LIGHTNING TECHNOLOGIES, AN NTS COMPANY

Test Report of

Lightning Direct Effects High Current Arc Entry Tests on Corrugated Stainless Steel Tubing (CSST) Samples and Lightning Detection/ Gas Flow Meter Detector

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Project No. PR024722

SIGNATURES

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REVISIONS

Revision	Reason for Revision	Date
-	Initial Release	22 Nov 13

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ADMINISTRATIVE DATA

A. PURPOSE OF TESTS

This report documents high current arc entry tests performed on Corrugated Stainless Steel Tubing (CSST) samples, black iron pipe, and a Lightning Detection/Gas Flow Meter Detector (patented by Mark Goodson). The test results contained in this report relate only to the test item/part number tested.

The tests were performed by D. A. DeBlois and J. E. Pryzby of Lightning Technologies in Pittsfield, MA on 4 November 2013 in accordance with the lightning test procedures contained in LC1027 "*PMG Listing Criteria for Conductive Jacketed Corrugated Stainless Steel Tubing*" and LC1024 "*PMG Listing Criteria for Conductive Jacketed Corrugated Stainless Steel Tubing*". Witnesses were M. Goodson from Goodson Engineering, M. Hergenrether (consultant), C. Colwell (Integrity Forensics), G. Nelson (Lubbock, TX Fire Marshal), R. Baily (Lubbock, TX Asst Fire Marshal), S. Carpenter (attorney), M. Wolf (attorney), and C. Connealy (Texas State Fire Marshal).

B. DESCRIPTION OF TEST ITEM(S)

The test articles were one meter long Corrugated Stainless Steel Tubing covered with either a non-conductive polyethylene jacketing, a conductive proprietary Flashguard^{TM} jacketing, or unjacketed. Tests on CSST were performed with and without the Lightning Detection/Gas Flow Meter Detector (LD/GFD) as indicated in the test result tables. A one meter length of black iron pipe was supplied for a comparison with CSST results. An additional direct effects test was performed on a Lightning Detection/Gas Flow Meter Detector prototype to evaluate its ability to shut off a gas supply under high current electrical surge conditions.

C. REFERENCES

1. ICC Evaluation Service, Inc. LC1027, "PMG Listing Criteria for Conductive Jacketed Corrugated Stainless Steel Tubing", September 2010

2. ICC Evaluation Service, Inc. LC1024, "PMG Listing Criteria for Conductive Jacketed Corrugated Stainless Steel Tubing", revised April 2010

3. ISO/IEC 17025:2005, *General Requirements for the Competence of Testing and Calibration Laboratories*, Second Edition, 2005

4. ANSI/NCSL Z540-1-1994, *Calibration Laboratories and Measuring and Test Equipment–General Requirements*, 1994

D. QUANTITY OF ITEMS TESTED

1 Lightning Detector

1 Black Iron Pipe

3 Gastite™

1 Flashshield™

1 Counterstrike™

E. SECURITY CLASSIFICATION

Public

F. TESTS CONDUCTED BY

Lightning Technologies, an NTS Company
10 Downing Industrial Parkway
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G. DISPOSITION OF TEST ITEMS

Returned to:

Mark Goodson/Scott Carpenter

H. STANDARD TEST CONDITIONS

Table 1 – Ambient Test Conditions

Date	Temperature (°F)	Humidity (%)	Barometric Pressure (in. Hg)
4 Nov 2013	66.9	27	29.58

I. TEST APPARATUS

All measurement equipment furnished by Lightning Technologies is calibrated by a commercial calibration agency in accordance with the requirements of ISO/IEC

17025:2005 (Ref. 3) and/or ANSI/NCSL Z540-1-1994 (Ref. 4) using standards traceable to the National Institute of Standards and Technology. Certification of calibration is on file subject to inspection by authorized personnel. Table 4 provides a list of calibrated equipment used during the tests.

