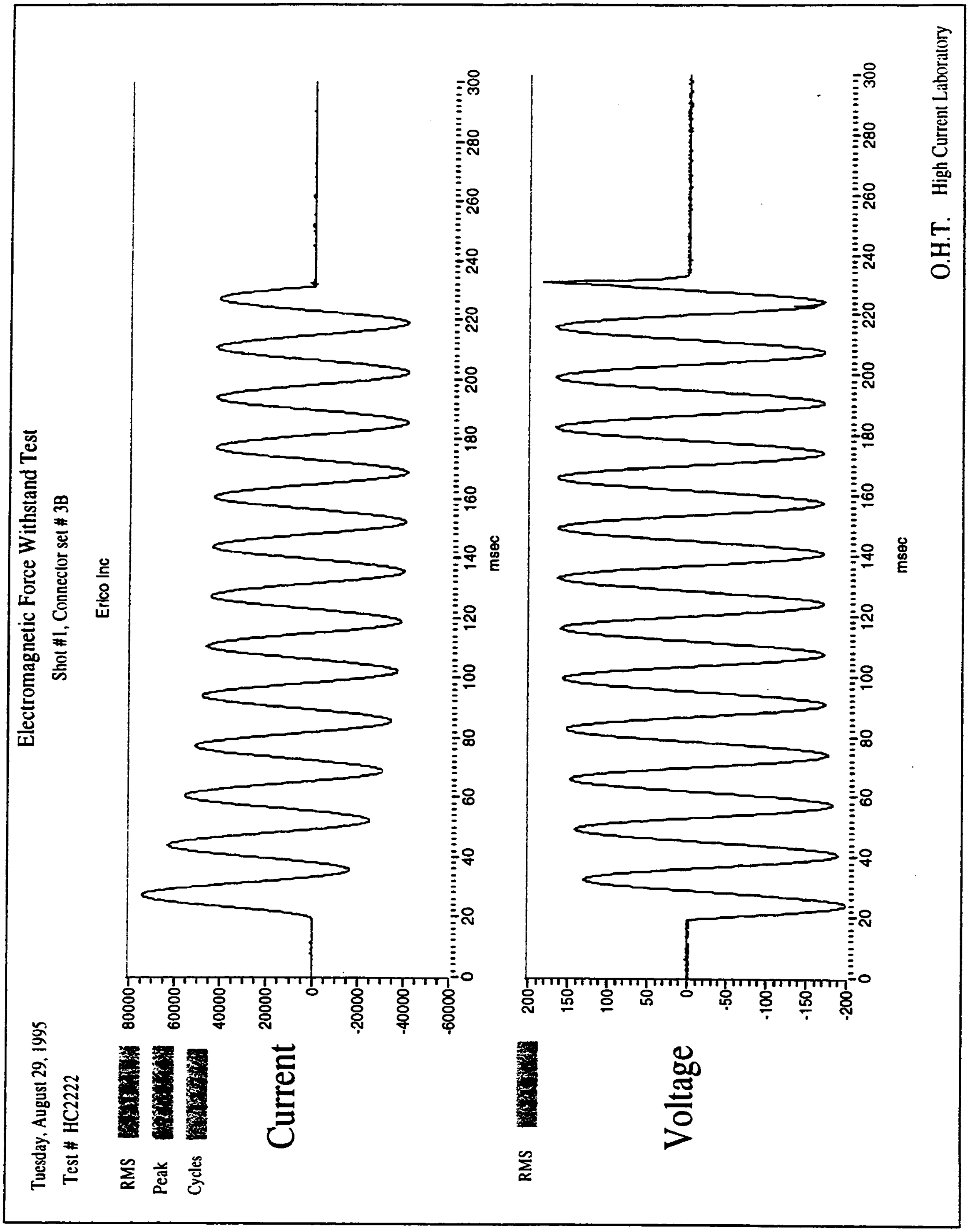
Connector Set 10: Acidic Test Group



Connector Set 10: Acidic Test Group

APPENDIX B

TYPICAL OSCILLOGRAMS OF ELECTROMAGNETIC FORCE TEST AND FAULT CURRENT TEST


Electromagnetic Force Withstand Test
Shot #1, Connector set # 3B
Erico Inc
Tuesday, August 29, 1995
Test # HC2222
RMS [redacted]
Peak [redacted]
Cycles [redacted]
Current
80000
60000
40000
20000
0
-20000
-40000
-60000
0 20 40 60 80 100 120 140 160 180 200 220 240 260 280 300
msec
RMS [redacted]
Voltage
200
150
100
50
0
-50
-100
-150
-200
0 20 40 60 80 100 120 140 160 180 200 220 240 260 280 300
msec
O.H.T. High Current Laboratory

