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KINECTRICS NORTH AMERICA INC. TEST REPORT FOR 3M COMPANY TO COMPARE THE LIGHTNING PERFORMANCE OF ACCR TO ACSR CONDUCTORS

Kinectrics North America Inc. Report No.: 9513-004-RC-0002-R00

September 26, 2003

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A series of Lightning Arc Tests were performed for and under contract to 3M Company on their Aluminum Conductor Composite Reinforced (ACCR) Conductor. These tests are part of a larger series of tests to demonstrate the viability of ACCR conductors for use on overhead electric power transmission lines. The tests were performed by Kinectrics Inc. personnel at 800 Kipling Avenue, Toronto, Ontario, M8Z 6C4, Canada. 3M own all data and copyright to this information and are publicly released by 3M.

TEST OBJECTIVE

The objective of the Lightning Arc Test program was to compare the physical performance of two(2) ACCR conductors to ACSR conductors of equivalent aluminum alloy areas (ie. kcmil) when subjected to increasing levels of lightning energy. Possible damages to conductors due to lightning arcs are breakage and/or melting of the aluminum strands. Splattering of melted metal may also cause damage to neighbouring strands that are not directly affected by the arc. Ultimately, loss of tensile strength of the conductor results from lightning.

TEST CONDUCTORS

Two(2) different sizes of ACCR and ACSR conductors were included in the testing.

The ACCR 477-T16, 26/7 conductor manufactured by 3M Company was compared to ACSR 477 kcmil, 26/7 “Hawk” conductor commonly used on overhead transmission lines. The construction of these conductors is the same in that there are 26 aluminum alloy wires in 2 layers surrounding 7 steel core wires. The outside diameter of both conductors is 0.858 inches (21.793 mm) and the individual wire diameters are also the same. The differences reside in the composition of the aluminum alloy wires and the core wires. The aluminum alloy in the ACCR conductor contains a small quantity of zirconium. The core wires of the ACCR are made from a metal matrix compound.

The ACCR 795-T16, 26/19 conductor manufactured by 3M Company was compared to ACSR 795 kcmil, 26/7 “Drake” conductor. The outside diameters of the conductors are both 1.108 inches (28.143 mm). The numbers and diameters of the aluminum alloy wires are also the same. There are 19 smaller diameter composite core wires in ACCR compared to 7 larger steel wires in ACSR.

Data sheets on the conductors used in the short circuit test are contained in Appendix A.

TEST SET-UP

The Lightning Arc Tests were carried out in Kinectrics’ High Voltage Laboratory.

Test Apparatus

Figure 1 shows a schematic diagram of the configuration for this test. The setup for this test involves a conductor sample approximately 12 m long. The test sample was supported by suitable deadend clamps. A turnbuckle was used to tension the conductor to the desired tension and a load cell was used to measure the tension.

The arc head, which is the electrode and return-current clamp assembly that supports the arc, is mounted on the sample part way along the span. A battery bank was used to provide the current to produce a continuing current waveform. A 5 cm fuse wire was used to initiate the arc. The magnetically-balanced arc head was designed to withstand both the heating and mechanical forces imposed by the current.

TEST PROGRAM

The conductor sample was tensioned to 15% of the rated tensile strength of the conductor. The ambient room temperature was about 22°C. Each test results in heating of the conductor and so the next experiment (i.e. arc strike) was initiated when the initial temperature of the conductors before each arc was about 40°C. Each arc strike was conducted approximately six inches (12.5 cm) from the previous site, and thus the conductor sample was progressively tested along the length under various conditions of charge transference.

Charge transference (current x duration) ranged from nominally 50 coulombs to 200 coulombs.

Typically currents are 100 – 400 amps and typically durations are 200-500 msec.

RESULTS AND DISCUSSION

Tables 1 and 2 summarize the results of the lightning arcs on the 477 kcmil and 795 kcmil conductors, respectively. Photographs of the damage and the current waveforms of each arc on the 477 kcmil and 795 kcmil conductors are contained in Appendix B and C, respectively.

TABLE 1
SUMMARY OF LIGHTNING ARC TESTS FOR 477 KCMIL ACCR and 477 KCMIL ACSR

Test Dates: September 12-13 & November 1, 2002

Hit No.	Coulombs	Initial Tension (lbf)	Initial Temp (°C)	Damaged Wires			Splatter	Figure No. in Appendix A
				Broken	Major Melting	Minor Melting		
477 ACCR								
11	47	2918	40	1	0	0	No	A1aa/A1ab
10	50	2925	42	1	0	0	No	A2aa/A2ab
9	51	2930	43	1	0	0	No	A3aa/A3ab
4	64	2900	42	0	0	0	Yes	A4aa/A4ab
1	90	2890	43	3	0	0	No	A5aa/A5ab
3	100	2920	40	1	0	1	No	A6aa/A6ab
2	102	2920	42	2	0	1	Yes	A7aa/A7ab
6	182	2920	43	0	0	0	Yes	A8aa/A8ab
7	190	2920	43	5	0	0	Yes	A9aa/A9ab
5	191	2950	42	4	0	0	Yes	A10aa/A10ab
8	192	2910	42	0	3	1	Yes	A11aa/A11ab
12	208	2913	43	4	0	0	Yes	A12aa/A12ab
477 ACSR								
14	48	2915	42	0	0	1	Yes	A13aa/A13ab
13	52	2925	41	0	0	2	No	A14aa/A14ab
15	53	2935	42	0	0	2	No	A15aa/A15ab
20	102	2925	42	2	0	0	Yes	A16aa/A16ab
21	109	2925	41	0	2	0	Yes	A17aa/A17ab
19	110	2785	42	2	0	0	Yes	A18aa/A18ab
16	127	2930	43	2	0	1	No	A19aa/A19ab
17	183	2915	42	1	0	1	Yes	A20aa/A20ab
23	189	2935	43	0	2	0	Yes	A21aa/A21ab
18	198	2925	43	0	0	4	Yes	A22aa/A22ab
22	198	2918	43	0	3	0	Yes	A23aa/A23ab
24	199	2923	43	0	3	1	Yes	A24aa/A24ab
16	210	2925	40	5	0	0	No	A25aa/A25ab
15	214	2930	41	5	0	0	No	A26aa/A26ab
14	220	2920	40	0	3	1	Yes	A27aa/A27ab

SUMMARY OF LIGHTNING ARC TESTS FOR 795 ACCR 3M and 795 ACSR

Test Dates: September 20, October 30-31, & November 1, 2002

Hit No.	Coulombs	Initial Tension (lbf)	Initial Temp (°C)	Damaged Wires			Splatter	**Figure No. in Appendix B**
				Broken	Major Melting	Minor Melting		
795 ACCR								
1	49	4646	42	0	0	0	Yes	B1aa/B1ab
2	51	4640	40	0	0	0	Yes	B2aa/B2ab
4	52	4640	41	0	0	1	No	B3aa/B3ab
3	54	4690	42	0	0	1	No	B4aa/B4ab
7	108	4660	43	0	0	0	Yes	B5aa/B5ab
6	109	4640	44	0	0	2	Yes	B6aa/B6ab
5	110	4680	42	2	0	0	Yes	B7aa/B7ab
					0			
10	188	4680	40	0	0	0	Yes	B8aa/B8ab
18	190	4640	41	0	1	1	No	B9aa/B9ab
12	194	4650	41	0	0	0	Yes	B10aa/B10ab
9	196	4647	41	0	0	2	Yes	B11aa/B11ab
17	200	4650	44	0	1	1	Yes	B12aa/B12ab
11	201	4630	42	0	0	0	Yes	B13aa/B13ab
13	201	4640	41	0	0	0	Yes	B14aa/B14ab
795 ACSR								
4	49	4610	42	0	0	2	Yes	B15aa/B15ab
5	49	4647	40	0	0	1	Yes	B16aa/B16ab
3	50	4661	41	0	0	2	Yes	B17aa/B17ab
2	98	4640	40	0	0	0	Yes	B18aa/B18ab
1	107	4652	40	0	1	0	Yes	B19aa/B19ab
0	108	4648	43	0	2	0	Yes	B20aa/B20ab
7	189	4647	40	2	0	2	Yes	B21aa/B21ab
8	200	4642	39	1	0	3	Yes	B22aa/B22ab
6	204	4660	40	1	1	2	Yes	B23aa/B23ab

The following comments and discussion are made to assist in the understanding and interpretation of the lightning test and the results obtained from the test.