Table 2 – Calibrated Equipment

Manufacturer	Equipment	Model Number	Serial Number	NTS Control Number	Calibration		
					Date	Due Date	Interval
4 November 2013							
Pearson	Attenuator	A5	101533	WC006371	1 Aug 13	1 Aug 14	1 Year
	Current Probe	1423	099639	WC006409	17 Jan 13	17 Jan 14	1 Year
			118521	WC006414	1 Jul 13	1 Jul 14	1 Year
Tektronix	Oscilloscope	TDS3032B	B033378	WC006461	11 Dec 12	11 Dec 13	1 Year
			B015906	WC006459	7 Feb 13	7 feb 14	1 Year
		TDS3034B	C010791	WC006463	7 Feb 13	7 feb 14	1 Year
T&M Research	Current Viewing Resistor	F-1000-4	8208-8	WC006425	6 Jun 13	6 Jun 14	1 Year
		W-2-01-4S	9039	WC006423	20 May 13	20 May 14	1 Year
Fluke	DVM	87V	87910393	WC006446	11 Jan 13	11 Jan 14	1 Year
Mannix	Hydro/temp	Sam990DW	9507251	WC006599	5 Feb 13	5 Feb 14	1 Year

J. PURCHASE ORDER NUMBER

139950-00

K. DATA BOOK NUMBER

DB 402, pp. 66-67

Table 3 – Test Summary

Paragraph	Test Title	Specification	Test Dates	Test Nos.	Results
3.1	LC1027 Direct Effects Tests	LC1027	4 Nov 13	1-2, 11-12	See Table 4
3.2	LC1024 Indirect Effects Tests	LC1024	4 Nov 13	3-10	See Table 5

FACTUAL DATA

1.0 WAVEFORMS

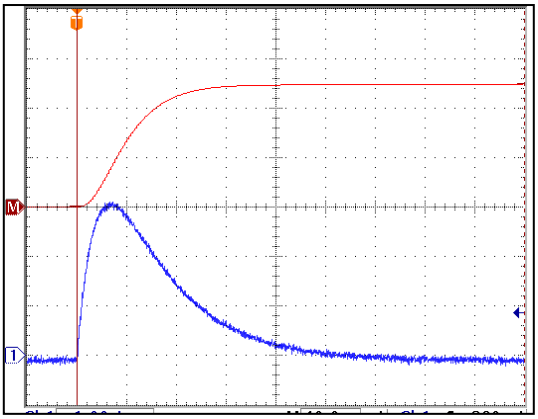
1.1 LC1027 Direct Effects Tests

The lightning current parameters are defined in Document LC1027 as follows. Typical waveform oscillograms are shown in Figure 1.

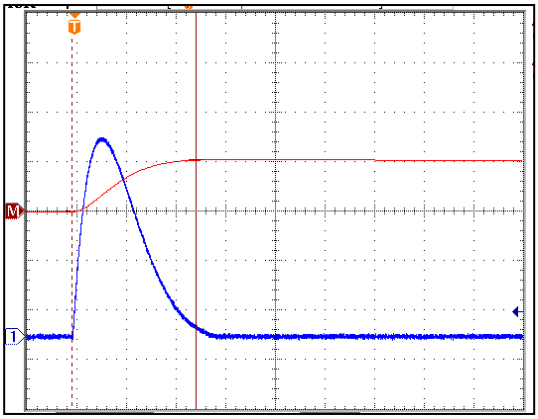
Component 1: Peak current amplitude (I_{pk}) = 30 kA minimum
Action integral (AI) = 0.055 x 10^6 A^2s minimum
Time Duration = ≤ 500 µs

Component 2: Average current amplitude (I_{av}) = 2 kA (±20%)
Maximum charge transfer = 10 coulombs (±10%)
Time Duration = ≤ 5 ms

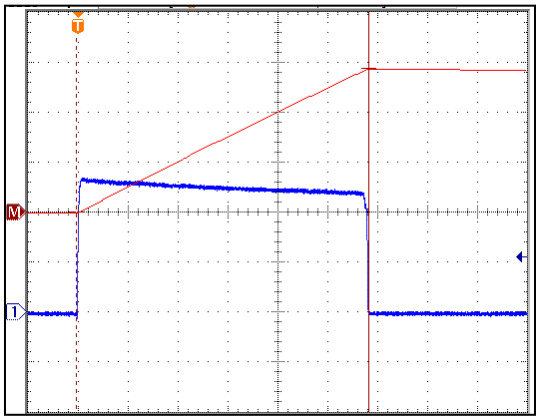
Component 3: Current amplitude = 200-800 A
Charge transfer = 26 coulombs minimum



Component 1



Component 2



Component 3

Figure 1 – LC1027 10 µs x 1,000 µs Applied Current Waveform Calibration

1.2 LC1024 Indirect Effects Tests

The minimum requirements for this waveform include a peak amplitude of at least 1,000 A and 4.5 Coulombs delivered in 20 ms. A typical waveform is shown in Figure 2.

