KINECTRICS

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KINECTRICS NORTH AMERICA INC. REPORT
FOR 3M COMPANY TO TEST SHORT CIRCUIT BEHAVIOUR OF 795-T16 ACCR
IN A TWO-CONDUCTOR BUNDLE CONFIGURATION USING PLP RIGID SPACER

Kinectrics North America Inc. Report No.: K-422235-RC-0001-R00
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3M Company contracted with Kinectrics North America Inc. under PO#USMMMR95N47 to conduct Short Circuit Tests on their 795-T16 Aluminum Conductor Composite Reinforced (ACCR) Conductor. The tests were performed on December 12-13, 2006 by Kinectrics North America Inc. personnel at 800 Kipling Avenue, Toronto, Ontario, M8Z 6C4, Canada.

TEST OBJECTIVE

The objective of the tests were to observe the dynamic mechanical behaviour of the 795-T16 ACCR conductor and a Preformed Line Products rigid spacer configured in a 2-conductor bundle when subjected to short circuit currents. There was concern that the high degree of bending that would be imposed on the conductors around the spacer during the collapse of the bundle during a short circuit occurrence could cause conductor damage. The tests were performed to determine if any damage was inflicted to the conductor and/or to the spacer due to application of short circuit current.

The tests were performed efficiently because a device called EMAT (***E***lectro-***M***agneto ***A***coustic ***T***ransformer) was used to detect any broken inner core wires beneath the outer aluminum alloy wires. The device made it unnecessary to dissect the conductors after each short-circuit shot, (although dissection of the conductors at the end of testing was performed to verify the EMAT conclusions). The EMAT device was operated by Dr. Rahmat Soureshi and Dr. Sun Lim of Innovative Technology Frontiers of Denver, CO. The principle of operation and other details of this device are not discussed in this report.

TEST CONDUCTOR AND SPACER

The 795-T16 ACCR conductor has an aluminum alloy circular area of 795 kcmils (400 mm^2). It is comprised of 26 round aluminum alloy wires stranded over 19 round composite core wires. The nominal outside diameter of the conductor is 1.108 inches (28.1 mm) and it has a rated tensile strength of 31,134 lbf (14,122 kgf). The data sheet for the 3M 795-T16 ACCR conductor used in the short circuit tests is contained in Appendix A.

A Preformed Line Products (PLP) THERMOLIGN® Rigid Twin Spacer with 6 Rods per conductor was used in the tests. The spacer had a centerline to centerline spacing of 18 inches (457 mm). The PLP spacer is shown installed on the ACCR conductors in Figure 2.

TEST SET-UP

The Short Circuit Tests were carried out at Kinectrics' Indoor High Current Facility.

Two(2) ACCR conductor samples, each about 42 ft (12.8 m) long, were tensioned in a horizontal configuration about 5 ft (1.5 m) above the ground. Rigid bars were used to space the conductors 18 inches (457 mm) apart at the deadends. The conductors were terminated and tensioned using Preformed Line Products DG grips. The cables of the bus from the current transformer were connected to the conductors using grounding clamps to complete the circuit. A turnbuckle was used to tension the conductors and a strain gauge load cell mounted at the east end was used to measure the tension in the conductor bundle. The initial tension of each conductor was about 1000 lbf (454 kgf) or 3.2% of the RTS of the ACCR conductor. The total tension for both conductors was 2000 lbf (908 kgf). The east and west deadend arrangements are shown in Figures 1a and 1b, respectively. The choice of tension level was dictated by the need to force the bundle into a condition of collapse. Lower tensions are required to do this on the short experimental span, in order to set up the most severe bending conditions at the spacer clamping points.

The PLP spacer was installed as per manufacturers' instructions between the conductors midway between the conductor dead-ends. The spacer installed on the conductor bundle is shown in Figure 2.

The short circuit currents were provided by a high level current transformer. For each short circuit application, or "shot", a high-speed data acquisition system recorded the short circuit current and tension at 5000 samples/second.

TEST PROCEDURE

The PLP THERMOLIGN rigid spacer with 6 rods was tested on December 12-13, 2006 using new, unused conductor samples.

After each shot, the conductors were visually inspected and also inspected with the EMAT device (Figure 3) to determine if any outer aluminum or inner core wires were damaged. If none were found, then the testing continued with the same conductors. After each shot, the EMAT device was alternately mounted on each of the conductors. It was positioned outboard of the stiffening rods of the spacer, pointing towards the spacer clamp. The EMAT device interrogates a conductor length of approximately 5 feet (1.5 m), and includes all the conductor that lies under the stiffening rods and the spacer clamp. Thus in each examination, all four positions of the bundle outboard of the stiffening rods were examined (both conductors and both sides of the spacer). If broken or damaged wires were detected, then new, unused conductor samples would have to be prepared.

The short circuit current and duration of each shot were adjusted to produce the desired energy imparted to the conductor. Each shot was applied with the maximum possible asymmetry (ie, maximum DC offset).

Analytical Study

In addition to the tests, an analytical study using a computer model was also performed. The computer model was originally developed for calculating short circuit forces in stations. Since the bundle collapse phenomenon is the same on transmission lines, the model is also applicable.

The main objective of the analytical study was to compare the calculated deformation, or bending of the conductors around the spacer of a typical field configuration to the observed deformation, or bending, during the laboratory tests. The degree of deformation is determined by the last point of conductor contact from the spacer. If the calculated last point of contact to the spacer during a short circuit event in the field was greater than or equal to what was observed in the laboratory tests then it could be concluded that the bundle response in the laboratory tests would be as, or more severe than what would be expected in real field configurations. The bending shape of the conductors at the spacer during the short circuit would also be as, or more severe than what would be expected in real field configurations. If the conductors survived the laboratory tests without damage then they could also be expected to survive a short circuit in the field without damage.

The input parameters for the computer model are shown in Table 1.

Table 1: Input Parameters for the Bundle Collapse Computer Program

Parameter	Value
Span Length	300 ft, 500 ft (90, 150m)
Number of Subspans	2
Subspan Length	150 ft, 250 ft (46, 76 m)
Conductor Diameter	1.108 ins (28.1 mm)
Conductor Weight	0.896 lbf/ft (1.34 kg/m)
Conductor Spacing	18 in (457 mm)
Conductor Modulus of Elasticity	$1.16 \cdot 10^7$ psi (80.0 GPa)
Horizontal Stiffness of dead-end	10^8 (infinite)
Vertical Stiffness of dead-end	10^8 (infinite)
Initial Static Phase Tension	variable
Conductor Sag at Center of Span	variable
Short Circuit Current	variable

TEST RESULTS

A total of nine (9) shots (Test Nos 06-4395 to 06-4401 and 06-4405 to 06-4406) were performed using the PLP THERMOLIGN rigid spacer with six (6) rods. The short circuit data for the nine(9) shots (Tests 06-4395 to 06-4401 and Tests 06-4405 and 06-4406) are shown in Figures 4a-4i. The spacer and conductor geometry before the shot and at maximum collapse during each shot are shown in Figures 5a-5d.

After each shot, the conductors were inspected visually and with the EMAT device for any signs of damage. The conductors did not experience any broken aluminum wires or core wires. The spacer and rods also were not damaged. Subsequent dissection of the conductor into individual constituent wires at the end of testing confirmed the EMAT conclusions of no damage. Furthermore, tensile testing of the dissected core wires was performed at the 3M Company, and exhibited full strength retention.

The following table summarizes the key test data and the key observations made by the EMAT device for the PLP spacer. The break in test numbers between 06-4401 and 06-4405 was for testing of a different type of spacer.

Test No	Initial Phase Tension (lbf)	Short Circuit Current (kA rms, (kA pk))	Duration (Cycles)	I^2t (kA^2sec)	Peak Phase Tension (lbf)	Observations
06-4395	2000	8.8 (17.3)	8.6	11.1	-	No damage to Al or core wires or to spacer
06-4396	2000	17.7 (36.2)	8.6	44.9	-	No damage to Al or core wires or to spacer
06-4397	2000	30.7 (63.1)	8.6	135.1	-	No damage to Al or core wires or to spacer
06-4398	2000	30.7 (63.1)	8.6	135.1	-	No damage to Al or core wires or to spacer
06-4399	2000	47.5 (100.3)	8.6	323.3	7500	No damage to Al or core wires or to spacer
06-4400	2000	54.4 (117.7)	15.6	743.2	8000	No damage to Al or core wires or to spacer
06-4401	1500	53.3 (117.1)	15.6	738.7	9000	No damage to Al or core wires or to spacer
06-4405	2000	43.0 (94.0)	15.6	482.1	10,400	No damage to Al or core wires or to spacer
06-4406	2000	51.0 (113.8)	15.6	676.3	10,200	Insulator failed, No broken Al or core wires

The individual data sheets for each test are shown in Figures 4a to 4i. The current waveform of the short circuit waveform is shown at the top of each figure. The output from the load cell in pounds is shown at the bottom. It was not possible to obtain tension traces free of 60 Hz electrical noise while the short circuit current was flowing through the conductor. Shots #1-#4 (06-4395 to 06-4398), Figures 4a-4d, do not provide any interpretable tension data, indeed figures 4c-4d show a loss of the tension signal. For the remaining shots, the only interpretable data occurs after the short circuit current had cleared. Two shots were run using extra shielding for noise reduction and a more reliable tension signal during the shot was observed (Figure 4h, 4i). For Shot #8 (06-4405), Figure 4h, the peak tension is estimated at 10,400 lbf (4,727 kgf). For shot #9 (064406), Figure 4i, the tension trace indicates the peak was 10,200 (4,636 kgf) at which point the insulator failed.

Figures 5a-5d show images taken from a high speed camera that show the most severe case of bundle collapse for each short-circuit condition. The last point of contact is estimated to be approximately 7 ft (84 inches) (2.1m) from the photograph taken from Test 06-4406 at 51 kA (Figure 5d). This test caused the most severe bending of the conductors around spacer and produced the minimum distance between the last point of contact of the conductors and the spacer.

During Test No. 06-4406, the insulator supporting the conductors at the east deadend location failed and the bundle fell to the ground. This marked the end of the testing, although the intended maximum target of 50kA had been reached.

EMAT Inspections

A separate report was prepared by Dr. Soureshi to document the results of the EMAT inspections. The report in its' original form is contained in Appendix B

Analytical Study

The results of the analytical study are contained in the graph in Figure 6. The last point of contact of 84 inches as estimated from the test is also shown by the dashed line on the graph. It can be seen that for short circuits in the range of 40 kA to 50 kA the last point of contact observed in the laboratory tests is approximately the same as the calculated value for typical field conditions. This provides confidence that the laboratory tests produced realistic conductor deformations for these short circuit currents. Last point of contact and conductor tension calculations were performed for the actual experimental span and for realistic field spans, and these are shown in Appendix C.

CONCLUSIONS

1. The analytical study demonstrated that the configuration of the tests performed at Kinectrics adequately simulated the bending of the conductor around the spacer that would be expected in field-scale sub-spans.
2. There was no damage to any of the outer aluminum alloy wires or to any of the composite core wires during any of the short circuit bundle collapse tests performed in the laboratory when using the PLP THERMOLIGN Rigid Spacer.