1) Although the ideal shape of the continuing current is a smooth square wave, the actual waveforms often contain noise. Subtle asymmetries in the way the current flows through the arc head can cause the arc to wander. The head is designed to maintain a reasonably stable arc but because of the large amounts of energy being transferred to the conductor in a very short period of time, there will be some degree of instability in the arc. This contributes to noisy current waveforms. Unless extreme, the noise doesn't significantly affect the damage to the conductor. The area under the curve, whether smooth or noisy, is calculated to give the energy transferred to the conductor.

2) The energy transferred to the conductors during these tests ranges from nominally 50 Coulombs to over 200 Coulombs. The actual amount that a conductor may see in the field depends on factors such as geographic location in the world, line configuration and length and grounding conditions. From a general perspective, 50 Coulombs would represent a moderate strike. A strike of 200 Coulombs would be considered an extremely severe and rare event.

3) Field samples damaged by lightning correlated to energy have not been archived to the extent where definitive statements on the relationship between energy and damage level can be ascertained. Laboratory tests show that for nominally the same energy, the resulting damage can vary widely. Damage can range from minor surface roughness to varying degrees and extent of splattering and/or melting of metal to fully broken strands. As shown in photographs, the full range of damage was evident during these tests. Assessing the damage caused by the simulated lighting arcs does have a subjective component.

4) To help quantify the damage inflicted on the conductor is to determine the residual tensile strength by performing tensile tests on each affected area. The damage caused by splattering over 4, 5 or 6 strands with no broken strands may result in a lower residual strength than damage that is limited to 1 or 2 broken strands with no damage to strands. The tested samples were returned to 3M for possible tensile testing.

SUMMARY OF OBSERVATIONS

- When comparing the damage to both sizes of ACCR and ACSR conductors for all test levels, the visual assessment does not show that one performs better or worse than the other for the same size conductor.
- The damage for all tests on both the 477 and 795 kcmil conductors was limited to the outer aluminum layer. There were no observations of damage to the inner aluminum layer or to the core.
- The 477 kcmil ACCR and ACSR conductors sustained more damage than the 795 kcmil ACCR and ACSR conductors for comparable energy levels. The 795 kcmil aluminum strand diameter (0.1749 inch) is larger than the 477 aluminum strand diameter (0.1355 inch). The smaller diameter wires are more vulnerable to damage.

ACKNOWLEDGEMENTS

This material is based upon work supported by the U.S. Department of Energy under Award No. DE-FC02-02CH11111.

J. Levine and G. Gouliaras performed the Lightning Arc Test.

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DISCLAIMER

Any opinions, findings, and conclusions or recommendations expressed in this material are those of the author(s) and do not necessarily reflect the views of the Department of Energy.

Kinectrics North America Inc. has prepared this report in accordance with, and subject to, the terms and conditions of the contract between Kinectrics North America Inc. and 3M Company, dated August 15, 2002.

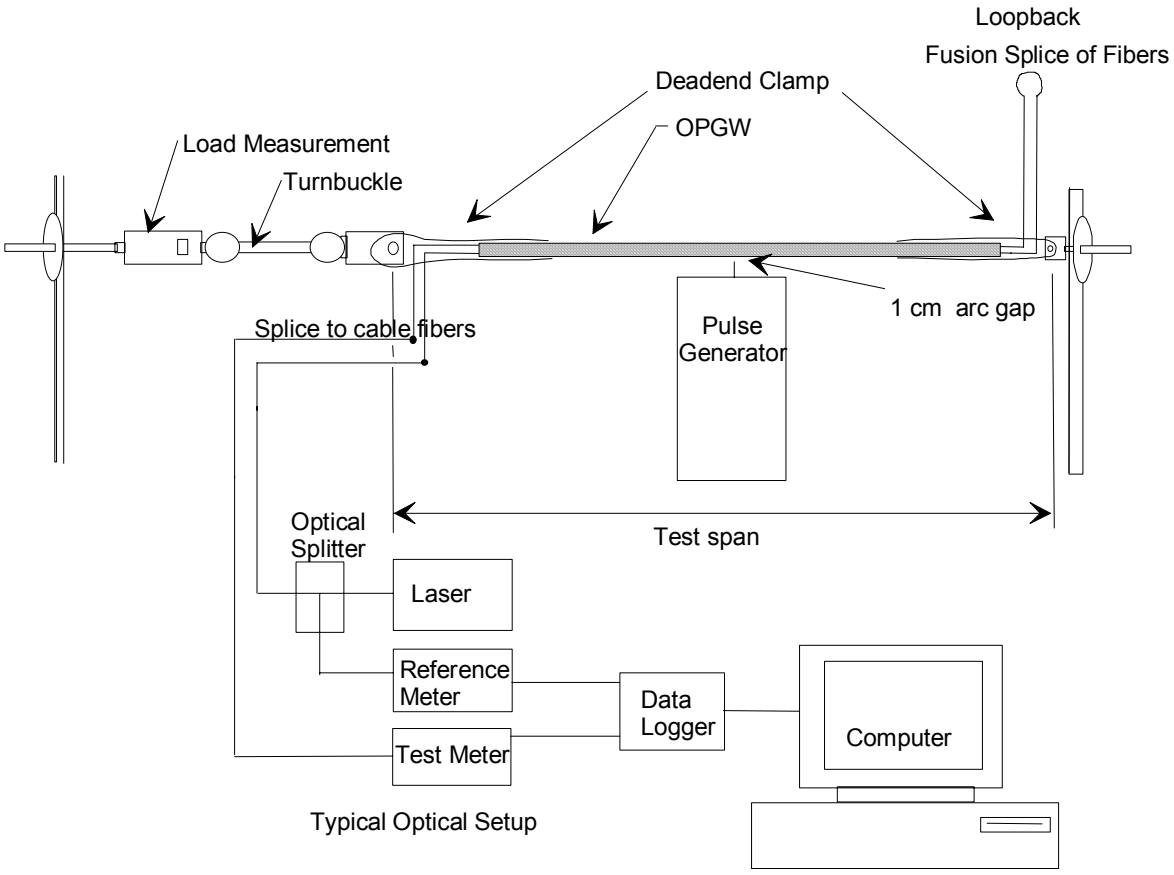

Figure 1 Set-up of Lightning Arc Test

APPENDIX A

Specifications for 477 kcmil and 795 kcmil ACCR and ACSR Conductors

3M Composite Conductor Specification

		ACCR		ACSR	
Conductor Physical Properties					
Designation		477-T16	795-T16	Hawk	Drake
Stranding		26/7	26/19	26/7	26/7
kcmils	kcmil	477	795	477	795
Diameter					
indiv Core	in	0.105	0.082	0.105	0.136
indiv Al	in	0.135	0.175	0.135	0.175
Core	in	0.320	0.410	0.316	0.408
Total Diameter	in	0.86	1.11	0.858	1.108
Area					
Al	in^2	0.374	0.624	0.374	0.625
Total Area	in^2	0.435	0.724	0.435	0.726
Weight	lbs/linear ft	0.539	0.896	0.657	1.093
Breaking Load					
Core	lbs	11,632	18,556		
Aluminum	lbs	7,844	12,578		
Complete Cable	000's lbs	19,476	31,134	19,500	31,500
Modulus					
Core	msi	31.4	31.4		
Aluminum	msi	8.0	7.4		
Complete Cable	msi	11.2	10.7		
Thermal Elongation					
Core	10^-6/F	3.5	3.5		
Aluminum	10^-6/F	12.8	12.8		
Complete Cable	10^-6/F	9.2	9.2		
Heat Capacity					
Core	W-sec/ft-C	13	22		
Aluminum	W-sec/ft-C	194	324		
Conductor Electrical Properties					
Resistance					
DC @ 20C	ohms/mile	0.1832	0.1100	0.1883	0.1129
AC @ 25C	ohms/mile	0.1875	0.1126	0.193	0.1166
AC @ 50C	ohms/mile	0.2061	0.1237	0.212	0.1278
AC @ 75C	ohms/mile	0.2247	0.1349		
Geometric Mean Radius	ft	0.0290	0.0375	0.0290	0.0375
Reactance (1 ft Spacing, 60hz)				0.430	0.399
Inductive Xa	ohms/mile	0.4296	0.3986	0.430	
Capacitive X'a	ohms/mile	0.0988	0.0912	0.0988	0.0912

APPENDIX B

Photographs and Current Waveforms from Lightning Arc Tests For 477 kcmil ACCR and ACSR Conductors