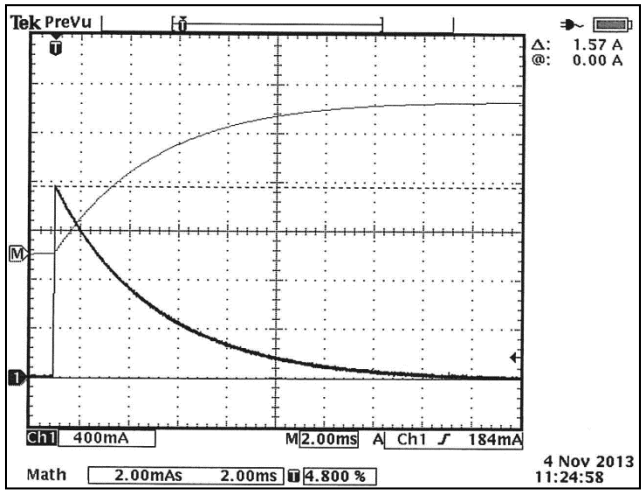


Figure 2 – LC1024 Applied Current Waveform (Test No. 5)

2.0 TEST SETUP

2.1 LC1027 Direct Effects Tests

The high current generators were configured for lightning current Components 1, 2, and 3 as specified in Document LC1027. The output of the generator was connected to a wire braid into an NPT fitting on one end of the CSST sample.

The lower section of the sample was positioned adjacent to a metal ground plate that was clamped to the generator ground bus. A fiberglass angle clamped to the ground plate was positioned to maintain a distance of 1/8 inch between the CSST sample and the plate. The laboratory setup is shown in Figures 3 and 4. An additional test was performed on a Lightning Detection/Gas Flow Meter Detector to evaluate its ability to shut off a gas supply under high current surge conditions. See Figure 5.