ACKNOWLEDGEMENTS

The authors wish to acknowledge the valuable contributions of Dr. Rahmat Shoureshi and Dr. Sun Lim of Innovative Frontier Technologies and the efforts of Claude Maurice of the High Current Laboratory at Kinectrics.

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DISCLAIMER

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 November 29, 2006.

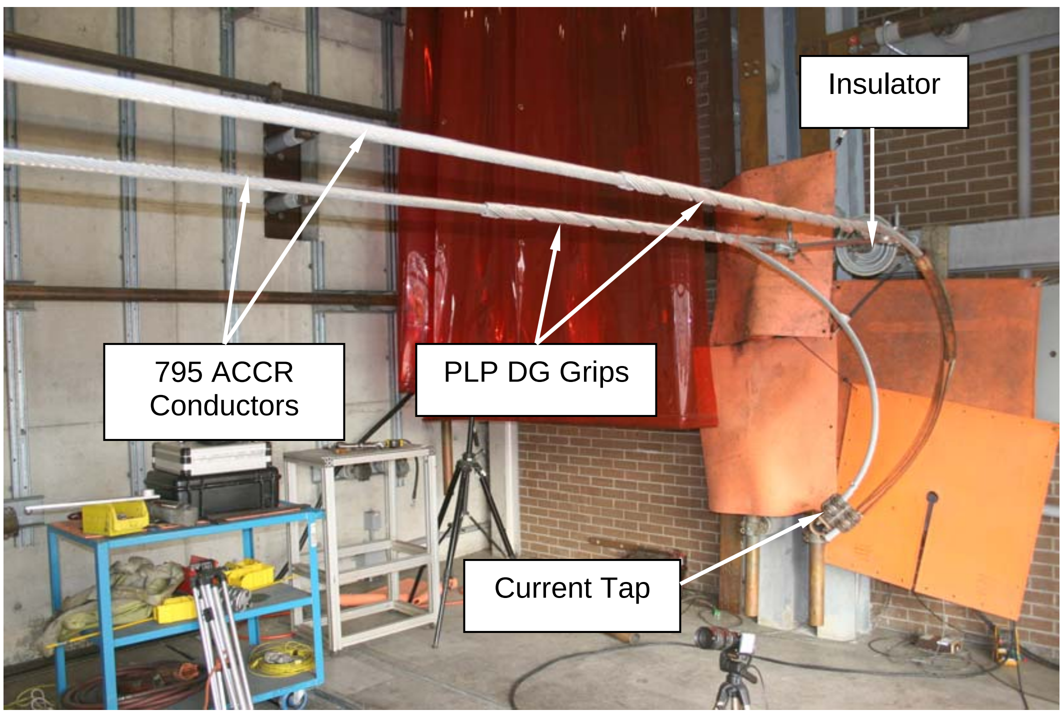


Figure 1a: East Dead-end Arrangement

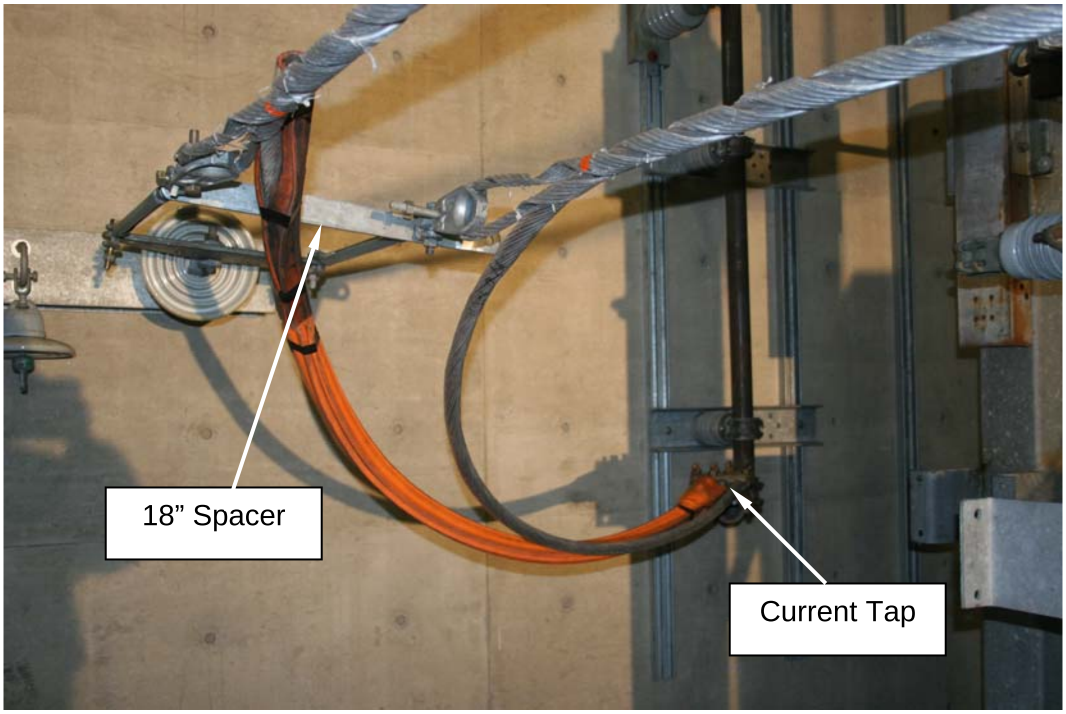


Figure 1b: West Dead-end Arrangement

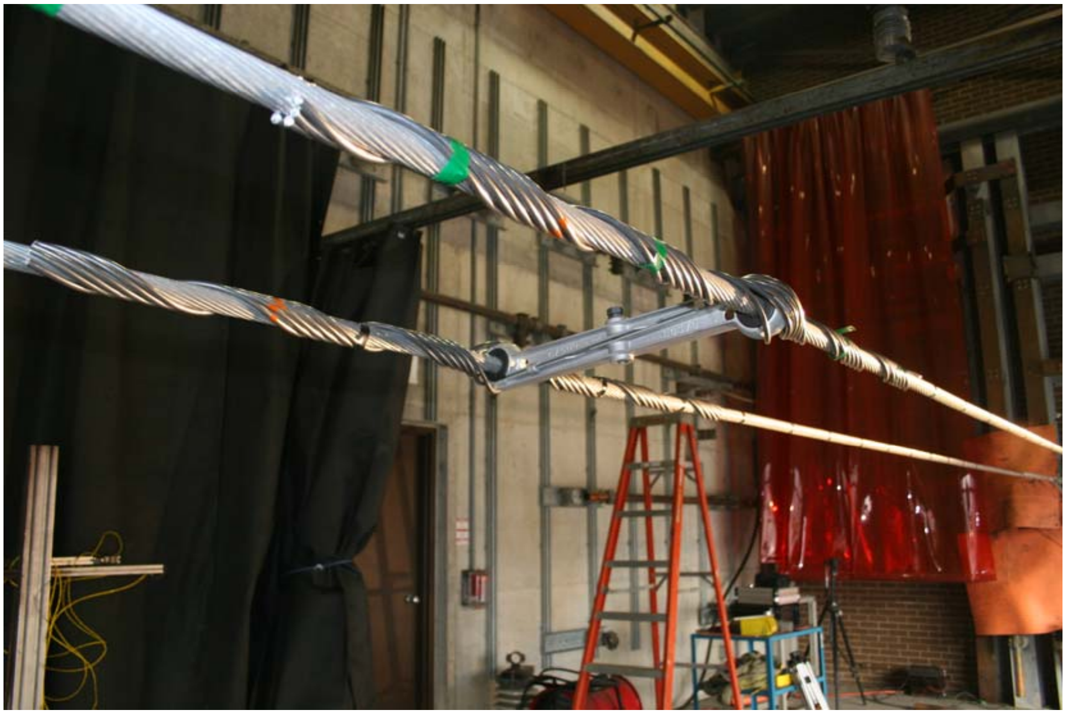


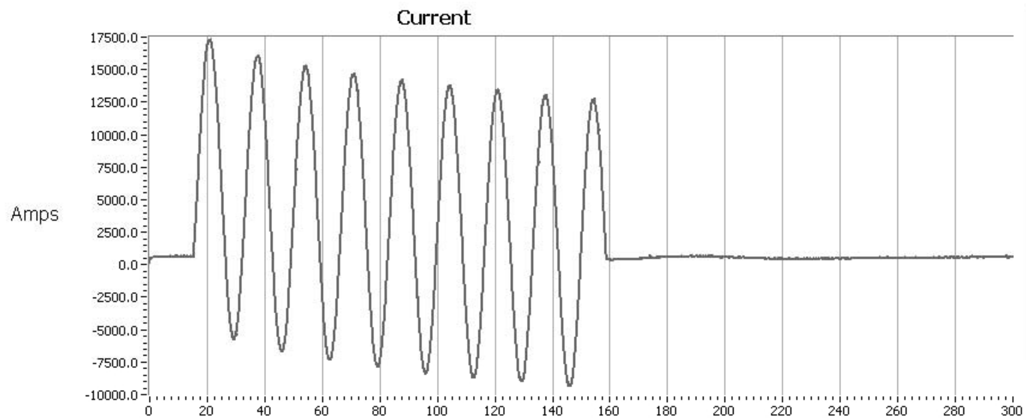
Figure 2: PLP Rigid Spacer and Rods Installed at Mid-Span on 2 x 795 ACCR Conductors

Figure 3a: EMAT Device (Open Position for Installing on Conductor)

Figure 3b: EMAT Device (Closed Position for Taking Measurement)

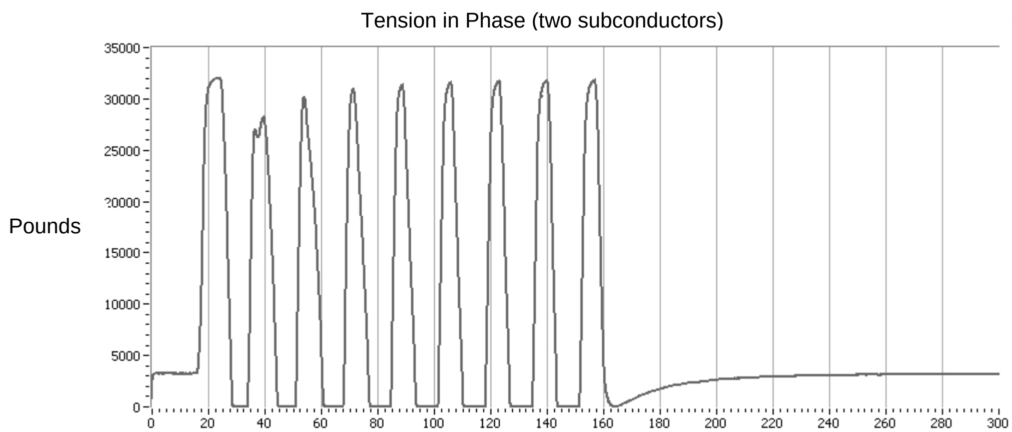
December 12, 2006	High Current Test Laboratory Kinectrics Inc. Test Sheet	KINECTRICS
Test # 06-4395		
WO#:		

Client:	Description:
3M Company	**Short circuit on 2 ACCR conductor Bundle** **Spacer: THERMOLIGN twin Spacer, with 6 rods** **Shot #1**



Rms (A) = 8781.5 Duration of fault in cycles = 8.6 Time (ms)