Test Dates:
September 12-13, 2002
November 1, 2002

ACCR 477 kcmil

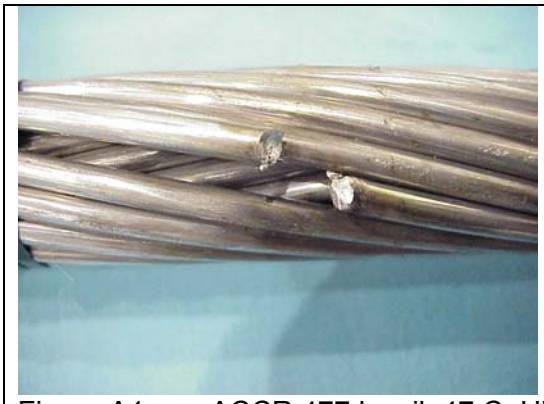

Figure A1aa – ACCR 477 kcmil, 47 C, Hit 11

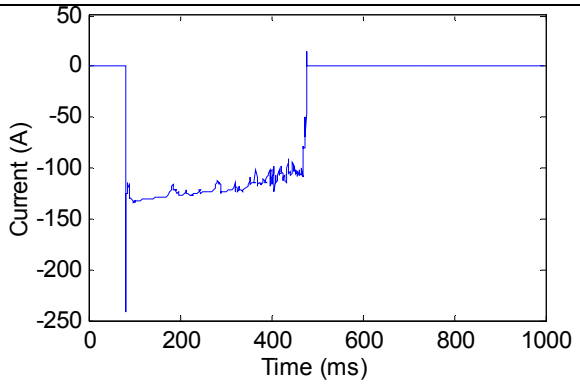

Figure A1ab – Current Waveform, 47 C, Hit 11

Figure A2aa – ACCR 477 kcmil, 50 C, Hit 10

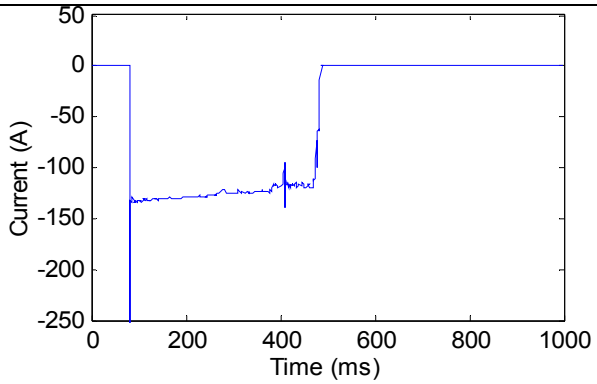

Figure A2ab – Current Waveform, 50 C, Hit 10

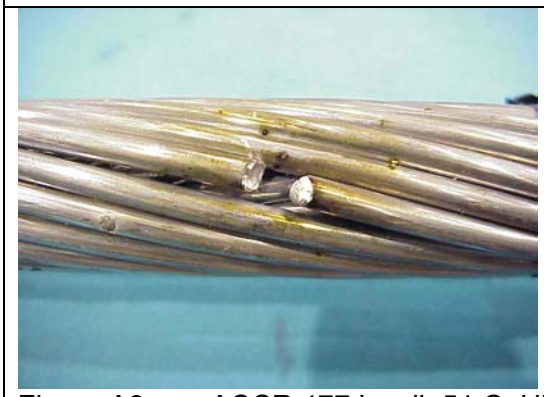

Figure A3aa – ACCR 477 kcmil, 51 C, Hit 9

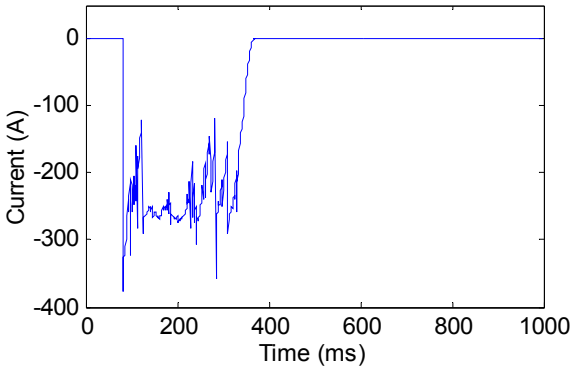

Figure A3ab – Current Waveform, 51 C, Hit 9

Figure A4aa – ACCR 477 kcmil, 64 C, Hit 4

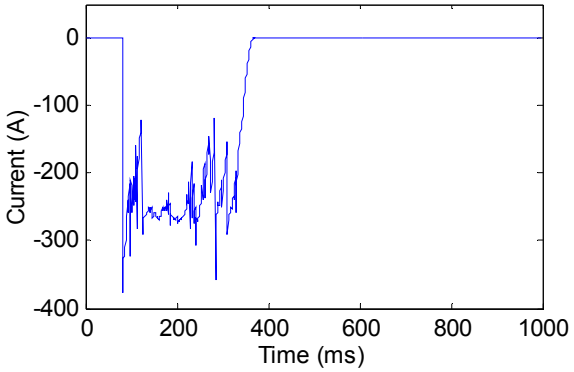

Figure A4ab – Current Waveform, 64 C, Hit 4

ACCR 477 kcmil

Figure A5aa – ACCR 477 kcmil, 90 C, Hit 1

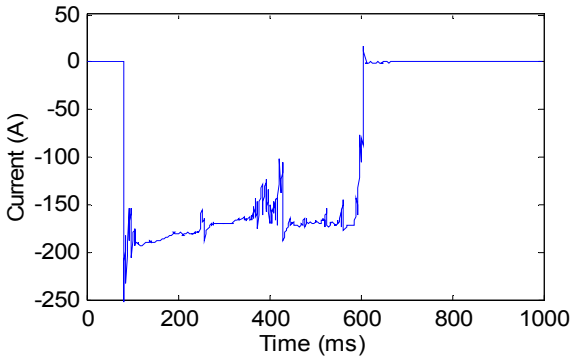

Figure A5ab – Current Waveform, 90 C, Hit 1

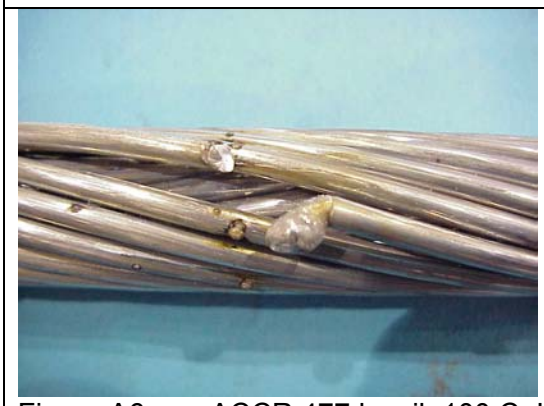

Figure A6aa – ACCR 477 kcmil, 100 C, Hit 3

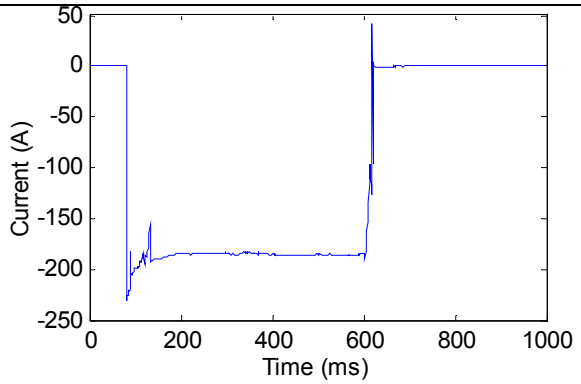

Figure A6ab – Current Waveform, 100 C, Hit 3

Figure A7aa – ACCR 477 kcmil, 102 C, Hit 2

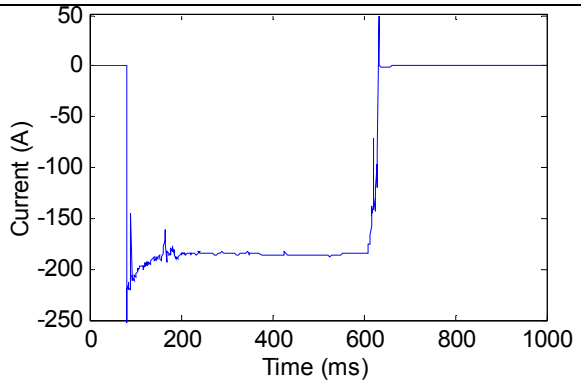

Figure A7ab – Current Waveform, 102 C, Hit 2

Figure A8aa – ACCR 477 kcmil, 182 C, Hit 6

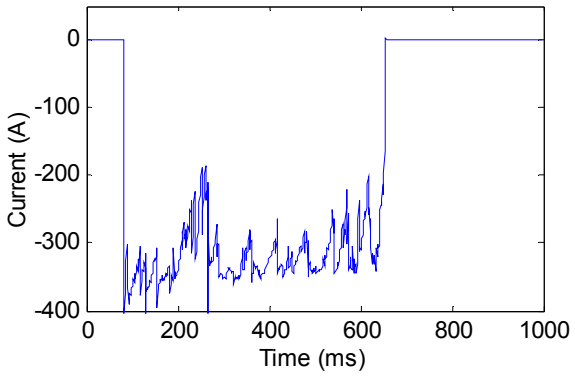

Figure A8ab – Current Waveform, 182 C, Hit 6

ACCR 477 kcmil

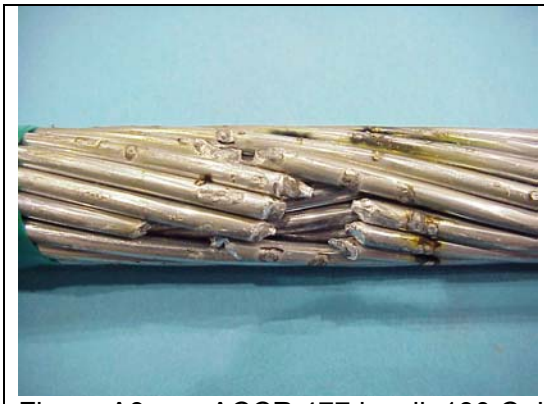

Figure A9aa – ACCR 477 kcmil, 190 C, Hit 7