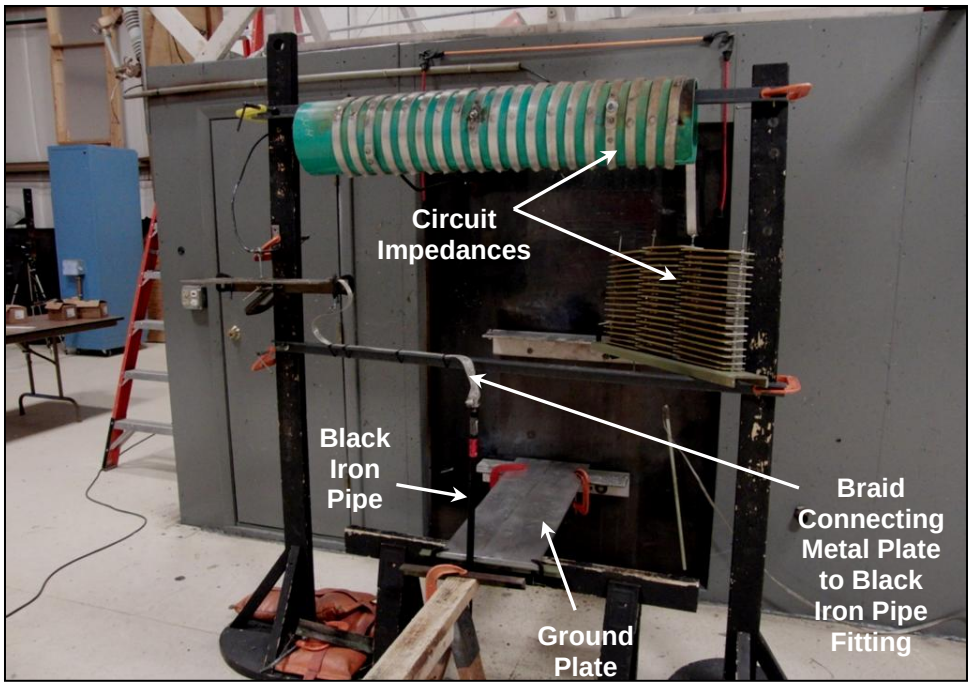


Figure 3 – Laboratory Setup for Direct Effects Lightning Current Waveform Tests

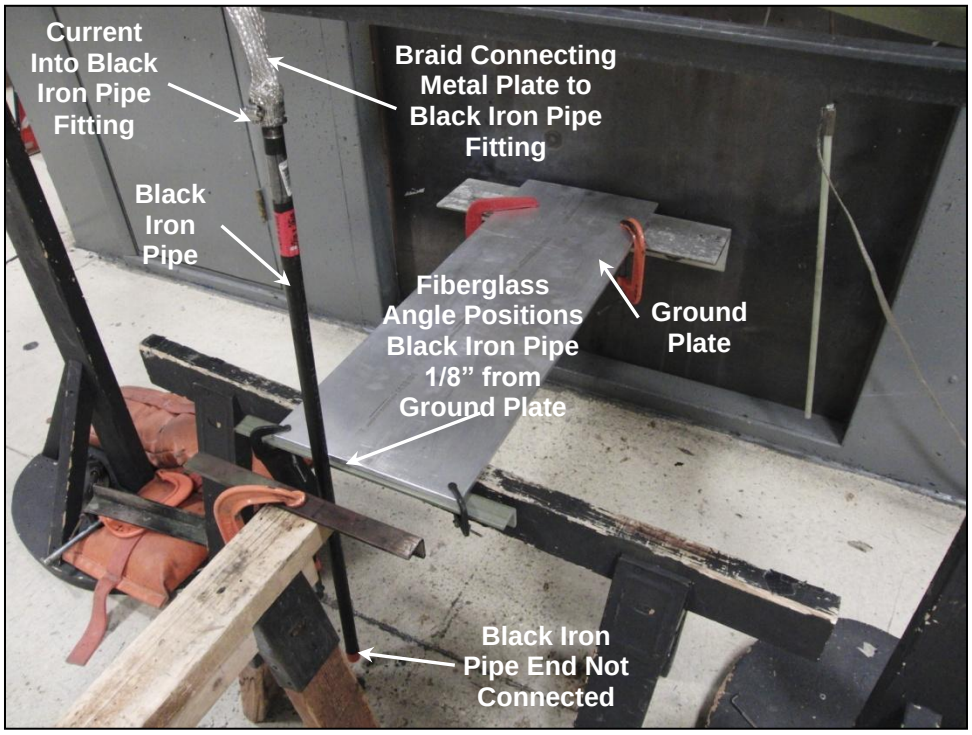


Figure 4 – Close-up of Black Iron Pipe Setup for Direct Effects Lightning Current Waveform Tests

Figure 5 – Lightning Detection/Gas Flow Meter Detector Test Setup

2.2 LC1024 Indirect Effects Tests

The test samples were prepared by stripping the protective jacket at one end and clamping the ground braid from the CSST to ground. One end of a wire braid was attached to the CSST with a hose clamp and the opposite end was clamped to the copper ground plane. The sample was laid over the copper ground plane but was isolated from it by dielectric sheets positioned beneath the sample.

A 1/4 inch rod electrode was connected to the output of the transient generator and positioned 1/8 inch above the sample at a distance of 12 inches from its grounded end. A current transformer (CT) measured the applied current which was discharged from the electrode into the cable jacket. The CT signal was sent to the input of an oscilloscope which measured the current amplitude and charge transfer. The laboratory setup is shown in Figure 6. The first two tests were conducted using a lightning detection/ gas flow meter detector unit, which is shown in Figure 7.