Peak, I pk (A) = 17295.3 I^2t (A^2s) = 11.1E+6

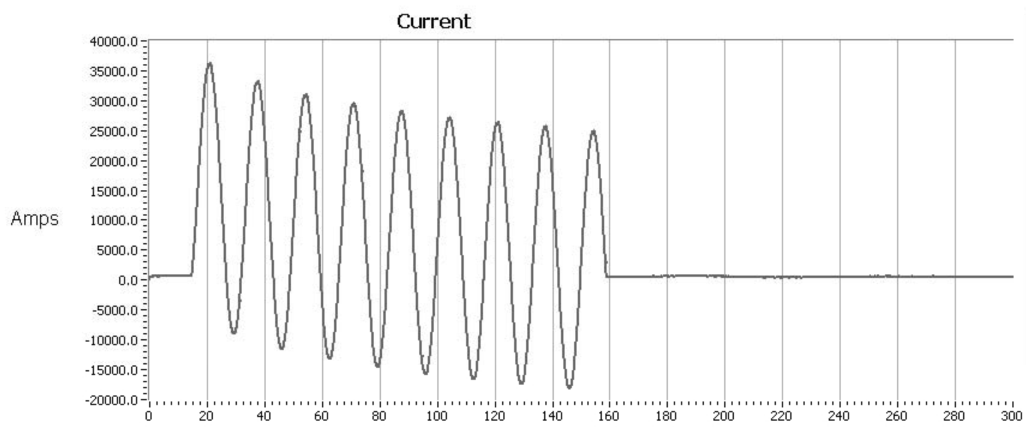


Short circuit voltage (rms) = 17693 Time (ms)

Figure 4a: PLP - Shot #1, Test 06-4395

December 12, 2006	High Current Test Laboratory Kinectrics Inc. Test Sheet	KINECTRICS
Test # 06-4396		
WO#:		

Client:	Description:
3M Company	**Short circuit on 2 ACCR conductor Bundle** **Spacer: THERMOLIGN twin Spacer, with 6 rods** **Shot #2**

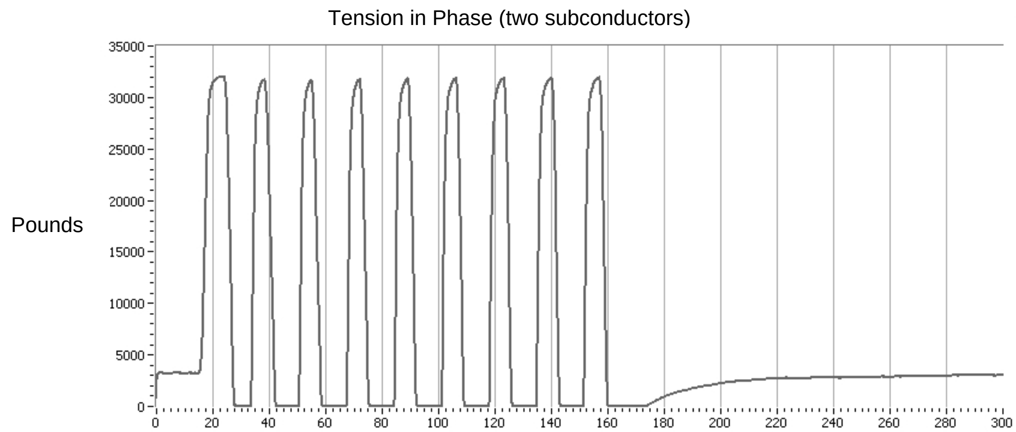


Rms (A) = 17698.4

Peak, I pk (A) = 36228.7

Duration of fault in cycles = 8.6

I^2t (A^2s) = 44.9E+6



Short circuit voltage (rms) = 18380

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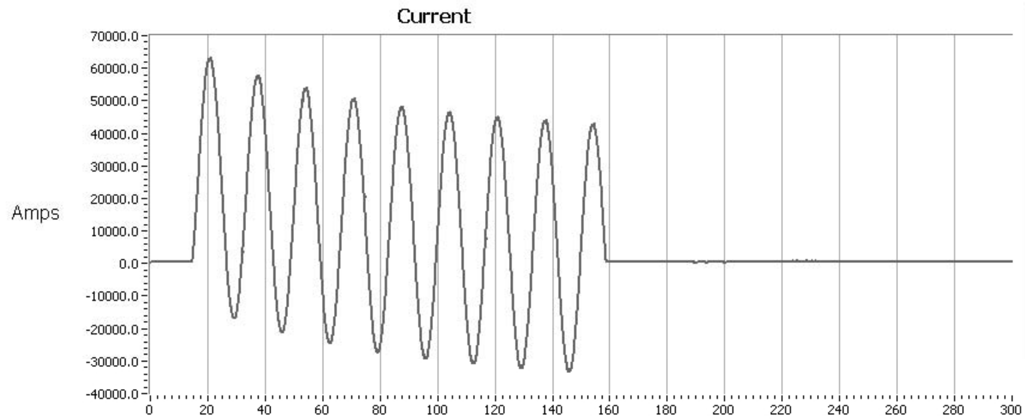
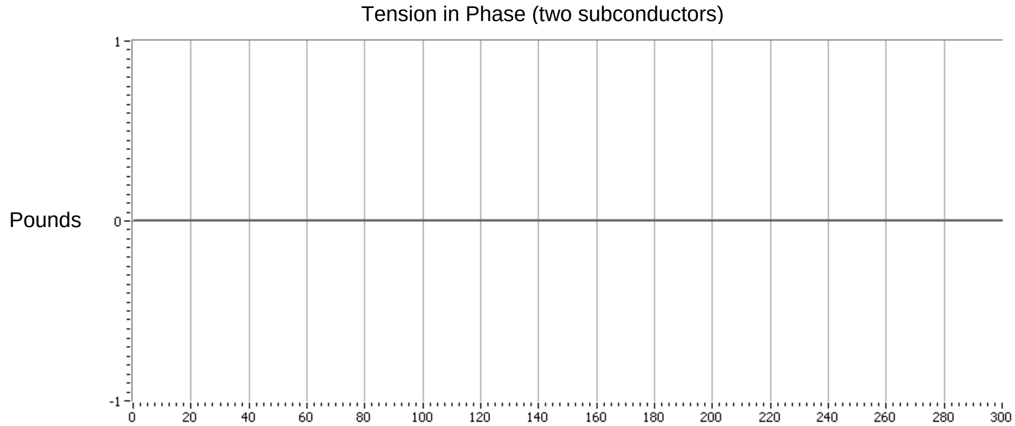
Figure 4b: PLP - Shot #2, Test 06-4396

December 12, 2006	High Current Test Laboratory Kinectrics Inc. Test Sheet	KINECTRICS
Test # 06-4397		
WO#:		

Client:	Description:
3M Company	Short circuit on 2 ACCR conductor Bundle Spacer: THERMOLIGN twin Spacer, with 6 rods Shot #3



Rms (A) = 30702.6
Peak, I pk (A) = 63144.9
Duration of fault in cycles = 8.6
I²t (A²s) = 135.1E+6
Time (ms)



Short circuit voltage (rms) = 17682
Time (ms)

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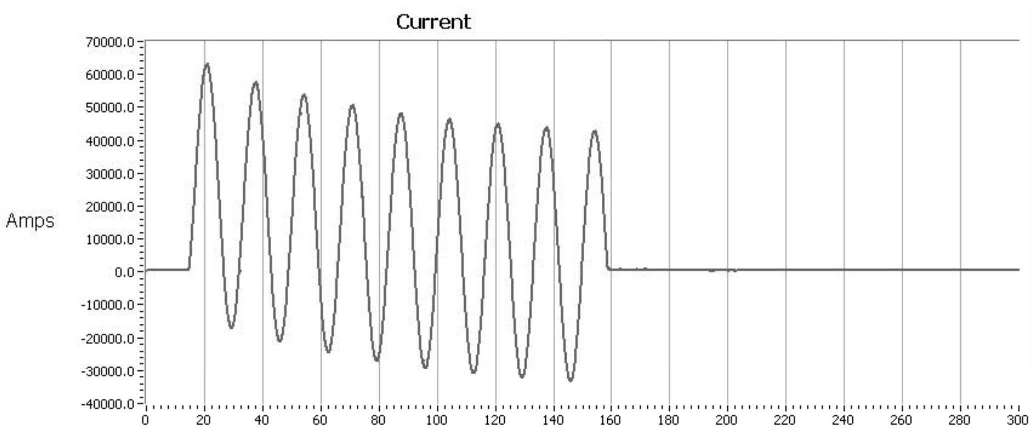
Figure 4c: PLP - Shot #3, Test 06-4397

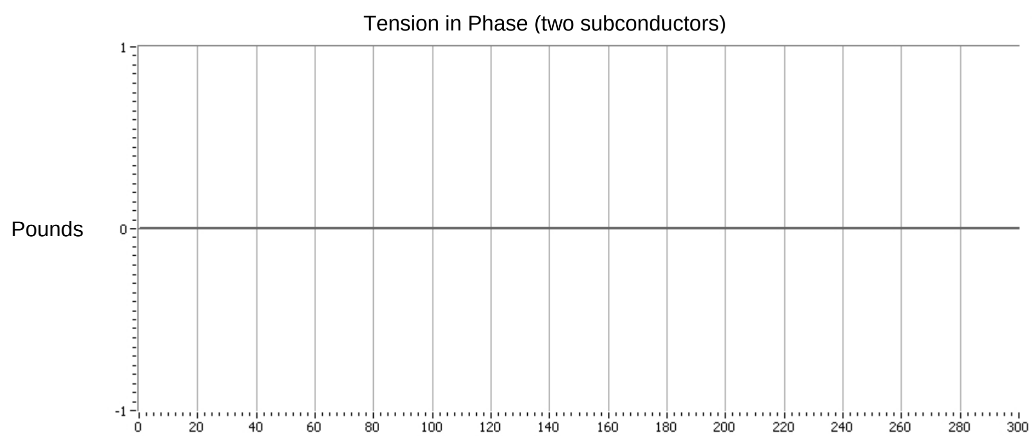
December 12, 2006	High Current Test Laboratory Kinectrics Inc. Test Sheet	KINECTRICS
Test # 06-4398		
WO#:		

Client:	Description:
3M Company	**Short circuit on 2 ACCR conductor Bundle** **Spacer: THERMOLIGN twin Spacer, with 6 rods** **Shot #4, 2000 lbs total tension**



Rms (A) = 30702.6 Duration of fault in cycles = 8.6 Time (ms)

Peak, I pk (A) = 63144.9 I^2t (A^2s) = 135.1E+6

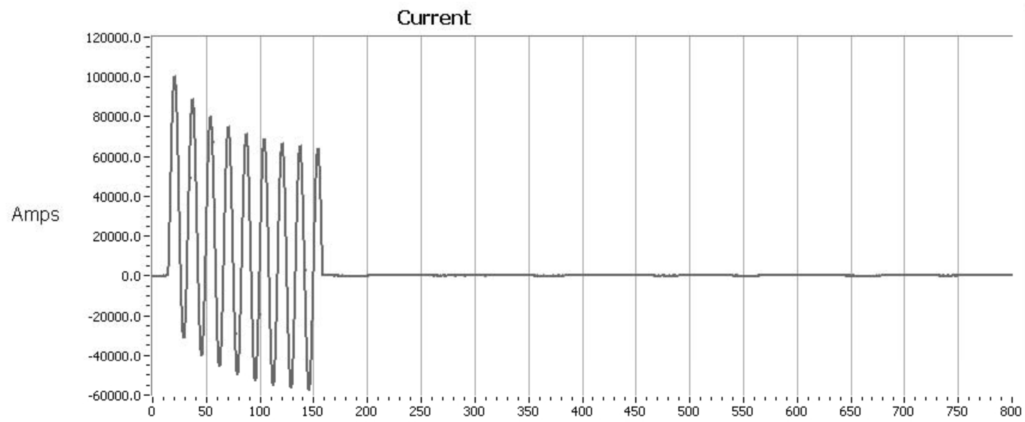


Short circuit voltage (rms) = 17682 Time (ms)