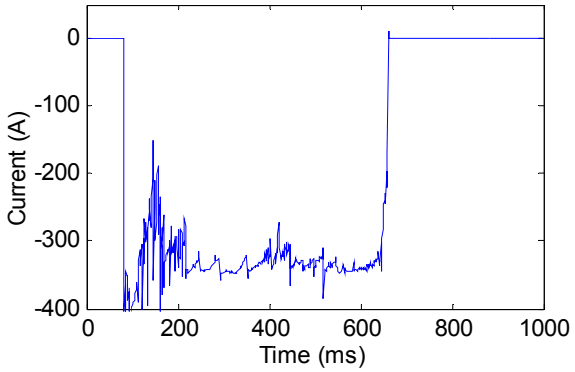

Figure A9ab – Current Waveform, 190 C, Hit 7

Figure A10aa – ACCR 477 kcmil, 191 C, Hit 5

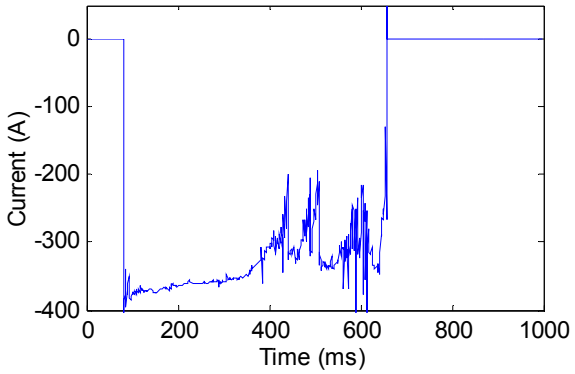

Figure A10ab – Current Waveform, 191 C, Hit 5

Figure A11aa – ACCR 477 kcmil, 192 C, Hit 8

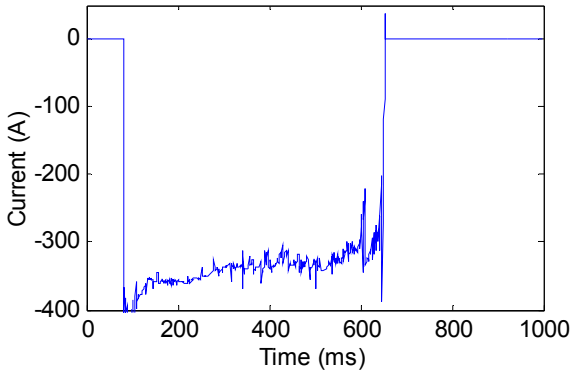

Figure A11ab – Current Waveform, 192 C, Hit 8

Figure A12aa – ACCR 477 kcmil, 208 C, Hit 12

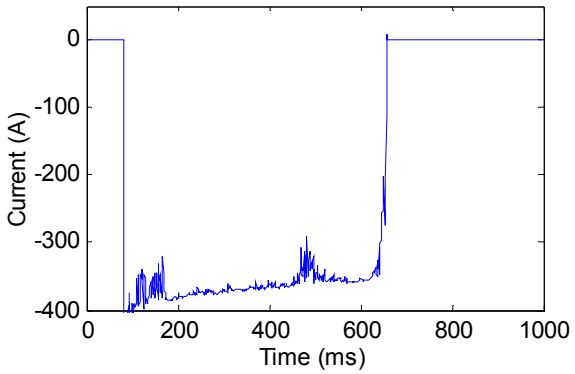

Figure A12ab - Current Waveform, 208 C, Hit 12

ACSR 477 kcmil

Figure A13aa – ACSR 477 kcmil, 48 C, Hit 14

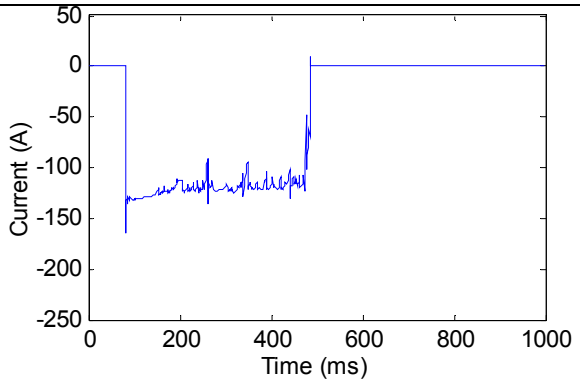

Figure A13ab – Current Waveform, 48 C, Hit 14

Figure A14aa – ACSR 477 kcmil, 52 C, Hit 13

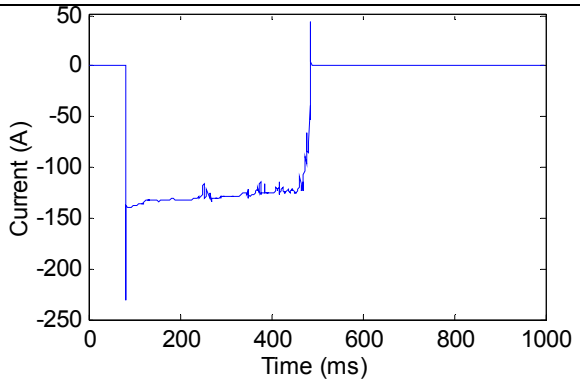

Figure A14ab – Current Waveform, 52 C, Hit 13

Figure A15aa – ACSR 477 kcmil, 53 C, Hit 15

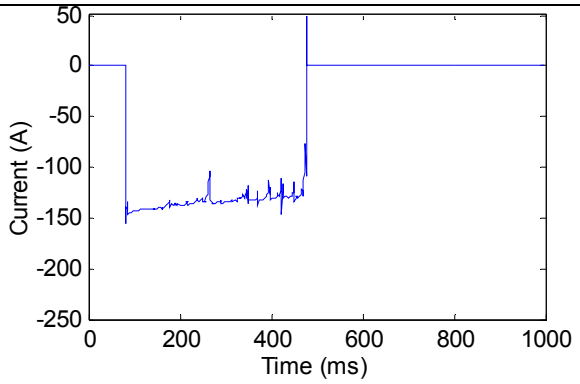

Figure A15ab – Current Waveform, 53 C, Hit 15

Figure A16aa – ACSR 477 kcmil, 102 C, Hit 20

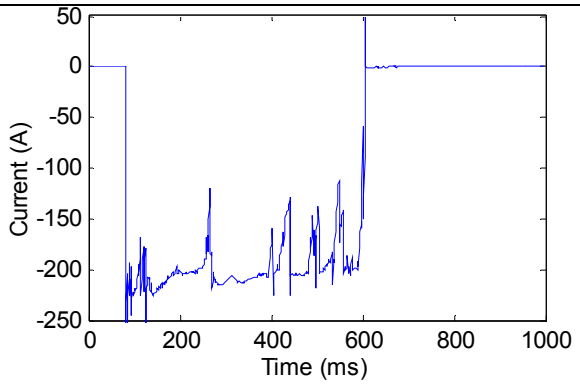

Figure A16ab - Current Waveform, 102 C, Hit 20

ACSR 477 kcmil

Figure A17aa – ACSR 477 kcmil, 109 C, Hit 21

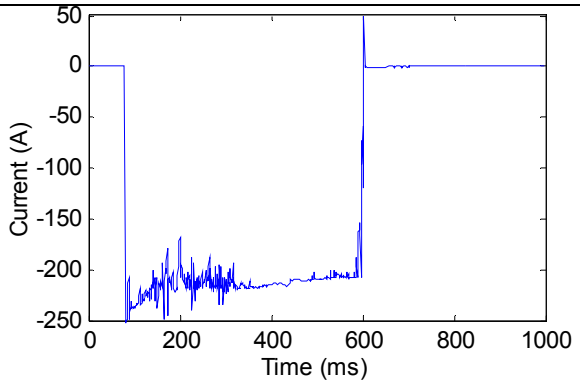

Figure A17ab – Current Waveform, 109 C, Hit 21

Figure A18aa – ACSR 477 kcmil, 110 C, Hit 19

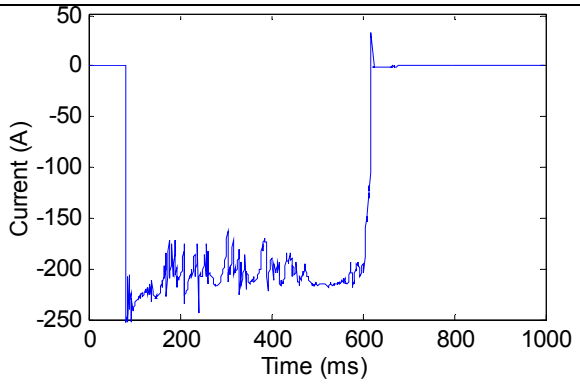

Figure A18ab – Current Waveform, 110 C, Hit 19

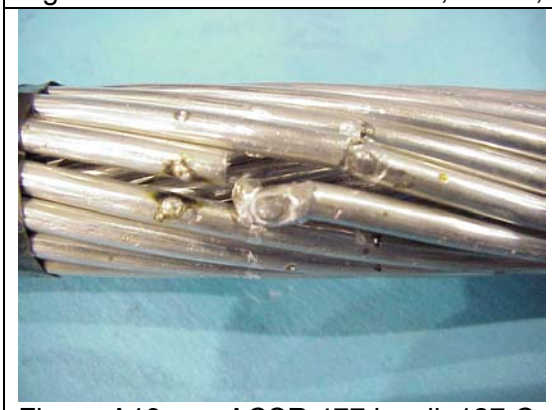