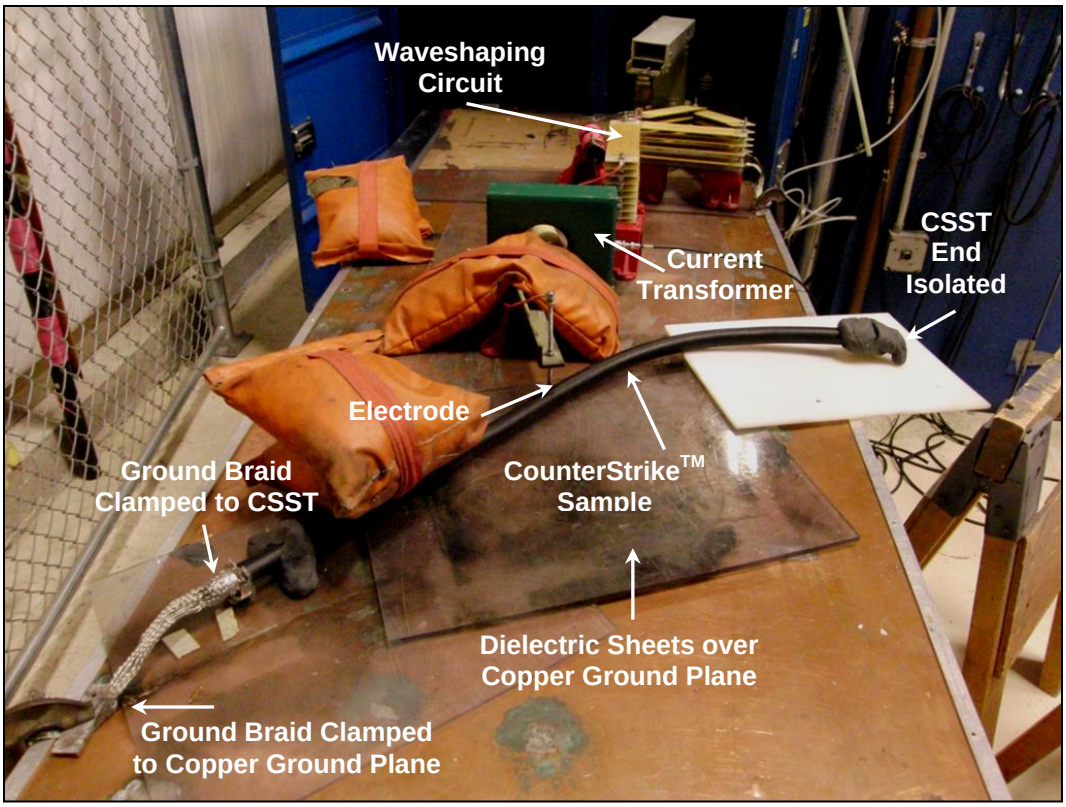


Figure 6 – Typical Laboratory Setup for Arcing Resistance Tests

Figure 7 – Lightning Detection/Gas Flow Meter Detector Unit Test Setup

3.0 TEST RESULTS

3.1 LC1027 Direct Effects Tests

A black iron pipe was tested with LC10127 Components 1-3 which resulted in at least a melting around the area of test. Goodson Engineering will provide the complete results of this test. Next, a 1" diameter CSST was tested which resulted in the CSST splitting in two and ignition of the yellow jacket that was manually extinguished, post-test. A lightning detection/gas flow meter detector unit was then tested with Component 1 which resulted in the unit shutting off the gas supply prior to internal failure. The last test included the application of Components 1 and 3 (with additional coloumb content to compensate for the lack of Component 2) to a FlashShield™ sample. Damage was observed of the outer jacket, but no damage to the CSST.

Post-test photographs for each test are provided in Figures 8 through 10. The test results are summarized in Table 4. Appendix A provides the raw data oscillograms in chronological order.