Thursday, August 31, 1995

Test # HC2277

Fault-Current Test

Shot #3, Connector set # 8A and 8B

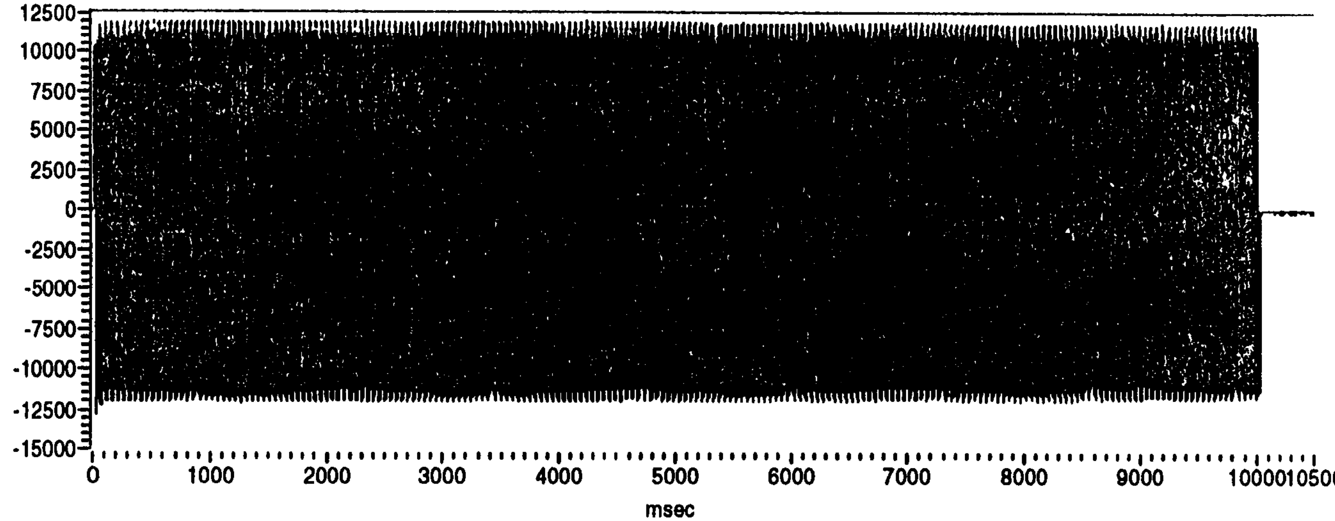
Erico Inc

RMS [redacted]

Peak [redacted]

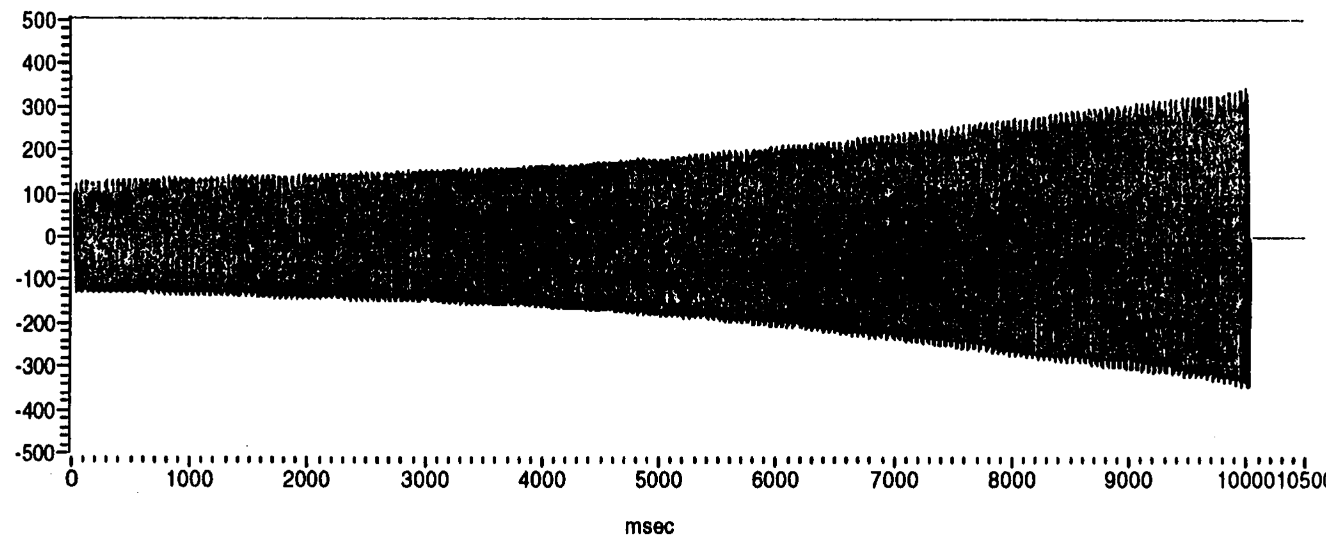
Cycles [redacted]