Figure A19aa – ACSR 477 kcmil, 127 C, Hit 16

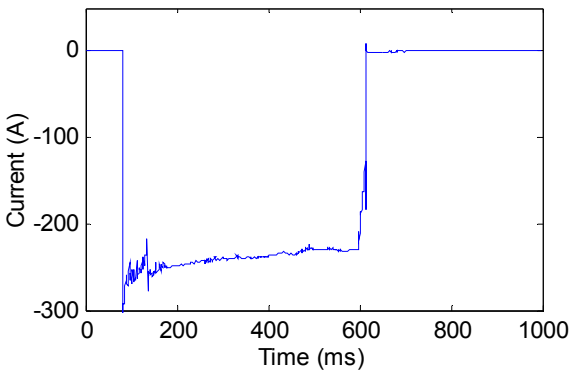

Figure A19ab – Current Waveform, 127 C, Hit 16

Figure A20aa – ACSR 477 kcmil, 183 C, Hit 17

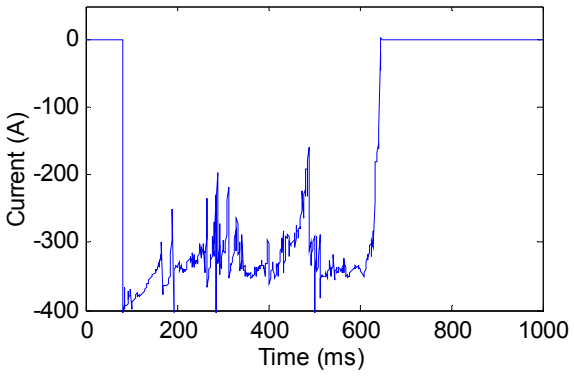

Figure A20ab - Current Waveform, 183 C, Hit 17

ACSR 477 kcmil

Figure A21aa – ACSR 477 kcmil, 189 C, Hit 23

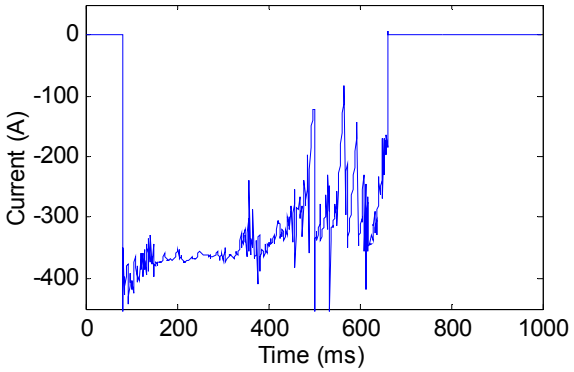

Figure A21ab – Current Waveform, 189 C, Hit 23

Figure A22aa – ACSR 477 kcmil, 198 C, Hit 18

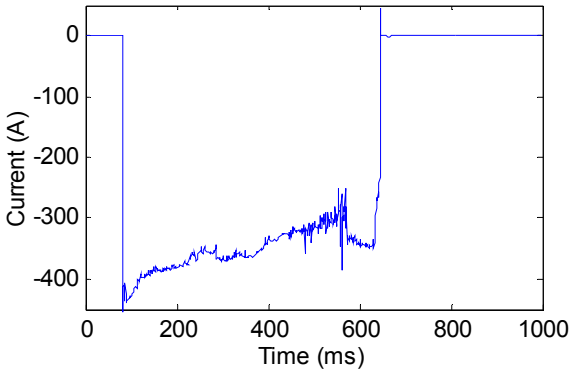

Figure A22ab – Current Waveform, 198 C, Hit 18

Figure A23aa – ACSR 477 kcmil, 198 C, Hit 22

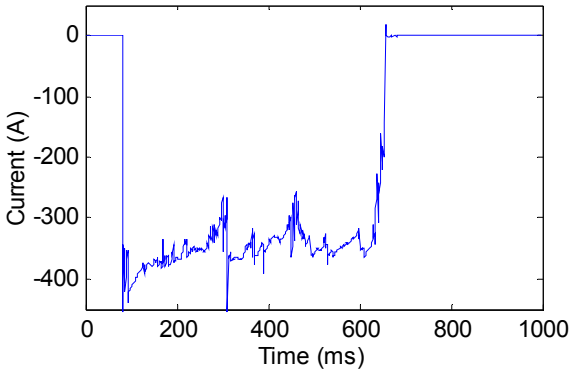

Figure A23ab – Current Waveform, 198 C, Hit 22

Figure A24aa – ACSR 477 kcmil, 199 C, Hit 24

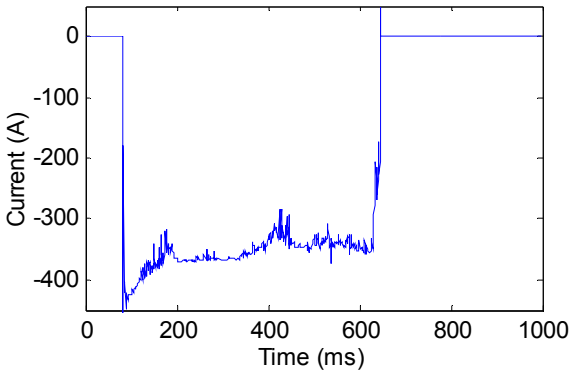

Figure A24ab - Current Waveform, 199 C, Hit 24

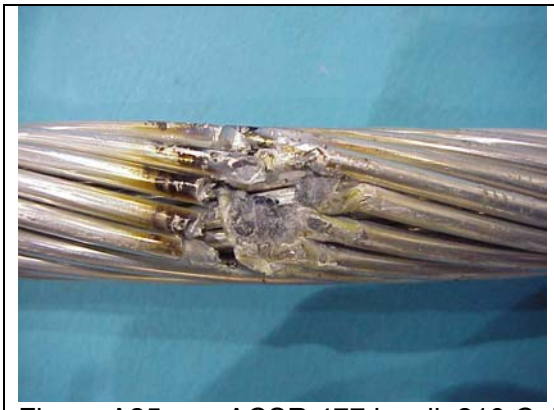

Figure A25aa – ACSR 477 kcmil, 210 C, Hit 16

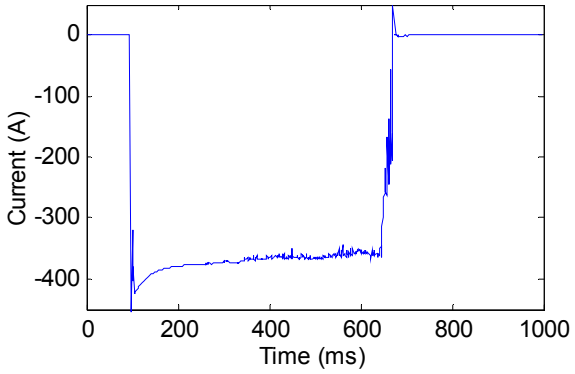

Figure A25ab – Current Waveform, 210 C, Hit 16

Figure A25aa – ACSR 477 kcmil, 214 C, Hit 15

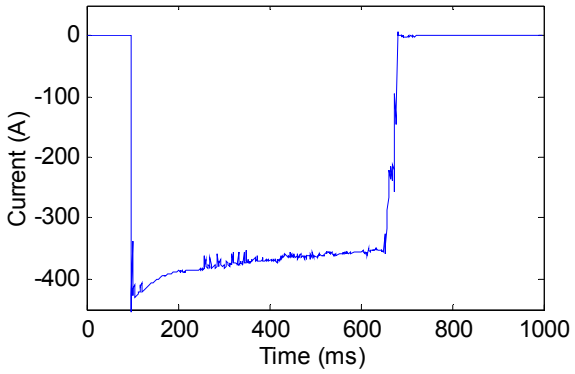

Figure A25ab – Current Waveform, 214 C, Hit 15

Figure A26aa – ACSR 477 kcmil, 220 C, Hit 14

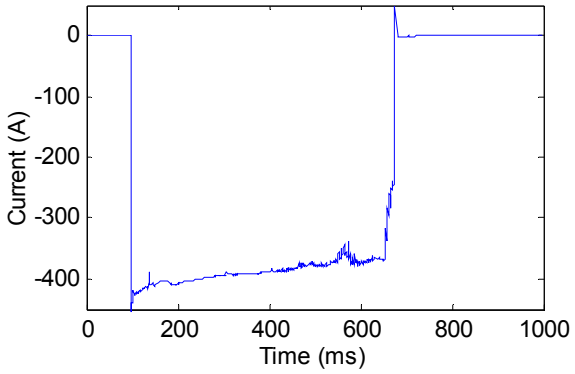

Figure A26ab - Current Waveform, 220 C, Hit 14

APPENDIX C

Photographs and Current Waveforms from Lightning Arc Tests
For 795 kcmil ACCR and ACSR Conductors