Figure 4d: PLP - Shot #4, Test 06-4398

December 12, 2006	**High Current Test Laboratory** **Kinectrics Inc.** **Test Sheet**	KINECTRICS
Test # 06-4399		
WO#:		

Client: **3M Company**	Description: **Short circuit on 2 ACCR conductor Bundle** **Spacer: THERMOLIGN twin Spacer, with 6 rods** **Shot #5, 2000 lbs total tension**

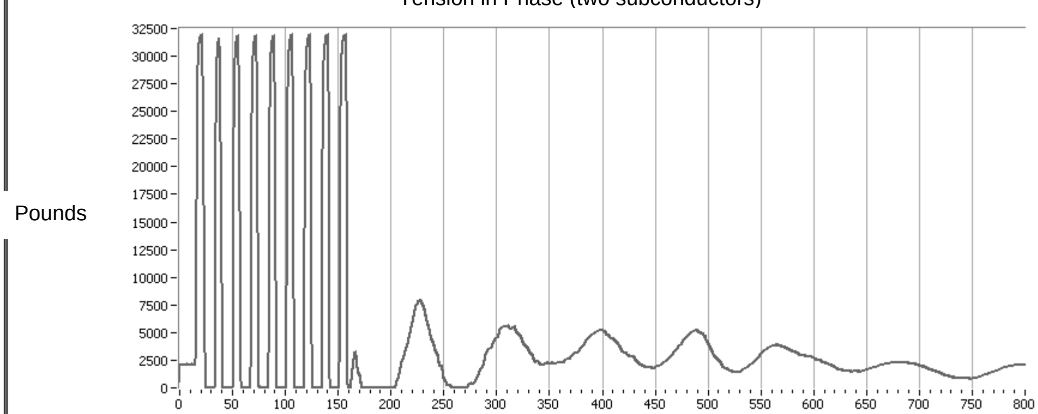


Rms (A) = 47499.1 Duration of fault in cycles = 8.6

Peak, I pk (A) = 100302.7 I²t (A²s) = 323.3E+6

Time (ms)

Tension in Phase (two subconductors)



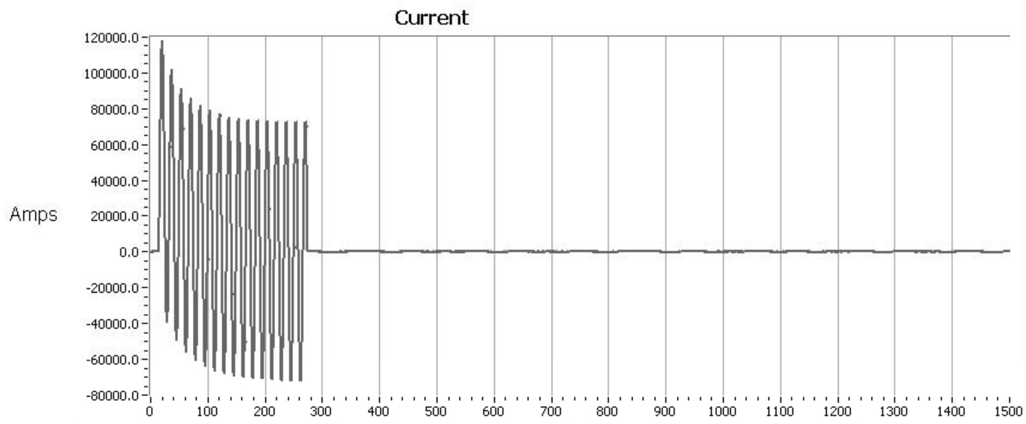
Short circuit voltage (rms) = 18313

Time (ms)

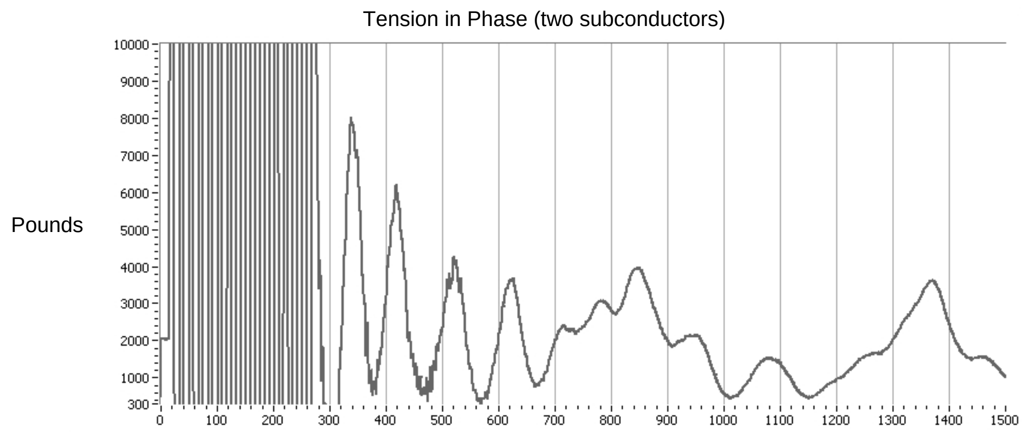
Figure 4e: PLP - Shot #5, Test 06-4399

December 12, 2006	High Current Test Laboratory Kinectrics Inc. Test Sheet	KINECTRICS
Test # 06-4400		
WO#:		

Client:	Description:
3M Company	**Short circuit on 2 ACCR conductor Bundle** **Spacer: THERMOLIGN twin Spacer, with 6 rods** **Shot #6, 2000 lbs total tension**



Rms (A) = 53423.6
Peak, I pk (A) = 117687.5
Duration of fault in cycles = 15.6
I²t (A²s) = 743.2E+6

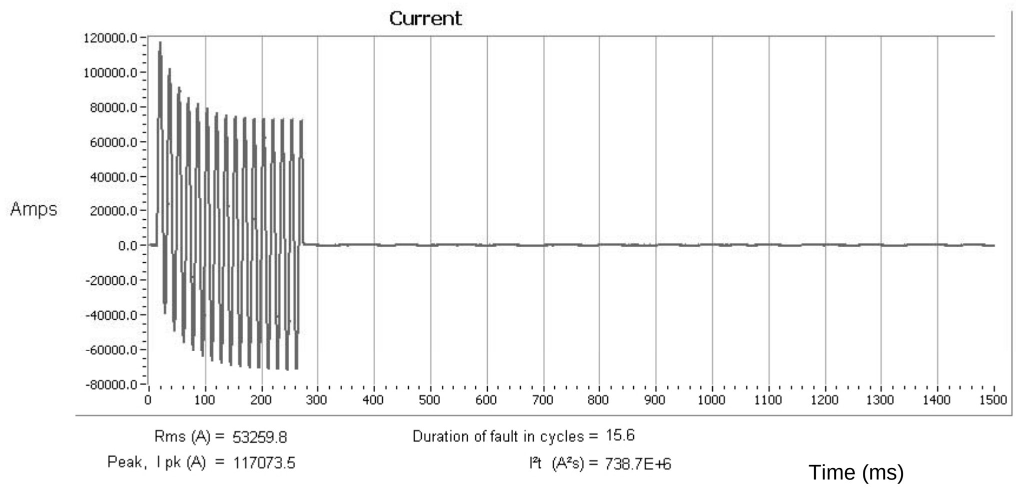


Short circuit voltage (rms) = 19150

Figure 4f: PLP - Shot #6, Test 06-4400

December 12, 2006	High Current Test Laboratory Kinectrics Inc. Test Sheet	KINECTRICS
Test # 06-4401		
WO#:		

Client:	Description:
3M Company	**Short circuit on 2 ACCR conductor Bundle** **Spacer: THERMOLIGN twin Spacer, with 6 rods** **Shot #7, 1500 lbs total tension**