Figure 8 – Post-Test Photograph, Test No. 1

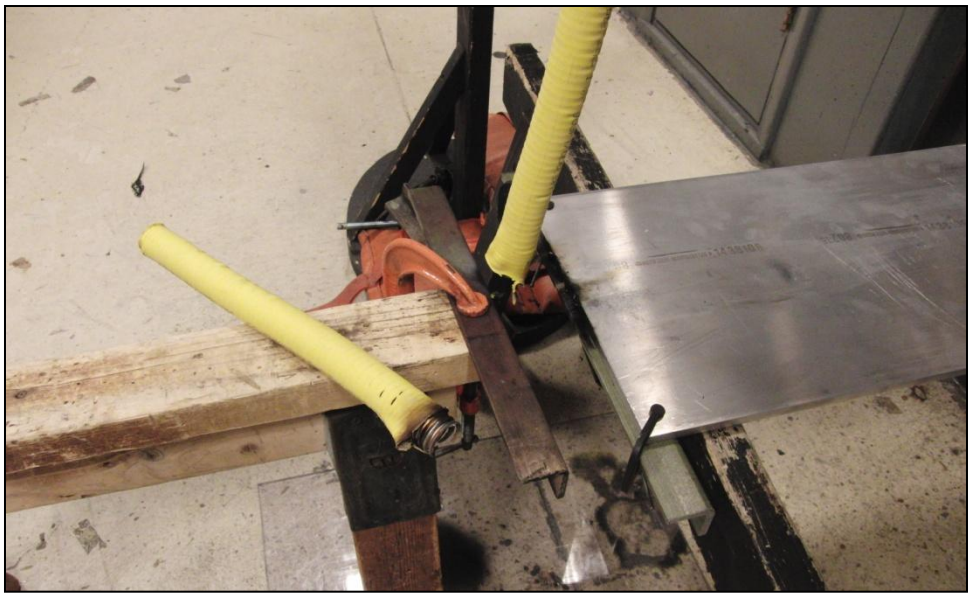


Figure 9 – Post-Test Photograph, Test No. 2

Figure 10 – Post-Test Photograph, Test No. 12

Table 4 – Summary of LC1027 Tests

Test No.	Component 1		Component 2		Component 3			Notes/Results
	Ipk (kA)	Action Integral ($x10^6$ A^2 s)	Ipk/Iav (kA)	Charge in 5ms (C)	Duration (ms)	Total Charge (C)	Average Current (A)	
4 November 2013								
1	31.0	0.05	3.94/2.08	10.4	582	288	495	Tested Black Iron Pipe; Melted Exterior at Test Area; Complete Results will be Provided by Goodson Engineering
2	33.4	0.06	3.94/2.06	10.3	586	264	451	Tested 1" CSST #1; Article Cut in Two; Portion of CSST Vaporized
11	32.8	~0.05	Not Applied					Tested Lightning Detection/Gas Flow Meter Detector Unit; Unit Shut Off Gas Supply before Failing Internally; Waveform went Off Scale (Action Integral is an Estimate)
12	32.8	0.063	Not Applied		406	139	56.4	Tested FlashShield™ Sample; Additional Charge transferred by Component 3 to Compensate for Lack of Component 2; Damage to Outer Jacket but No Damage to CSST

3.2 LC1024 Indirect Effects Tests

CSST #2 was tested twice with faults detected at ~1,300 A and 640 A. An unjacketed CSST sample was tested at first at a low level (304 A) which resulted in no formed hole. Then, it was tested at 1,760 A which did result in a hole. Lastly, a ¾" Counterstrike™ sample was tested at 1,430 A which resulted in a slight crack in the jacket, but no hole. The second test to the 3/4" Counterstrike™ sample was performed at 1,710 A with the jacket intentionally pin pricked prior to test. This test resulted in a hole formed in the jacket and CSST.

Post-test photographs for each test are provided in Figures 11 through 14. The test results are summarized in Table 5. Appendix A provides the raw data oscillograms in chronological order.