Current



RMS [redacted]

Voltage



O.H.T. High Current Laboratory

APPENDIX C

DETAILED CONNECTOR RESISTANCE

Connector Series #7 4/0 to 4/0
Salt Spray
Resistance in milliohms

Sample #	Initial Resistance	Connector resis	Resistance After Temp. Cycling	Connector Resis	Change	Resistance After Freeze thaw test	Connector Resis	Change	Resistance After Salt Spray	Connector Resis	Change	Resistance after Fault current	Connector Resis	Change in Connector
7A1	0.2256	0.0204	0.3336	0.1157	467.2%	0.4363	0.2239	997.5%	0.4803	0.2653	1200.5%	unstable, loose con	n.a.	n.a.
7A2	0.2212	0.016	0.2892	0.0713	345.6%	0.3804	0.168	950.0%	0.4987	0.2837	297.9%	unstable, loose con	n.a.	n.a.
7A3	0.2252	0.02	1.4158	1.1979	Failed at heat cycle							n.a.	n.a.	n.a.
7A4	0.2228	0.0176	0.2556	0.0377	114.2%	0.3136	0.1012	475.0%	0.5193	0.3043	707.2%	damaged	n.a.	n.a.
7AC	0.2052		0.2179			0.2124			0.215			0.2081		1.4%
7B1	0.2231	0.017	0.2293	0.0183	7.6%	0.2494	0.0374	120.0%	0.2573	0.0432	154.1%	0.3412	0.1331	682.9%
7B2	0.2236	0.0175	0.2308	0.0198	13.1%	0.2364	0.0244	39.4%	0.2393	0.0252	44.0%	0.2579	0.0498	184.6%
7B3	0.2277	0.0216	0.2331	0.0221	2.3%	0.2456	0.0336	55.6%	0.2522	0.0381	76.4%	0.3125	0.1044	383.3%
7B4	0.2231	0.017	0.2287	0.0177	4.1%	0.2597	0.0477	180.6%	0.3319	0.1178	592.9%	0.3433	0.1352	695.3%
7BC	0.2061		0.211			0.212			0.2141			0.2081		1.0%
7C1	0.211	0.009	0.2204	0.0103	14.4%	0.2186	0.0105	16.7%	0.214	0.0098	8.9%	0.2182	0.0095	5.6%
7C2	0.2116	0.0096	0.2208	0.0107	11.5%	0.2192	0.0111	15.6%	0.2148	0.0106	10.4%	0.2189	0.0102	6.3%
7C3	0.2125	0.0105	0.2217	0.0116	10.5%	0.2199	0.0118	12.4%	0.2156	0.0114	8.6%	0.2198	0.0111	5.7%
7C4	0.2115	0.0095	0.2199	0.0098	3.2%	0.2181	0.01	5.3%	0.2141	0.0099	4.2%	0.2189	0.0102	7.4%
7CC	0.202		0.2101			0.2081			0.2042			0.2087		3.3%
7T1	0.22	0.0152	0.2287	0.0187	23.0%	0.4653	0.2539	1570.4%	8	7.794	51176.3%	0.662	0.4513	2869.1%
7T2	0.2209	0.0161	0.2289	0.0189	17.4%	0.496	0.2846	1667.7%	14.13	13.924	86384.5%	n.a.	n.a.	n.a.
7T3	0.2208	0.016	0.2285	0.0185	15.6%	0.3116	0.1002	526.3%	9.984	9.778	61012.5%	0.5236	0.3129	1855.6%
7T4	0.2209	0.0161	0.2278	0.0178	10.6%	0.452	0.2406	1394.4%	9.193	8.987	55719.9%	0.85	0.6393	3870.8%
7TC	0.2048		0.21			0.2114			0.206			0.2107		2.9%