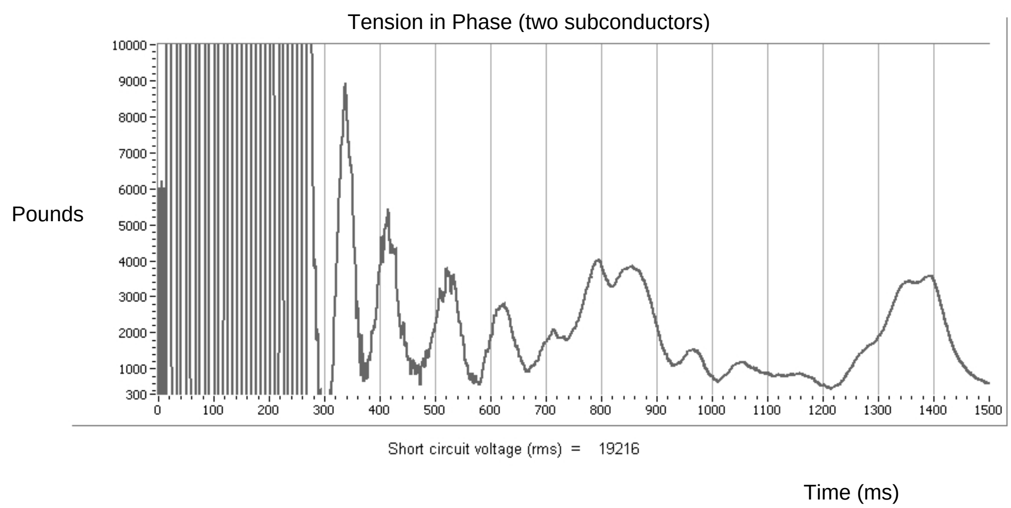


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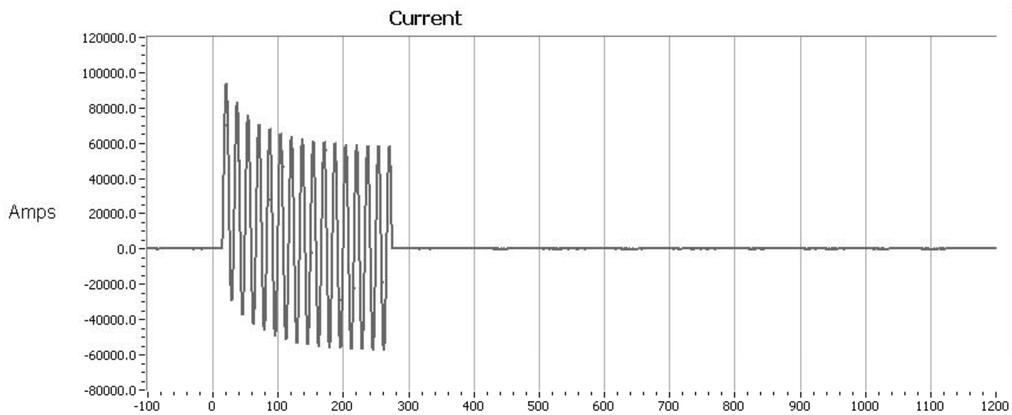
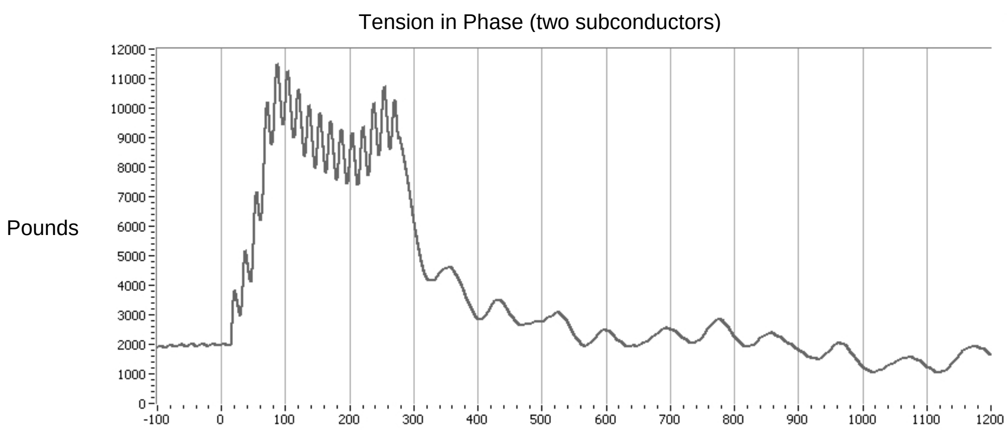
Figure 4g: PLP - Shot #7, Test 06-4401

December 13, 2006	**High Current Test Laboratory** **Kinectrics Inc.** **Test Sheet**	KINECTRICS
Test # 06-4405		
WO#:		

Client: **3M Company**	Description: **Short circuit on 2 ACCR conductor Bundle** **Spacer: THERMOLIGN twin Spacer, with 6 rods** **Shot #8, 2000 lbs total tension**



Rms (A) = 43036.8
Peak, I pk (A) = 93997.7
Duration of fault in cycles = 15.6
I^2t (A^2s) = 482.1E+6
Time (ms)

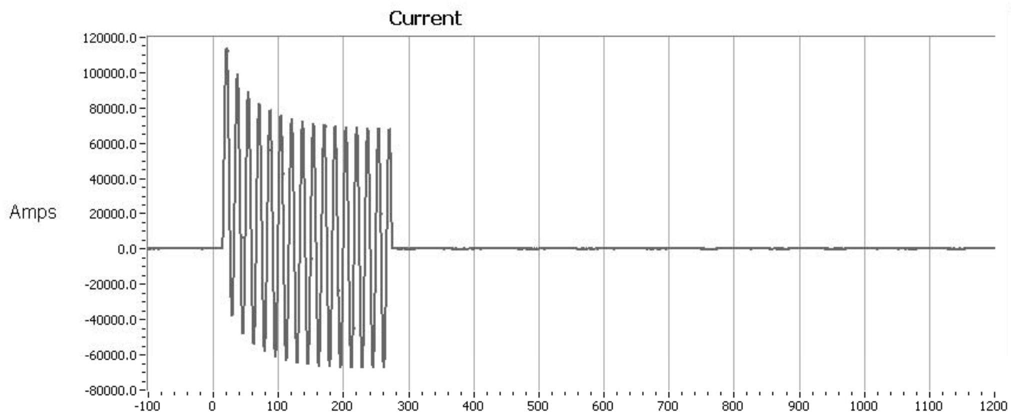


Short circuit voltage (rms) = 6678
Time (ms)

Figure 4h: PLP - Shot #8, Test 06-4405

December 13, 2006	**High Current Test Laboratory** **Kinectrics Inc.** **Test Sheet**	KINECTRICS
Test # 06-4406		
WO#:		

Client:	Description:
3M Company	**Short circuit on 2 ACCR conductor Bundle** **Spacer: THERMOLIGN twin Spacer, with 6 rods** **Shot #9, 2000 lbs total tension**



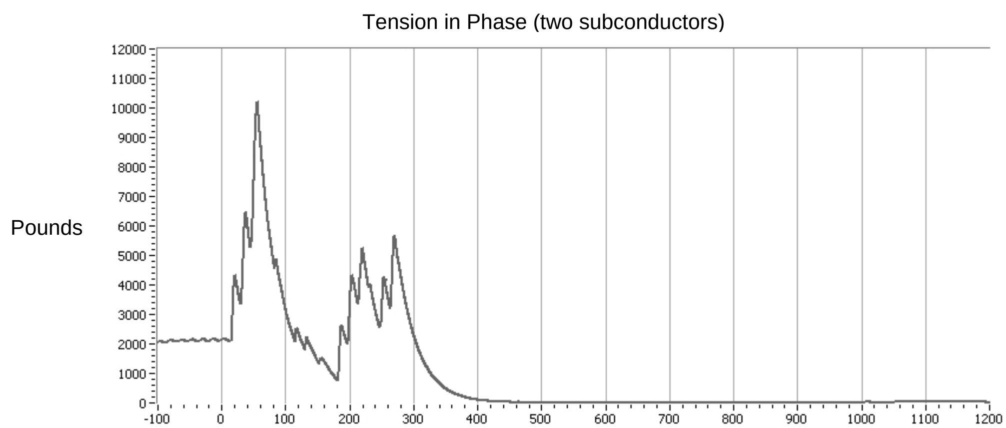
Rms (A) = 50971.3

Peak, I pk (A) = 113798.5

Duration of fault in cycles = 15.6

I^2t (A^2s) = 676.3E+6

Time (ms)



Short circuit voltage (rms) = 3796

Time (ms)

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Figure 4i: PLP - Shot #9, Test 06-4406

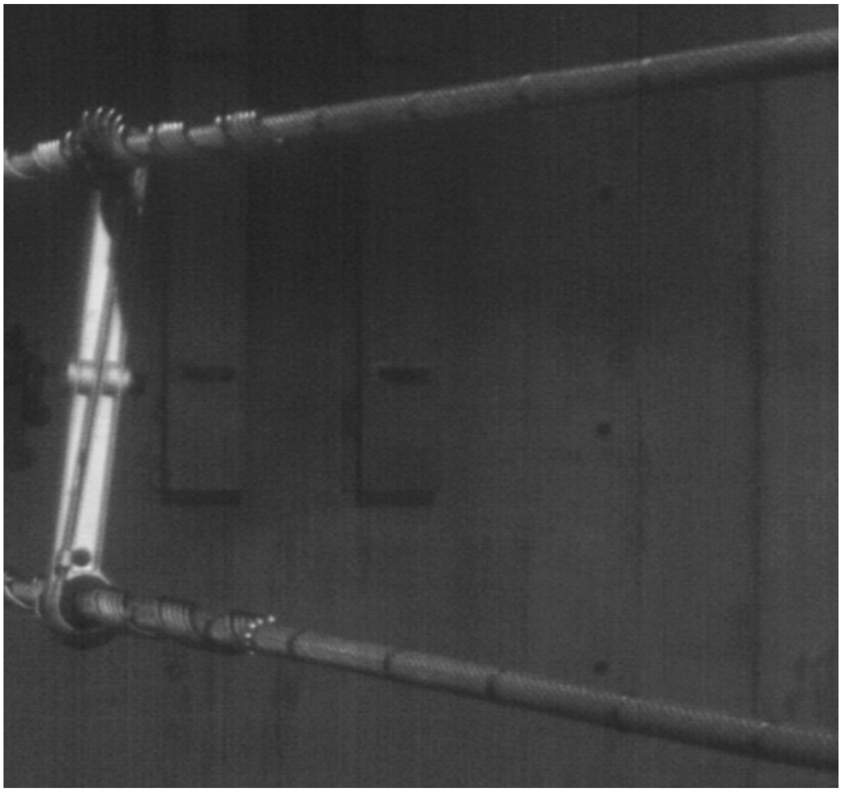

Figure 5a: Initial Position of Spacer Before Short Circuit Applied

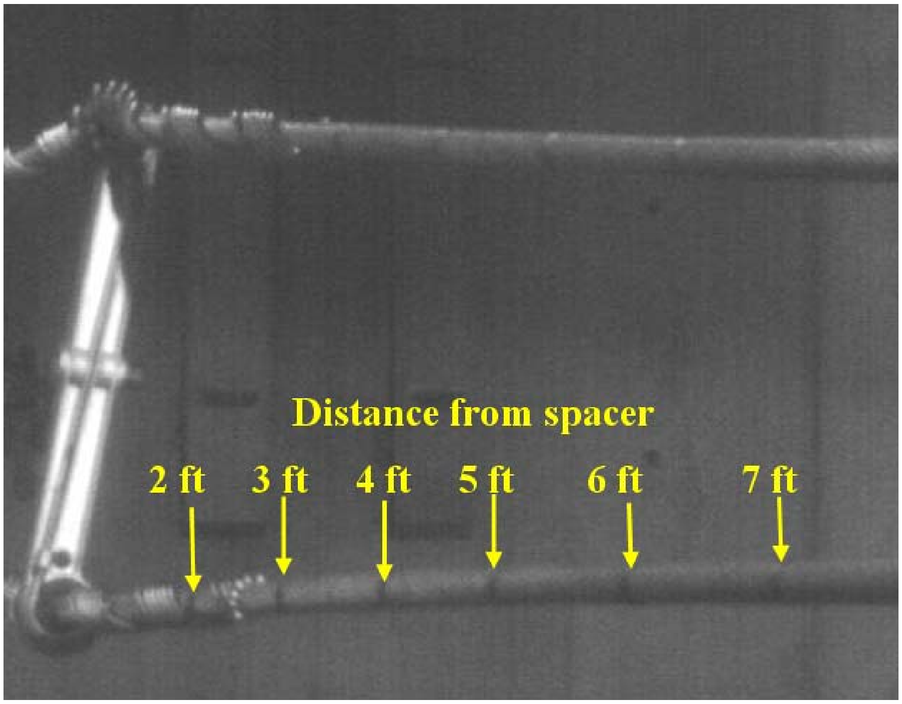

Figure 5b: Maximum Deformation of Conductors During 30.7 kA Short Circuit (Initial Tension=2000 lbf/phase) (1 ft = 305 mm)