Test Dates:
September 20, 2002
October 30-31, 2002
November 1, 2002

ACCR 795 kcmil

Figure B1aa – ACCR 795 kcmil, 49 C, Hit 1

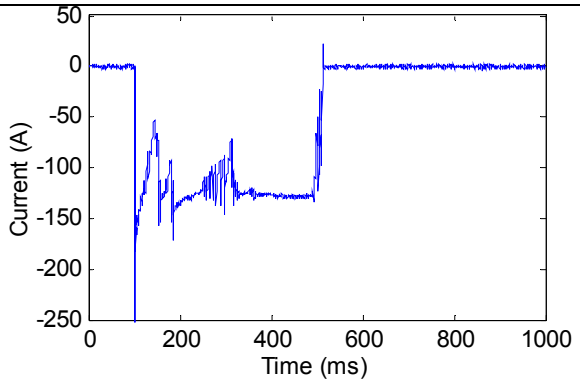

Figure B1ab – Current Waveform, 49 C, Hit 1

Figure B2aa – ACCR 795 kcmil, 51 C, Hit 2

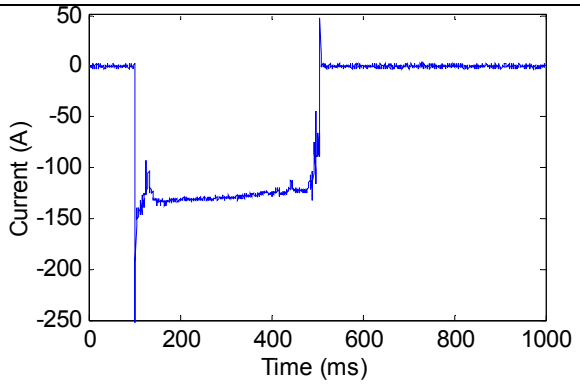

Figure B2ab – Current Waveform, 51 C, Hit 2

Figure B3aa – ACCR 795 kcmil, 52 C, Hit 4

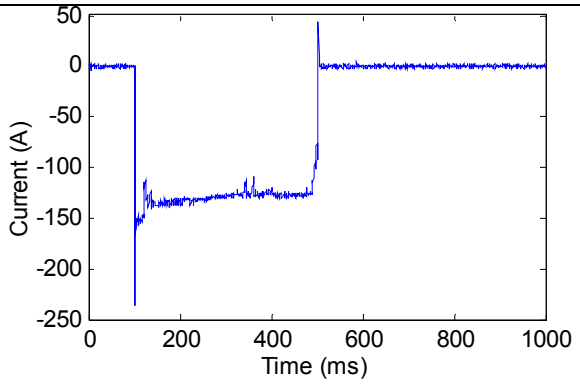

Figure B3ab – Current Waveform, 52 C, Hit 4

Figure B4aa – ACCR 795 kcmil, 54 C, Hit 3

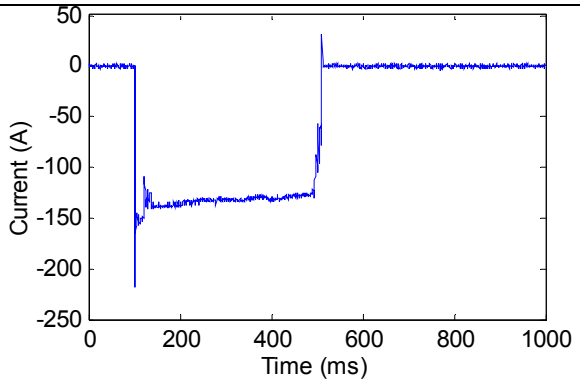

Figure B4ab – Current Waveform, 54 C, Hit 3

ACCR 795 kcmil

Figure B4aa – ACCR 795 kcmil, 108 C, Hit 7

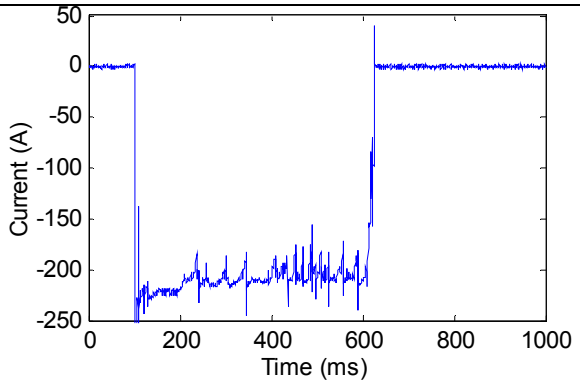

Figure B4ab – Current Waveform, 108 C, Hit 7

Figure B5aa – ACCR 795 kcmil, 109 C, Hit 6

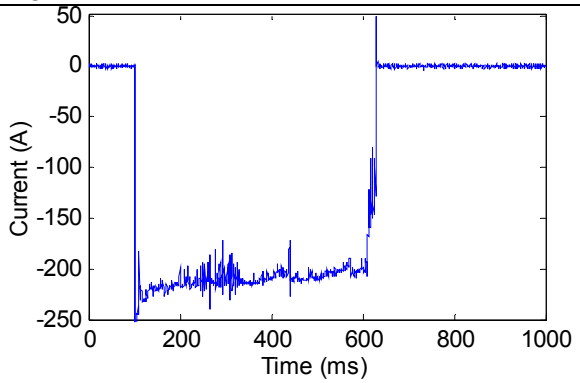

Figure B5ab – Current Waveform, 109 C, Hit 6

Figure B6aa – ACCR 795 kcmil, 110 C, Hit 5

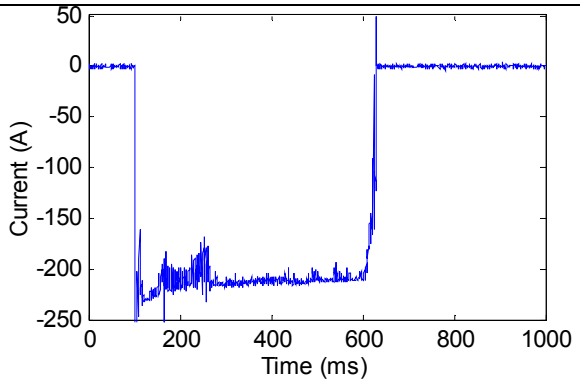

Figure B6ab – Current Waveform, 110 C, Hit 5

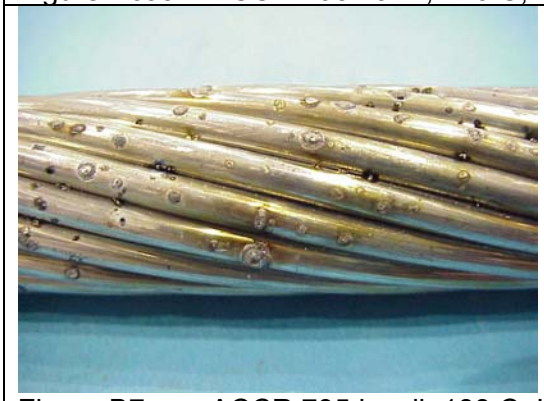

Figure B7aa – ACCR 795 kcmil, 188 C, Hit 10

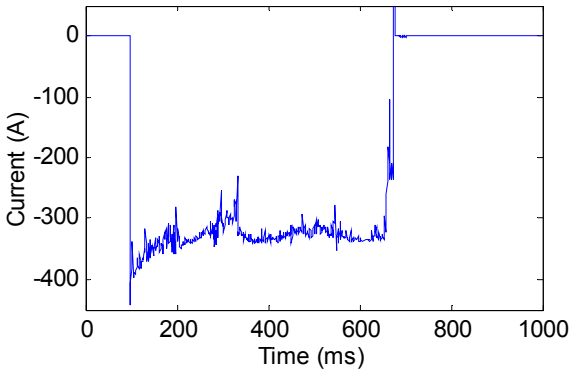