Connector Series #8 4/0 to 3/4 GRND ROD
Salt Spray

Sample #	Initial Resistance	Resistance After Temp. Cycling	Change	Resistance After Freeze thaw test	Change	Resistance After Salt Spray	Change	Resistance after Fault current	Change
8A1	0.4204	0.4353	3.5%	0.4377	4.1%	0.43	2.3%	0.4544	8.1%
8A2	0.435	0.4523	4.0%	0.4631	6.5%	0.455	4.6%	0.4947	13.7%
8A3	0.4389	0.4552	3.7%	0.4546	3.6%	0.4519	3.0%	0.5128	16.8%
8A4	0.4431	0.4597	3.7%	0.4716	6.4%	0.4744	7.1%	0.79	78.3%
8AC	0.63	0.64	1.6%	0.6156	-2.3%	0.5974	-5.2%	0.6141	-2.5%
8B1	0.4328	0.4559	5.3%	0.5275	21.9%	0.4497	3.9%	2.095	384.1%
8B2	0.436	0.4507	3.4%	0.5193	19.1%	0.4467	2.5%	0.463	6.2%
8B3	0.4368	0.6258	43.3%	0.6944	59.0%	0.5152	17.9%	0.5925	35.6%
8B4	0.4347	0.641	47.5%	0.6511	49.8%	0.4737	9.0%	0.593	36.4%
8BC	0.6466	0.6603	2.1%	0.6552	1.3%	0.6366	-1.5%	0.6685	3.4%
8C1	0.4383	0.4503	2.7%	0.446	1.8%	0.4389	0.1%	0.4492	2.5%
8C2	0.4228	0.435	2.9%	0.4272	1.0%	0.423	0.0%	0.4301	1.7%
8C3	0.4311	0.448	3.9%	0.4457	3.4%	0.4386	1.7%	0.4497	4.3%
8C4	0.4219	0.4284	1.5%	0.426	1.0%	0.4188	-0.7%	0.4279	1.4%
8CC	0.6355	0.6188	-2.6%	0.6171	-2.9%	0.5982	-5.9%	0.619	-2.6%
8T1	0.4533	0.4982	9.9%	0.5321	17.4%	1.1672	157.5%	n.a. (loose connec	-100.0%
8T2	0.4306	0.4601	6.9%	0.4838	12.4%	.550 to .900	-100.0%	up to .8 (unstable)	-100.0%
8T3	0.4355	0.4505	3.4%	0.4547	4.4%	0.5088	16.8%	up to .9 (unstable)	-100.0%
8T4	0.4508	0.4688	4.0%	0.4698	4.2%	.600 to 1.5	-100.0%	up to 1.5 (unstabl	-100.0%
8TC	0.6422	0.661	2.9%	0.6543	1.9%	0.6353	-1.1%	0.665	3.6%