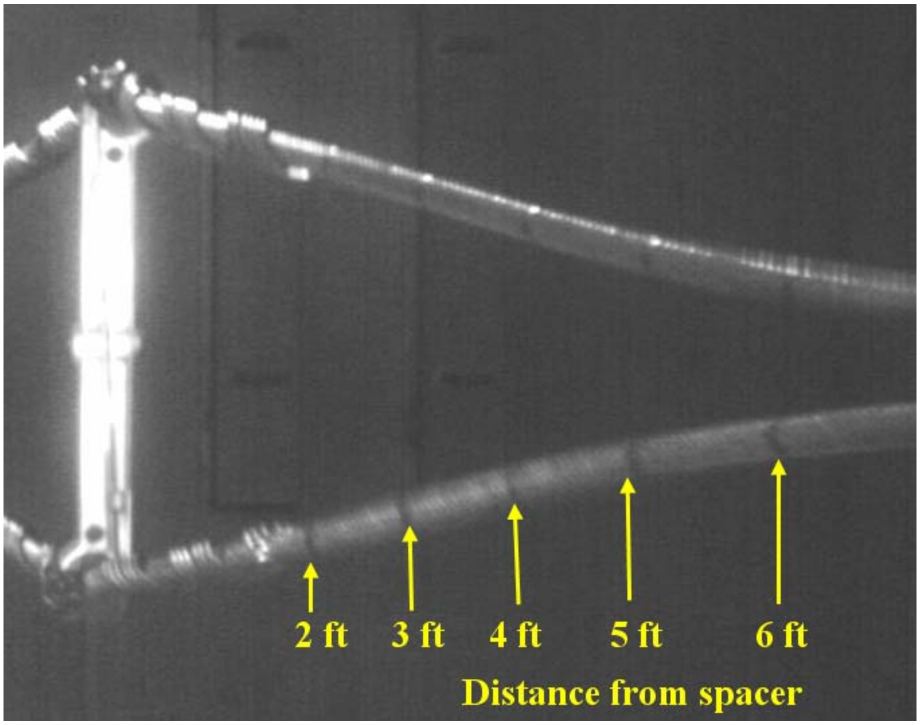

Figure 5c: Maximum Deformation of Conductors During 43 kA Short Circuit (Initial Tension=2000 lbf/phase) (1 ft = 305 mm)

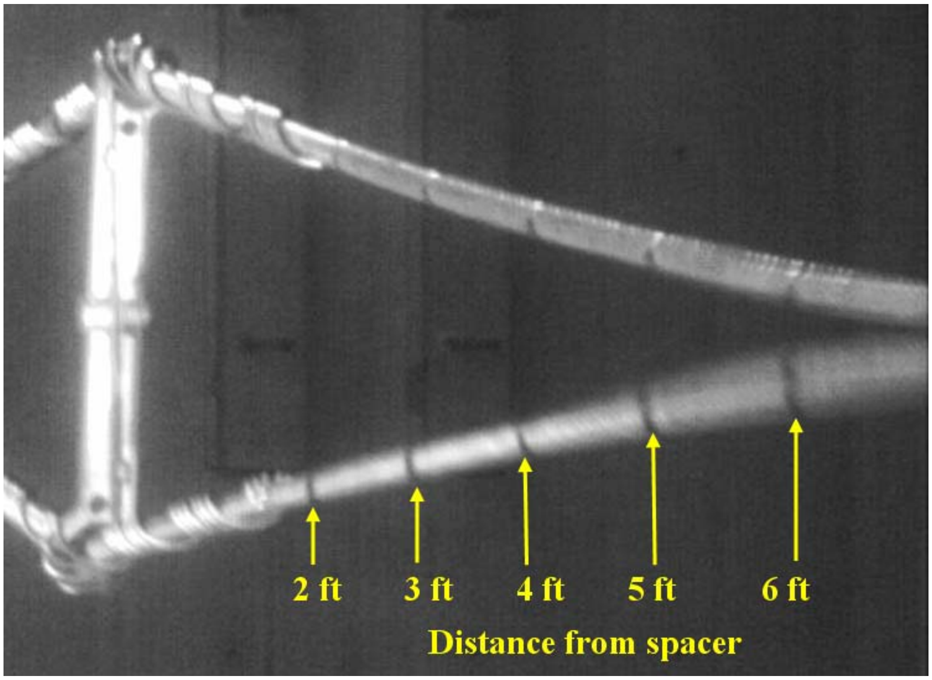

Figure 5d: Maximum Deformation of Spacer During 51 kA Short Circuit (Initial Tension=2000 lbf/phase) (1 ft = 305 mm)

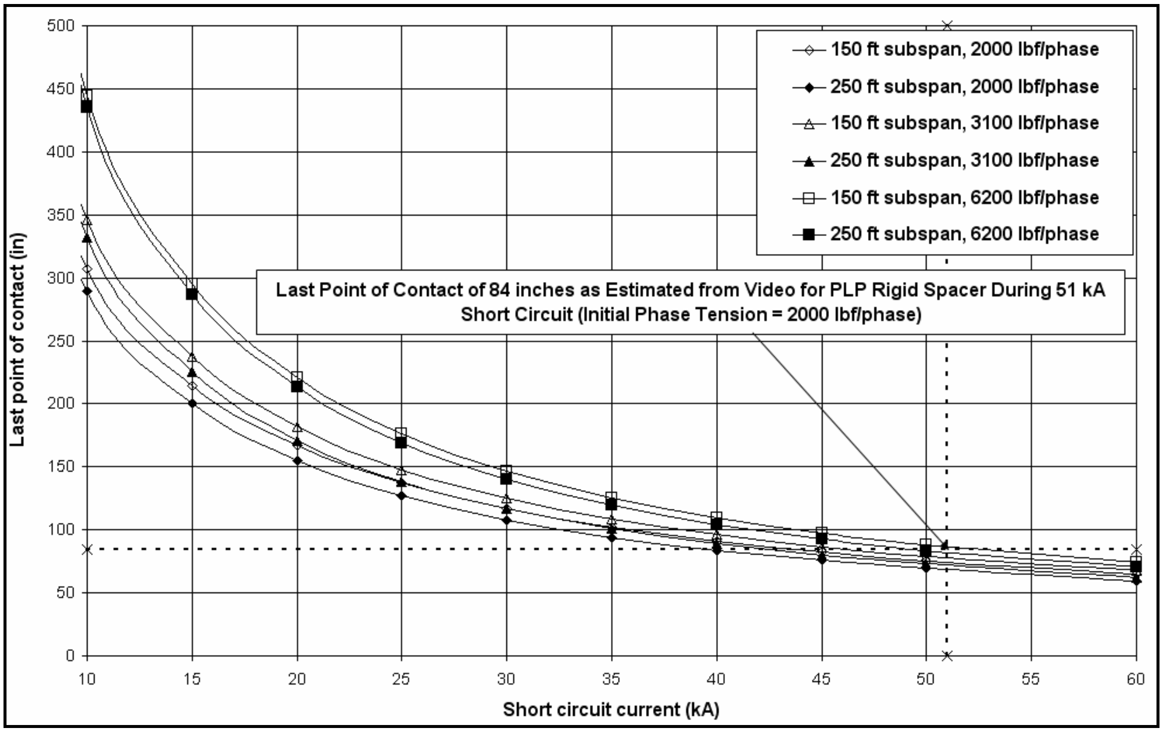

Figure 6: Results of Analytical Study

APPENDIX A

Specifications for 795-T16 ACCR Conductor

3M Composite Conductor Specification

Conductor Physical Properties

Designation		795-T16		795-T16
Stranding		26/19		26/19
kcmils	kcmil	795		
Diameter				
indiv Core	in	0.082	mm	2.1
indiv Al	in	0.175	mm	4.4
Core	in	0.41	mm	10.4
Total Diameter	in	1.11	mm	28.1
Area				
Al	in^2	0.624	mm^2	403
Total Area	in^2	0.724	mm^2	467
Weight	lbs/linear ft	0.896	kg/m	1.333
Breaking Load				
Core	lbs	18,556	kN	82.5
Aluminum	lbs	12,578	kN	55.9
Complete Cable	lbs	31,134	kN	138.5
Modulus				
Core	Msi	31.4	GPa	216
Aluminum	Msi	7.4	GPa	51
Complete Cable	Msi	10.7	GPa	74
Thermal Elongation				
Core	10^-6/F	3.5	10^-6/C	6.3
Aluminum	10^-6/F	12.8	10^-6/C	23.0
Complete Cable	10^-6/F	9.2	10^-6/C	16.3
Heat Capacity				
Core	W-sec/ft-C	22	W-sec/m-C	71
Aluminum	W-sec/ft-C	324	W-sec/m-C	1,062

Conductor Electrical Properties

Resistance				
DC @ 20C	ohms/mile	0.1100	ohms/km	0.0683
AC @ 25C	ohms/mile	0.1126	ohms/km	0.0700
AC @ 50C	ohms/mile	0.1237	ohms/km	0.0769
AC @ 75C	ohms/mile	0.1349	ohms/km	0.0838
Geometric Mean Radius	ft	0.0375	cm	1.1416
Reactance (1 ft Spacing, 60hz)				
Inductive Xa	ohms/mile	0.3986	ohms/km	0.2491
Capacitive X'a	ohms/mile	0.0912	ohms/km	0.0570

APPENDIX B

Results of EMAT Inspection

3M Spacer Failure Tests Using EMAT

795 ACCR Conductor

December 12 & 13, 2006

Toronto, Canada

Presented by:
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1. Introduction

On December 12 and 13, 2006, 3M requested to use EMAT to assess the integrity of conductor during spacer testing. We conducted these tests at Kinectrics facilities in Toronto, Canada. The EMAT system was employed to detect possible inner core broken strands from 3M 795 ACCR conductors near the position of spacer placement. Two parallel conductors were installed with a 50 feet span. The current in these two parallel conductors was gradually increased to the point that both conductors would attract each other, due to the induced strong field, and this attraction could cause core strand damage near the spacer. The main objective of these tests was to identify durability of these spacers in terms of preventing breakage of core strands, by using the EMAT for the conductor integrity assessment. The test setup is shown in the Figure 1.

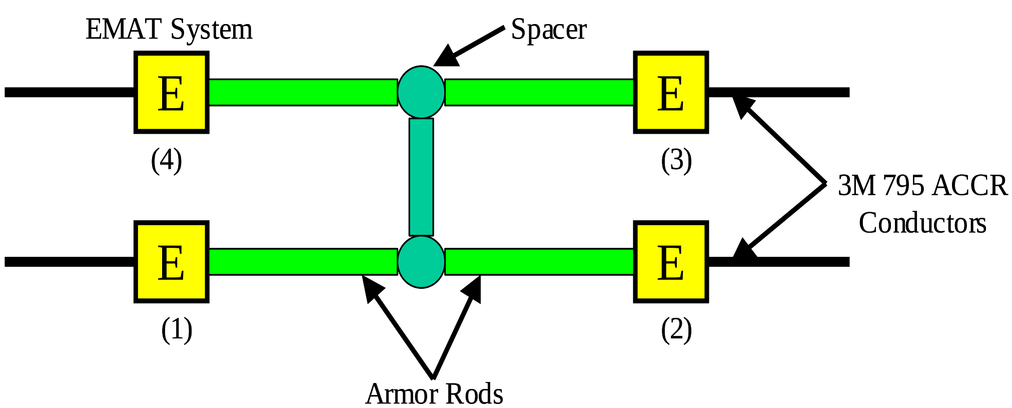

Figure 1: Test Setup and EMAT Position

2. PLP Rigid Spacers

The first sets of tests were conducted with the PLP rigid spacers. Signatures were collected from the four positions, (1) through (4) in Figure 1, after the current incremental tests had been done. Figures 2 through 6 show the signatures from positions (1) through (4) at different condition tests, as listed below (target conditions listed):

PLP Rigid Spacer Tests at Different Current and Conductor Tension
30 kA, 1000 lbs/sub-conductor
40 kA, 1000 lbs/sub-conductor
50 kA, 1000 lbs/sub-conductor
50 kA, 750 lbs/sub-conductor

Only the most severe cases are presented where there was at least some conductor deflection to merit measurement.