Figure B7ab – Current Waveform, 188 C, Hit 10

ACCR 795 kcmil

Figure B8aa – ACCR 795 kcmil, 190 C, Hit 18

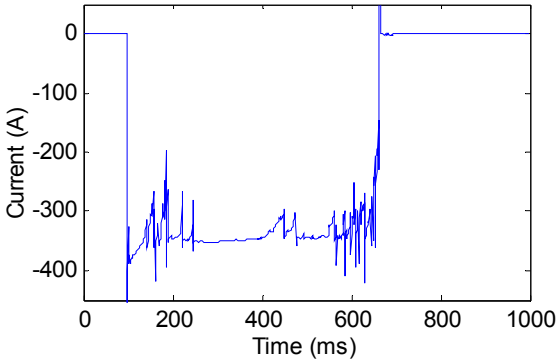

Figure B8ab – Current Waveform, 190 C, Hit 18

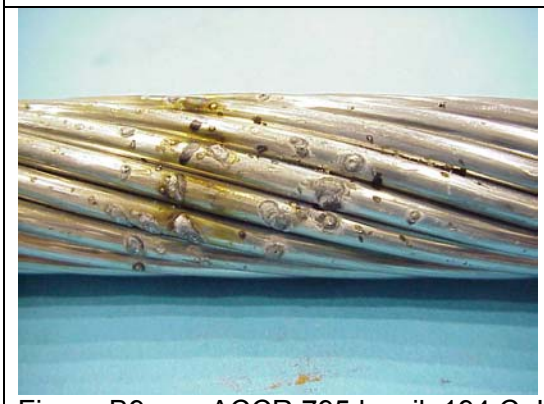

Figure B9aa – ACCR 795 kcmil, 194 C, Hit 12

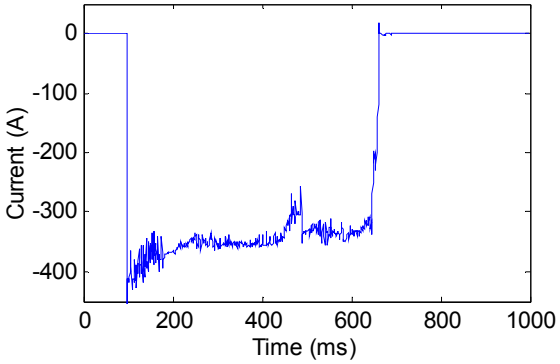

Figure B9ab – Current Waveform, 194 C, Hit 12

Figure B10aa – ACCR 795 kcmil, 196 C, Hit 9

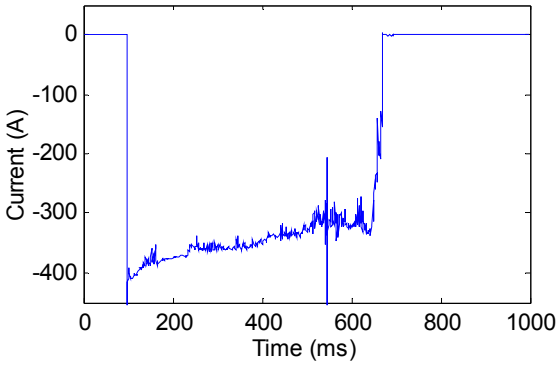

Figure B10ab – Current Waveform, 196 C, Hit 9

Figure B11aa – ACCR 795 kcmil, 200 C, Hit 17

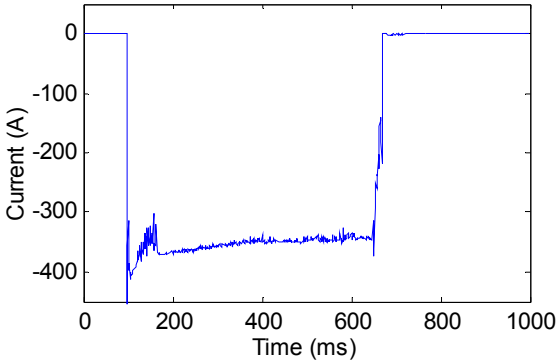

Figure B11ab – Current Waveform, 200 C, Hit 17

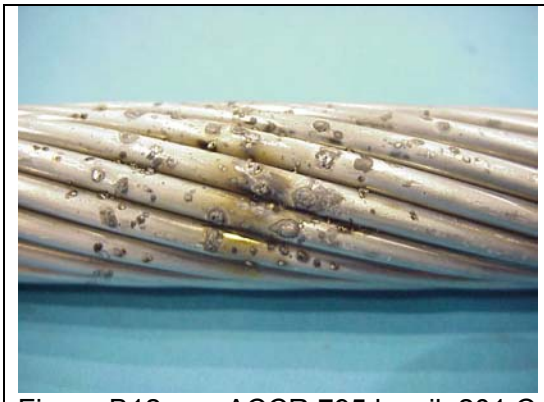

Figure B12aa – ACCR 795 kcmil, 201 C, Hit 11

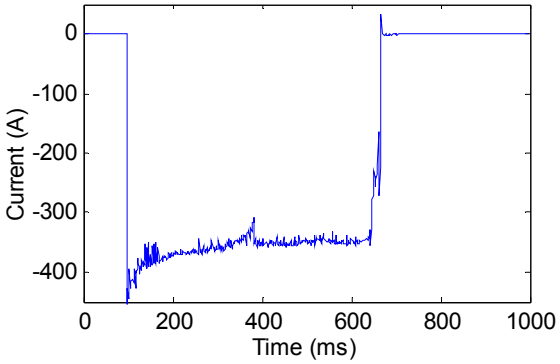

Figure B12ab – Current Waveform, 201 C, Hit 11

Figure B13aa – ACCR 795 kcmil, 201 C, Hit 13

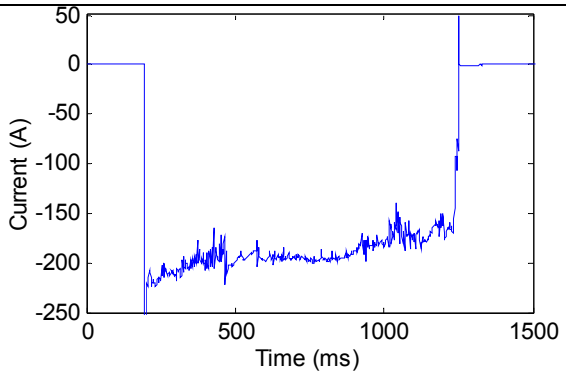

Figure B13ab – Current Waveform, 201 C, Hit 13

ACSR 795 kcmil

Figure B14aa – ACSR 795 kcmil, 49 C, Hit 4

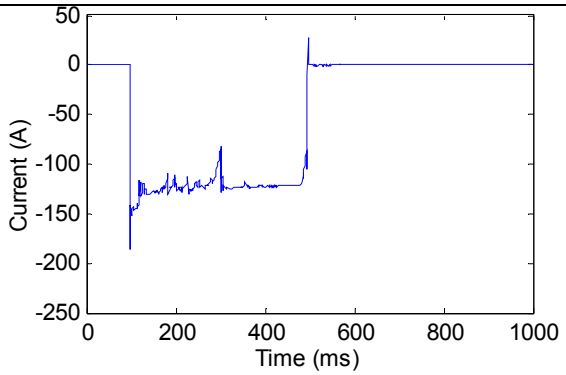

Figure B14aa - Current Waveform, 49 C, Hit 4