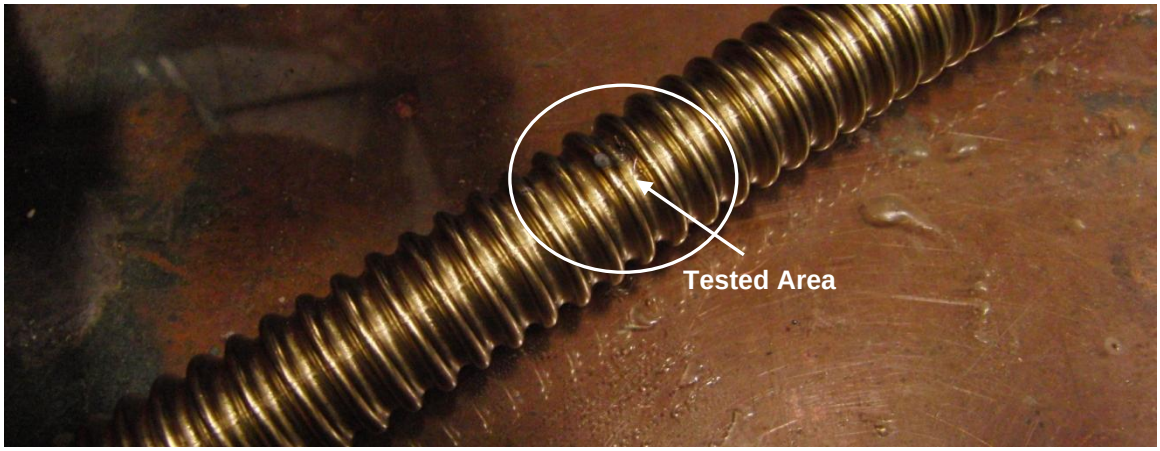


Figure 11 – Post-Test Photograph, Test No. 7

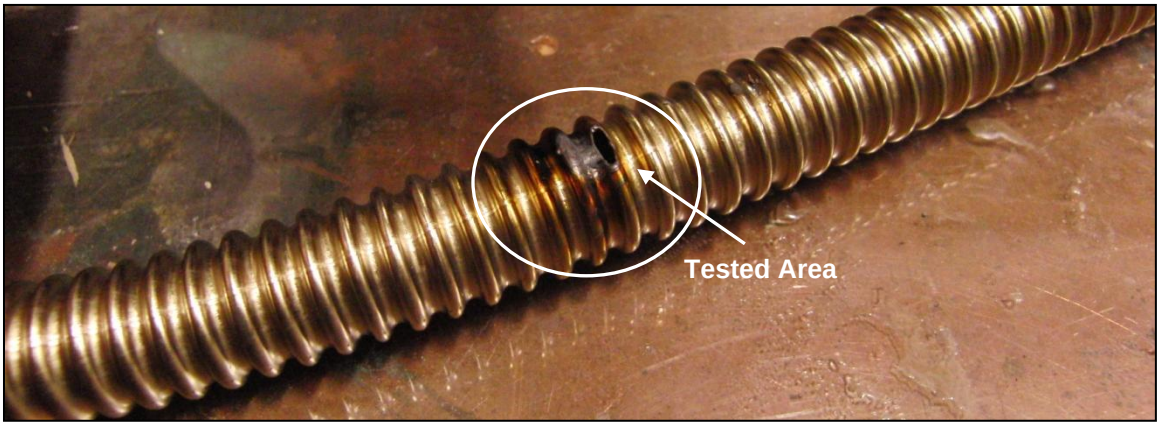


Figure 12 – Post-Test Photograph, Test No. 8

Figure 13 – Test Photograph, Test No. 9

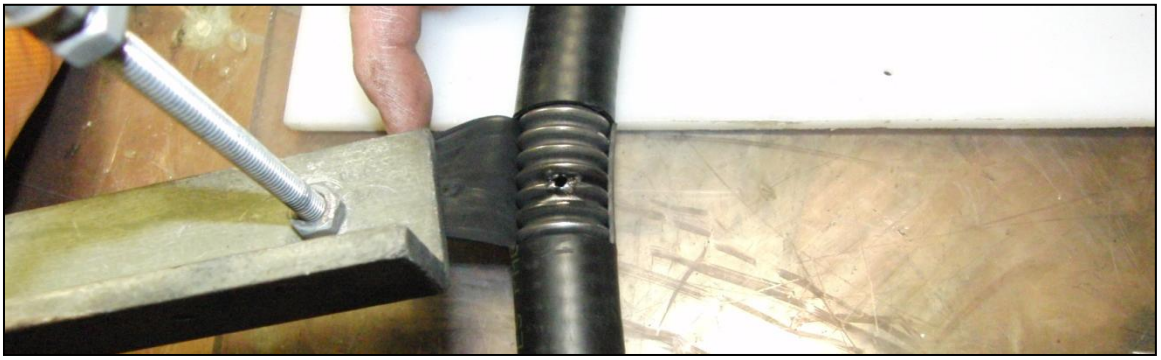


Figure 14 – Post-Test Photograph, Test No. 10

Table 5 – Summary of LC1024 Tests

Test No.	Applied Current		LD/GFD Present (Y/N)	Notes/Results
	Ipk (A)	Charge (C)		
3	~1,300	--	Y	Tested CSST #2; Fault Detected; Waveform Went off Scale; Hole in CSST Jacket
4	640	2.56	Y	Second Test on CSST #2; Fault Detected; Hole in CSST Jacket
5	1,570	6.24	Y	Tested Unjacketed CSST Sample; Sample had Inadvertent Ground; Invalid Test
6	--	--	Y	Tested Unjacketed CSST Sample; No Oscillograms Recorded; Hole Formed in CSST
7	304	1.3	Y	Tested Unjacketed CSST Sample at Low Level; No Hole formed in CSST
8	1,760	6.9	Y	Tested Unjacketed CSST Sample; Hole Formed in CSST
9	1,430	5.3	N	Tested 3/4" Counterstrike™ Sample; Slight Crack in Jacket; No Hole in CSST
10	1,710	6.7	N	Tested 3/4" Counterstrike™ Sample; Jacket Pin Pricked Prior to Test; Hole formed in Jacket and CSST