In all signature plots, they show some reflections near 1000th to 4000th data points. The compacted wave packets around 1000th to 2500th data points are transmitter signal that comes from the high voltage-driving signal. Thus, this part does not include any reflections due to the mechanical damage of the conductor.

The most meaningful information is contained in the data points at 3000th to 6000th. During this span of data points, there are some noticeable reflections, as shown in Figures 2 through 6. However, these reflections do not come from any inner or outer broken strands. Actually, these are resulted from the spacing between layers and between strands of contact points. These reflections show up normally when we test with brand-new conductors.

Over 6000th data point, we do not see any distinctive reflections except in Figures 5 and 6 at position (2). Usually, over 6000th data points are used for the verification of the defects that are shown already in between 3000th and 6000th data points. This means those reflections shown with data points of over 6000 come from the between the strand contact points between layers, and not from broken strands.

After these high current tests, each conductor was disassembled to find out if any of the core composite strands were damaged. This was also to verify the EMAT readings. It was determined that EMAT diagnostics were correct and the core was not damaged.

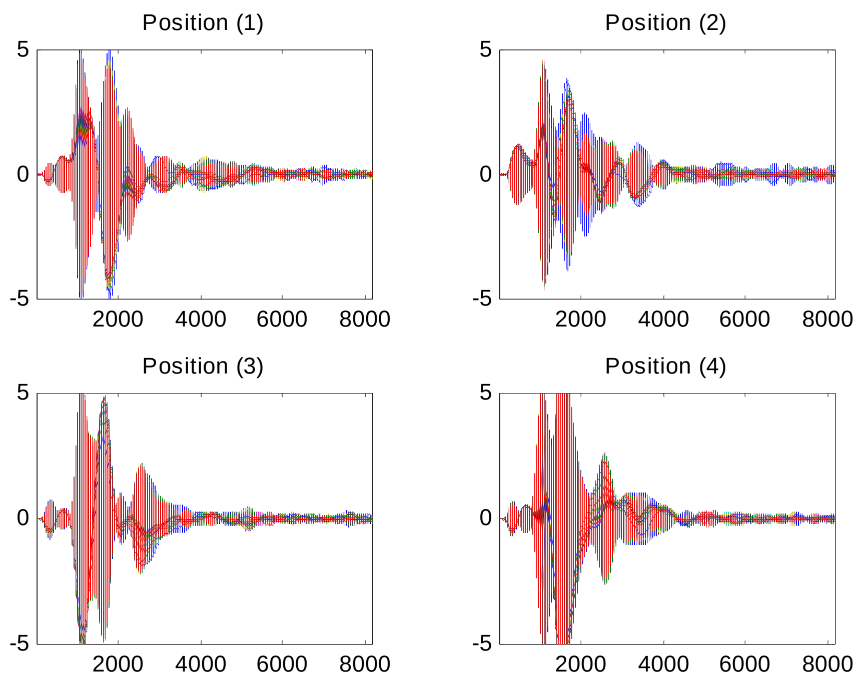

Figure 2: Signatures after 30.7 kA Short-Circuit Current and 1,000 lb/conductor Tension. I^2t = 135.1 kA^2s.

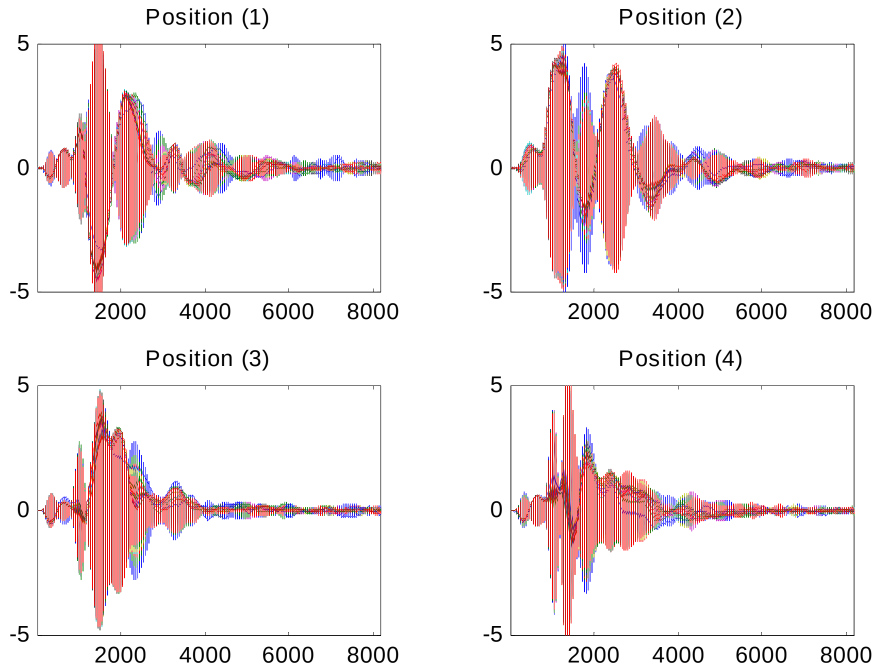

Figure 3: Signatures after 47.5 kA Short-Circuit Current and 1,000 lb/conductor Tension. I^2t = 323 kA^2s.

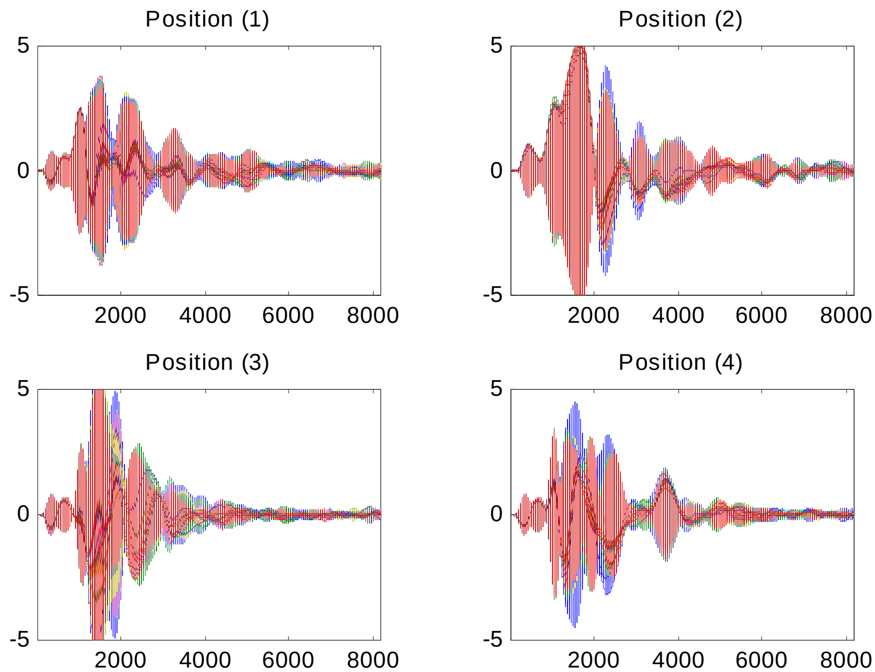

Figure 4: Signatures after 54.4 kA Short-Circuit Current and 1,000 lb/conductor Tension. I^2t = 743.2 kA^2s.

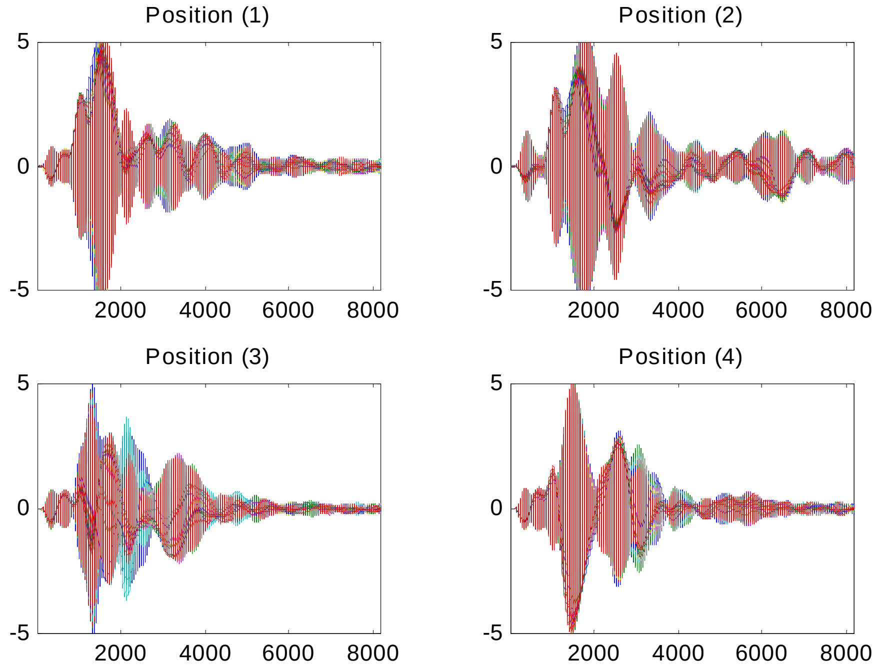

Figure 5: Signatures after 53.3 kA Short-Circuit Current and 750 lb/conductor Tension. I^2t = 738.7 kA^{2}s.

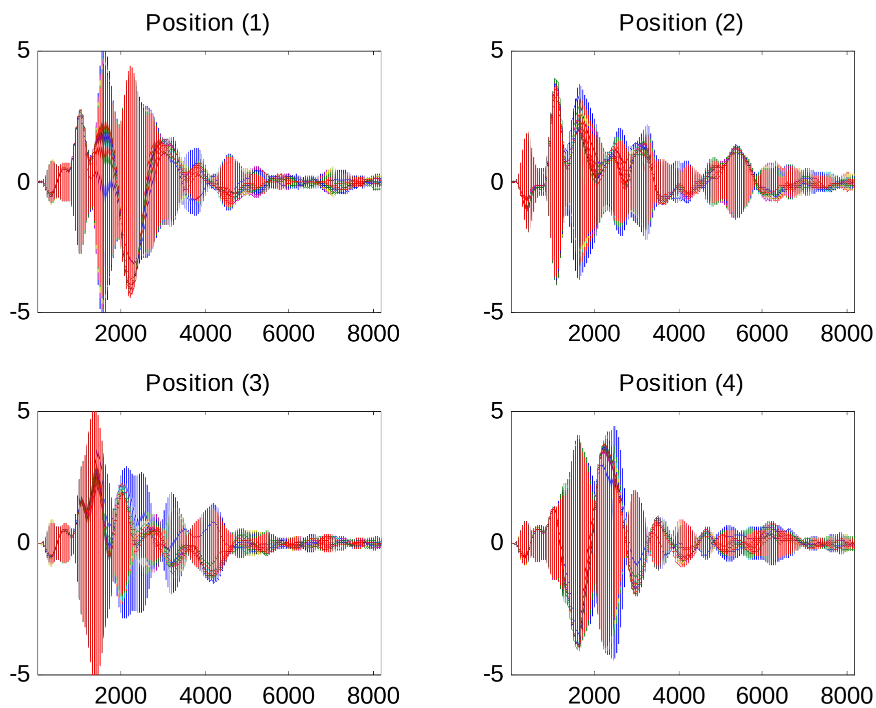

Figure 6: Signatures after 51.0 kA Short-Circuit Current and 1,000 lb/conductor Tension (2nd Test). I^2t = 676.3 kA^{2}s.