Figure B15aa – ACSR 795 kcmil, 49 C, Hit 5

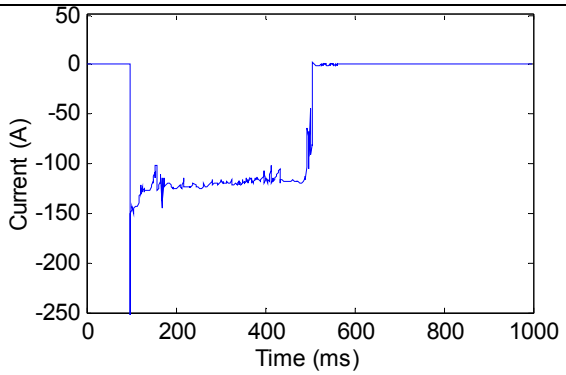

Figure B15ab – Current Waveform, 49 C, Hit 5

Figure B16aa – ACSR 795 kcmil, 50 C, Hit 3

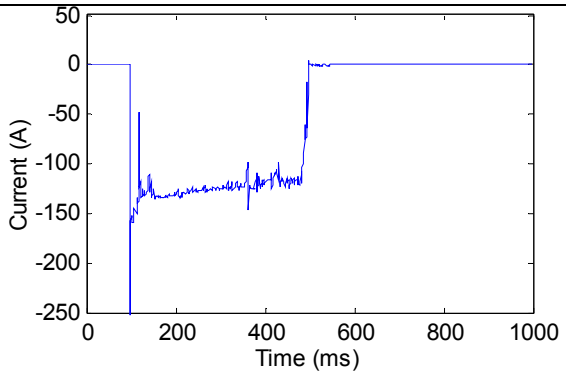

Figure B16ab – Current Waveform, 50 C, Hit 3

Figure B17aa – ACSR 795 kcmil, 98 C, Hit 2

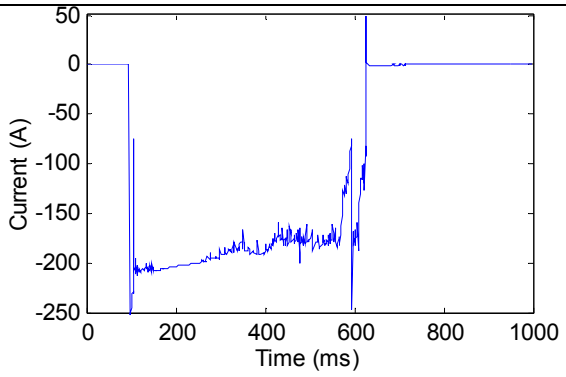

Figure B17ab – Current Waveform, 98 C, Hit 2

ACSR 795 kcmil

Figure B18aa – ACSR 795 kcmil, 107 C, Hit 1

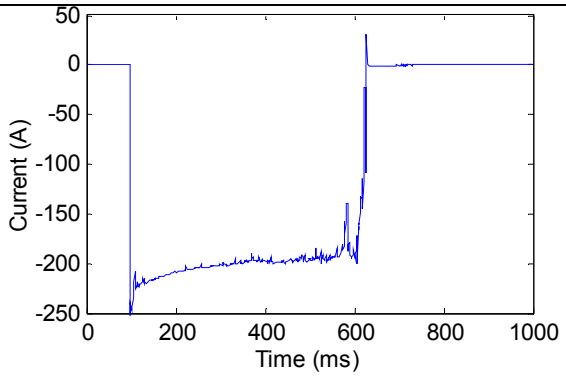

Figure B18aa - Current Waveform, 107 C, Hit 1

Figure B19aa – ACSR 795 kcmil, 108 C, Hit 0

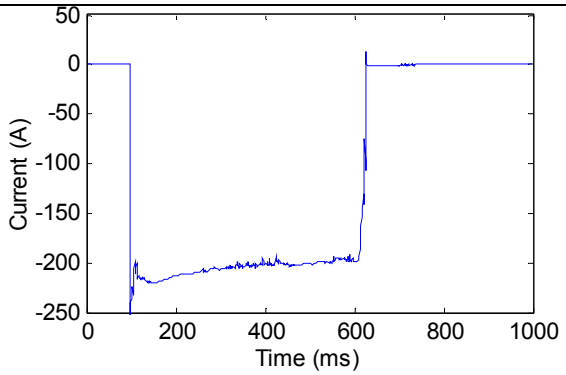

Figure B19ab – Current Waveform, 108 C, Hit 0

Figure B20aa – ACSR 795 kcmil, 189 C, Hit 7

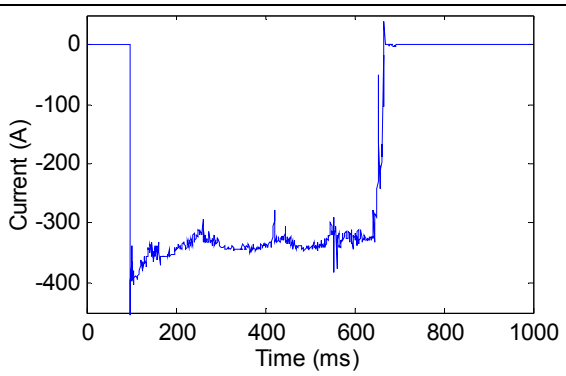

Figure B20ab – Current Waveform, 189 C, Hit 7

Figure B21aa – ACSR 795 kcmil, 200 C, Hit 8

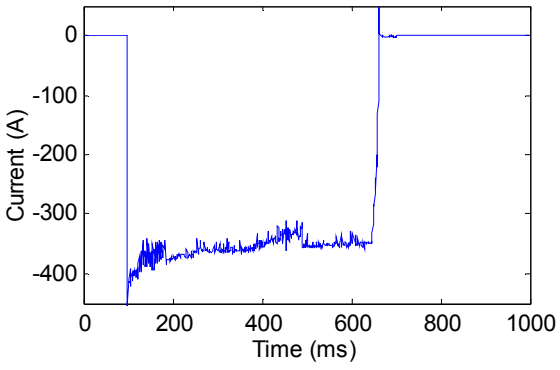

Figure B21ab – Current Waveform, 200 C, Hit 8

Figure B22aa – ACSR 795 kcmil, 204 C, Hit 6

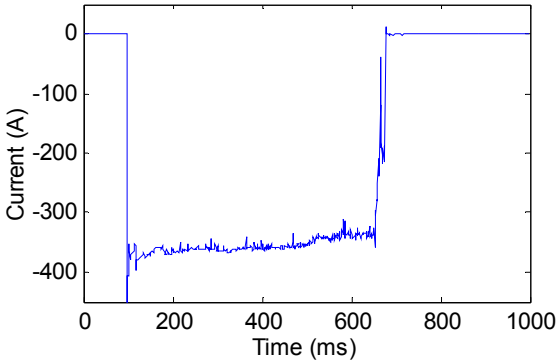

Figure B22aa Current Waveform, 204 C, Hit 6

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