Connector Series #9 4/0 to 4/0
Acid Bath

Sample #	Initial Resistance	Connector resis	Resistance After Temp. Cycling	Connector Resis	Change	Resistance After Freeze thaw test	Connector Resis	Change	Resistance After acid bath	Connector Resis	Change	Resistance after fault current	Connector Resis	Change
9A1	0.2282	0.0216	0.2594	0.0527	144.0%	0.5287	0.3276	1416.7%	0.297	0.069	219.4%	0.61	0.342	1483.3%
9A2	0.2273	0.0207	0.2394	0.0327	58.0%	0.2944	0.0933	350.7%	0.299	0.071	243.0%	0.413	0.145	600.5%
9A3	0.2278	0.0212	0.2414	0.0347	63.7%	0.3352	0.3352	1481.1%	0.311	0.311	1367.0%	0.54	0.54	2447.2%
9A4	0.2329	0.0263	0.259	0.0523	98.9%	0.3348	0.1337	408.4%	0.303	0.075	185.2%	0.45	0.182	592.0%
9AC	0.2066		0.2067			0.2011			0.228			0.268		
9B1	0.2301	0.0233	0.2305	0.0245	5.2%	0.2186	0.0246	5.6%	0.276	0.047	101.7%	conductor fused at di	-0.239	n.a.
9B2	0.2323	0.0255	0.2316	0.0256	0.4%	0.2215	0.0275	7.8%	0.276	0.047	84.3%	0.2833	0.0443	73.7%
9B3	0.2313	0.0245	0.2309	0.0249	1.6%	0.2259	0.0319	30.2%	0.281	0.052	112.2%	0.2873	0.0483	97.1%
9B4	0.2296	0.0228	0.2296	0.0236	3.5%	0.2322	0.0382	67.5%	0.282	0.053	132.5%	0.2896	0.0506	121.9%
9BC	0.2068		0.206			0.194			0.229			0.239		
9C1	0.2207	0.0145	0.226	0.0155	6.9%	0.213	0.017	17.2%	n.a., fused conduc	-0.2422	**********	damaged conductor	-0.247	n.a.
9C2	0.2175	0.0113	0.2243	0.0138	22.1%	0.2116	0.0156	38.1%	0.259	0.0168	48.7%	0.264	0.017	21.4%
9C3	0.22	0.0138	0.2251	0.0146	5.8%	0.2137	0.0177	28.3%	n.a., fused conduc	-0.2422	**********	damaged conductor	-0.247	n.a.
9C4	0.2187	0.0125	0.2244	0.0139	11.2%	0.2121	0.0161	28.8%	0.2588	0.0166	32.8%	0.264	0.017	20.7%
9CC	0.2062		0.2105			0.196			0.2422			0.247		
9T1	0.2247	0.0191	0.233	0.0259	35.6%	0.3066	0.1096	473.8%	unstable up to 1.2	0	n.a.	unstable	0	n.a.
9T2	0.2246	0.019	0.2325	0.0254	33.7%	0.7081	0.5111	2590.0%	unstable .482	0	n.a.	unstable	0	-100.0%
9T3	0.236	0.0304	0.2424	0.0353	16.1%	0.4832	0.2862	841.4%	unstable, .55	0	n.a.	unstable	0	-100.0%
9T4	0.2262	0.0206	0.2324	0.0253	22.8%	0.4523	0.2553	1139.3%	unstable, 600-800	0	n.a.	unstable	0	-100.0%
9TC	0.2056		0.2071			0.197			n.a. broken strands			damaged		-100.0%

Connector Series #10 4/0 to 3/4" GRND ROD,
Acid Bath Series

Sample #	Initial Resistance	Resistance After Temp. Cycling	Change	Resistance After Freeze thaw test	Change	Resistance After acid bath	Change	Resistance after Fault current	Change
10A1	0.4447	0.449	1.0%	0.4381	-1.5%	0.6198	39.4%	0.605	36.0%
10A2	0.4533	0.4611	1.7%	0.4512	-0.5%	0.6345	40.0%	0.6287	38.7%
10A3	0.4375	0.4374	-0.0%	0.4297	-1.8%	0.6091	39.2%	0.6052	38.3%
10A4	0.4417	0.4454	0.8%	0.4346	-1.6%	0.5914	33.9%	0.583	32.0%
10AC	0.6654	0.655	-1.6%	0.6378	-4.1%	0.9325	40.1%	0.9222	38.6%
10B1	0.4472	0.4945	10.6%	0.4351	-2.7%	0.5948	33.0%	1.05	134.8%
10B2	0.4432	0.6081	37.2%	0.6174	39.3%	0.5891	32.9%	0.7344	65.7%
10B3	0.4608	1.0064	118.4%	0.6261	35.9%	0.6091	32.2%	0.625	35.6%
10B4	0.4465	3.361	652.7%	0.4423	-0.9%	0.582	30.3%	0.5955	33.4%
10BC	0.6372	0.6136	-3.7%	0.6048	-5.1%	0.841	32.0%	0.823	29.2%
10C1	0.4432	0.4481	1.1%	0.4336	-2.2%	0.591	33.3%	0.5801	30.9%
10C2	0.4289	0.4353	1.5%	0.4186	-2.4%	0.569	32.7%	0.5571	29.9%
10C3	0.4397	0.4474	1.8%	0.4282	-2.6%	0.581	32.1%	0.5715	30.0%
10C4	0.4365	0.442	1.3%	0.4249	-2.7%	0.584	33.8%	0.571	30.8%
10CC	0.6795	0.6653	-2.1%	0.6462	-4.9%	1.135	67.0%	n.a.	damaged
10T1	0.4472	0.448	0.2%	0.4511	0.9%	0.61	36.4%	0.607	35.7%
10T2	0.4507	0.4548	0.9%	0.452	0.3%	0.641	42.2%	0.88	95.3%
10T3	0.4514	0.4578	1.4%	0.4466	-1.1%	0.6299	39.5%	0.618	36.9%
10T4	0.437	0.4348	-0.5%	0.4287	-1.9%	0.5937	35.9%	0.605	38.4%
10TC	0.639	0.6103	-4.5%	0.6013	-5.9%	0.8624	35.0%	0.8425	31.8%

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