APPENDIX C

Results of Analytical Study

Plots of calculated data on the spacer test

The peak phase tension of the conductor and the last point of conductor contact from the spacer are calculated analytically. The analytical model has been calculated by the bundle collapse computer program. The program is based on the energy balance method to determine the transient conditions following the short circuit forces at the instant of maximum conductor displacement. The resulting non-linear equation is solved for the distance from the spacer to the last point of contact by Newton's method.

1.0 Field configuration of 150 ft and 250 ft subspan length

Model parameters:

Span length:	300 and 500 ft
Conductor diameter:	1.108 in
Weight of conductor:	0.896 lb/ft
Bundle conductor spacing:	18 in
Conductor modulus of elasticity:	$1.16 \cdot 10^7$ psi
Number of subspans:	2
Horizontal stiffness of dead-end:	10^8 lbf/in
Vertical deflection:	10^8 lbf/in
Initial static phase tension:	variable
Conductor sag at center of span:	variable
Short circuit current:	variable

The last point of contact (LPC) of conductors from the bundle spacer versus fault current is shown in Figure 6. The LPC is illustrated for two subspan lengths with various initial tensions and it shows an estimated value from laboratory tests. It was concluded that the LPC, and consequently the shape of the conductor near the spacer in "real spans" is well reproduced by the small-scale laboratory tests for 40 kA – 50 kA.

Figure C-1 shows the peak phase tension for typical field configurations and an estimated value from the laboratory test. Generally, the analytical predictions for field conditions show higher peak phase tension than the estimated value from the test, except for two configurations (250 ft subspan length, initial tensions of 3100 lbf/phase and 2000 lbf/phase). It is interesting to note, that the peak phase tension decreases for longer subspan lengths. This suggests that "real span" configurations with subspan length longer than 250 ft and with initial tensions lower than 3600 lbf/phase would result in lower tensions than the present laboratory configuration (21 ft subspan, 2000 lbf/phase).

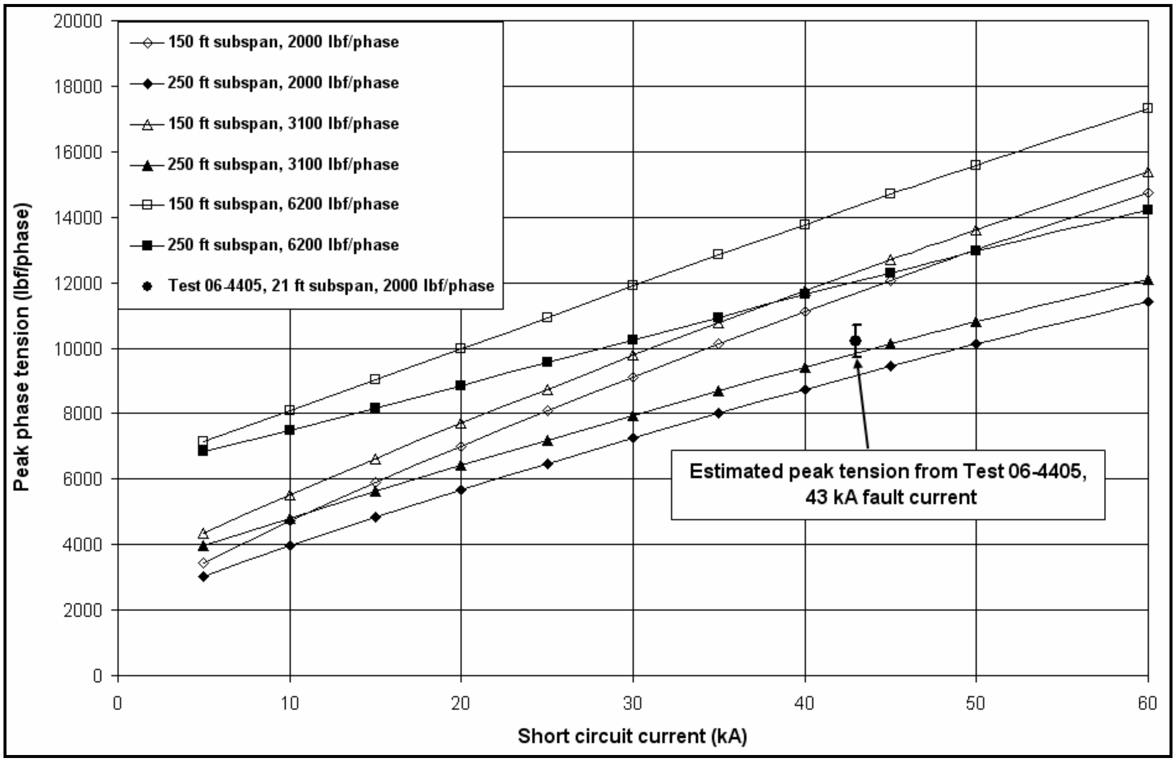

Figure C-1: Peak phase tension as a function of short circuit current for 150 ft and 250 ft subspan lengths with various initial tensions

2.0 Laboratory test configuration of 21 ft subspan length and with various initial tensions

Model parameters:

Span length:	42 ft
Conductor diameter:	1.108 in
Weight of conductor:	0.896 lb/ft
Bundle conductor spacing:	18 in
Conductor modulus of elasticity:	$1.16 \cdot 10^7$ psi
Number of subspans:	2
Horizontal stiffness of dead-end:	10^8 lbf/in
Vertical deflection:	10^8 lbf/in
Initial static phase tension:	variable
Conductor sag at center of span:	variable
Short circuit current:	variable

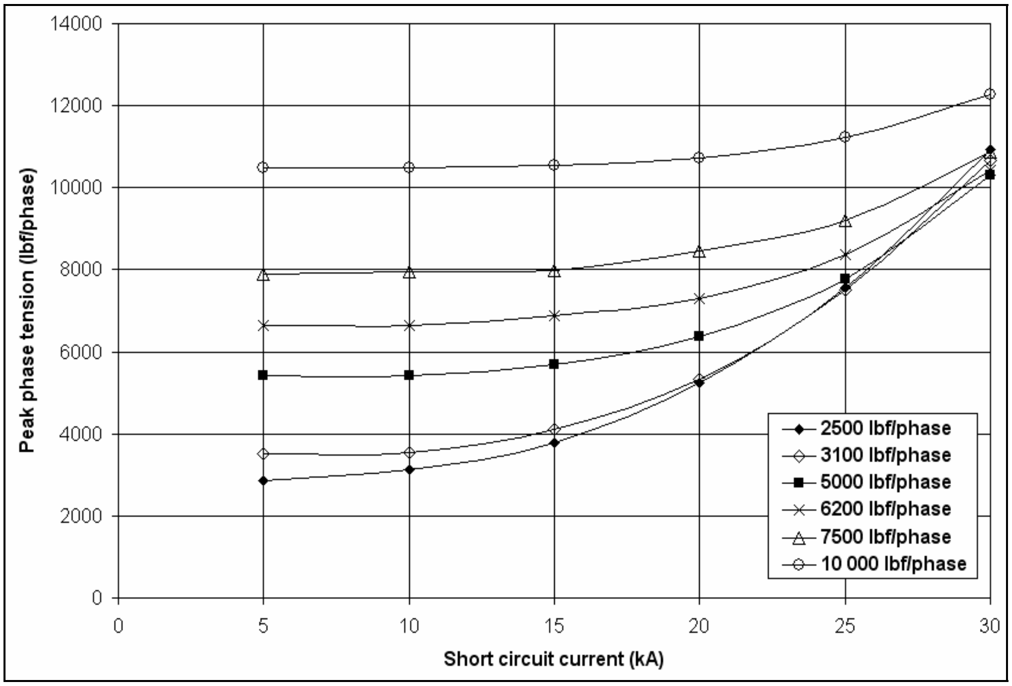

Figure C-2: Peak phase tension versus fault current for 21 ft subspan length with various initial tensions

As Figure C-2 shows, the peak phase tension is increasing with increasing fault current and with higher initial tensions in the conductors. The curves have the initial phase tension value at 0 kA.

The peak phase tension is more sensible on the fault current increase at lower initial tensions. In other words, the increase of peak phase tension in conductors with increasing fault currents is more significant for conductors with lower initial tension. At high initial tensions of 10 000 lbf/phase, the peak phase tension in the conductor is practically constant for fault currents in range of 5-15 kA. The peak phase tension increases significantly with increasing fault current in the conductor with initial tension of 2500 lbf/phase.

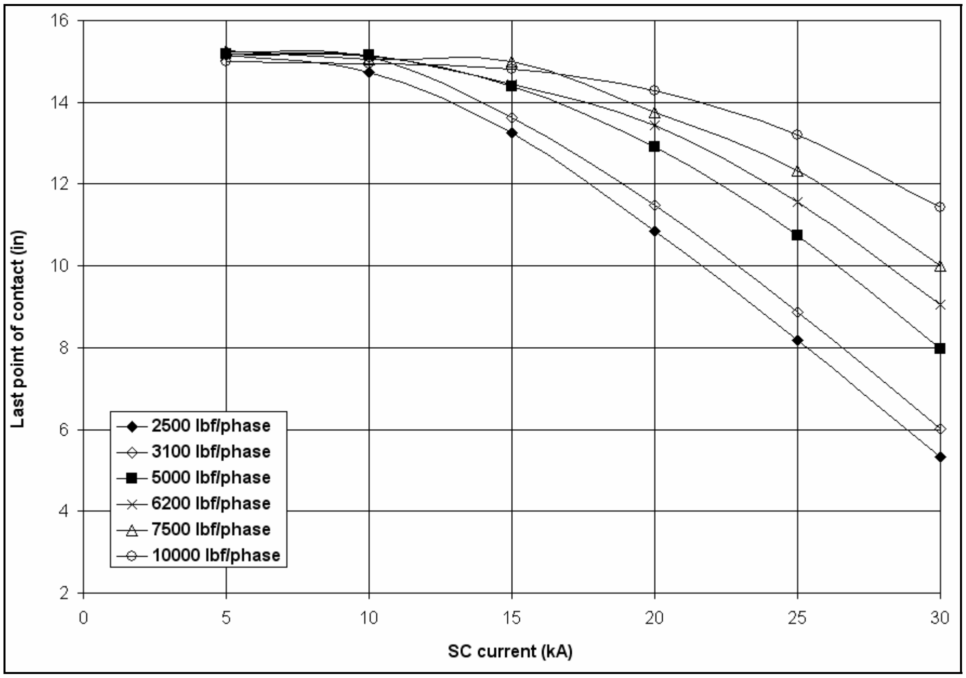

Figure C-3: Last point of contact as a function of short circuit current for 21 ft subspan length with various initial tensions

It appears that the bundle collapse program may tend to overestimate the phase tension and underestimating the LPC for those cases where the contact length of the subconductors is quite small (laboratory configuration). This probably relates to that the model does not account for the conductor's bending stiffness around the spacer. The model also assumes that the two parallel current-carrying cables coming together at the same time throughout their full length. Therefore, the "end-effects" becomes significant for short span length.

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