National Institute for Aviation Research
Wichita State University

1845 N. Fairmount

Wichita, Kansas 67260-0093

21-2152-RR52520

Kansas Aviation Research and Technology (KART)

KART 25.954 (25.981) Fastener Database Composite Report

DISCLAIMER

The results and data of this report apply only to the test articles as listed in the Customer Equipment List and in the environments described.

This report shall not be reproduced except in full without approval of the laboratory.

EXPORT CONTROLLED DATA.

This document may contain technical data whose export is restricted by the International Traffic in Arms Regulations (ITAR) or the Export Administration Regulations (EAR). Violations of these export laws are subject to severe criminal penalties.

Report No: 21-2152-RR52520

Revision -		
Written by:		Date: 05/28/2021
Reviewed by:		Date: 06/29/2021
Approved by:		Date: 11/03/2021
Section	Description	
All	Initial Release of Document	

TABLE OF CONTENTS

List of Abbreviations, Acronyms, and Symbols

A, Amp	Amperes
As	Ampere seconds, unit of charge transfer
ARP	Aerospace Recommended Practice
C	Coulomb
CFR	Code of Federal Regulations
DC, dc	Direct Current
DEL	Direct Effects of Lightning
ETL	Environmental Test Laboratory
kA	Kilo amperes
kAAs, kA^2s	Kilo amperes squared, unit of action integral
µs	Microseconds
ms	miliseconds
NIAR	National Institute for Aviation Research
SAE	Society of Automotive Engineers
Ω	Ohms

LIST OF TABLES

TABLE **TITLE** **PAGE**

LIST OF FIGURES

FIGURE **TITLE** **PAGE**

References and Applicable Documents

Document Number	Description
SAE Aerospace ARP 5412B Revised 2013	Aircraft Lightning Environment and Related Test Waveforms
SAE Aerospace ARP 5414A Reaffirmed 2012	Aircraft Lightning Zone
SAE Aerospace ARP 5416A Revised 2013	Aircraft Lightning Test Methods
14 CFR 25.954	Fuel System Lightning Protection
SAE AE-2 Camera Calibration White Paper	Recommended Camera Calibration and Image Evaluation Methods for Detection of Ignition Sources
NIAR ENV-RP-2016-003–Rev A	KART 25.981 Fastener Database Metal Report

Scope

This document contains the test results and conclusions for the conducted current lightning testing of the test articles in Table 1. Testing took place at the NIAR Environmental Test Lab located at 3800 S. Oliver Wichita, Kansas 67210 and was performed for Kansas Aviation Research and Technology (KART) research project R52520. The test took place from April 26, 2021 to May 28, 2021.

The purpose of these tests are experimental identification of the occurrence of potential ignition sources emanated by a fastener-containing joint as a result of induced lightning conducted current within the joint. The data from this test report will be put towards implementation of the NIAR/WSU KART “Fastener Database” project, the purpose of which is compiling a fastener ignition source threshold database for metal, composite, and hybrid test article coupons containing both nominal and fault fastener installations for the fasteners commonly utilized in aircraft fuel tank structures. The test level at which no visible light is observed, utilizing the photographic test method per ARP 5416A, establishes the ignition source threshold for a particular joint assembly. Detailed test summaries are in Section 5.0 of this report. The waveform parameters and test data table is provided in Appendix A. Photographs of the test setups can be found in Appendix B. Appendix C contains the test article drawings. Appendix D contains the 200 μJ camera calibration documentation.

Test Setup

Test setups for the two lightning generators, the lower amplitude 25.981 generator and the full scale direct effects of lightning (DEL) generator, can be seen in Figure 1 - Figure 5 below. The test articles were oriented such that at both generators, the direction of current flow passed through Joint 3 first and exited through Joint 1.

Figure 1: Nichrome Waveform Verification Strip Installation

Figure 2: 25.981 Generator Test Set Up

Figure 3: Test Camera in Shielded Box

Figure 4: Blowout Film for Pressure Changes in Test Chamber

Figure 5: DEL Generator Test Setup – Test Chamber with Cameras in Shielded Boxes

Figure 6: DEL Generator Test Setup – Generator Output

Use of Multiple Test Cameras

Initial testing, and the majority of testing at 10 kA or below, was performed with cameras 6 and 7. When test levels were increased past 10 kA, these cameras began to malfunction due to electromagnetic interference from the lightning generator. Testing was paused while two replacement cameras (camera 3 and camera 8) were calibrated and shielded boxes were fabricated to protect the new cameras from interference. Testing resumed using cameras 3 and 8 and was completed without any additional camera malfunctions.

Isolating Sparking from Opposite Camera

In many cases, sparking was too bright to determine if the sparks were coming from the head or tail side. This was important to determine, specifically for countersink fasteners, for which sparking is allowable on the head side of the test article (exterior side) but is not allowable on the collar side of the test article (internal to fuel tank). To remedy this issue of spark identification, a physical divider made of tape was placed around the edges of the test article to block off the view of the tail side sparking from the head side camera and vice versa. Calibrated camera thresholds were not used in the analysis due to the extreme light interference. Instead a visual inspection of the photos was implemented to determine if a sparking event took place.

Test Article Intake

There were 32 unique test configurations evaluated, which are listed in Table 1. The test article naming convention can be found in Table 2 below. Nearly half of the configurations were hybrid carbon-fiber-composite and aluminum joints, in which the carbon represented the skin and the aluminum represented internal structure for the test articles with countersink fasteners. In the case of the hybrid joints with protruding fasteners, both the carbon and aluminum coupons represented internal structure. The rest of the test articles were carbon-fiber-composite to composite joints representing both skin to internal structure configurations and internal structure to internal structure configurations.

Composite versus hybrid joints, fastener head type, fastener type, fastener coating, and the presence of faults were variables in the test article configurations that were evaluated for this test.

All test articles were received with the correct pins, collars, and faults. The expected quantity of test articles was received. Some of the test articles were received with extra spots of primer on both the head and tail side of the test article. The faulted fastener hole locations of the CF8-4C20A configuration were not square with the other fastener locations. The CF4-4C20A configuration was received with primer touch-up spots on the head side, which appear to be covering up scratches that were made on the head side instead of the tail side. These erroneous scratches in the fuel tank coating were not expected to impact test results since the primer was repaired.

Table 1: Test Article Configurations

Configuration	Joint Type	Fastener Type	Head Type	Fault Type	Coating
CF9-4C20A	Carbon	Hi-Kote/Hi-Lite	Countersink	Substitute Hi-Kote	
CF9-4C18E	Carbon	Hi-Kote/Hi-Lite	Protruding	Substitute Hi-Kote	
HF9-4C20C	Hybrid	Hi-Kote/Hi-Lite	Countersink	Substitute Hi-Kote	
HF9-4C18D	Hybrid	Hi-Kote/Hi-Lite	Protruding	Substitute Hi-Kote	
CN-4C21A	Carbon	Hi-Lite	Countersink	Nominal	Hi-Kote
CN-4C21E	Carbon	Hi-Lite	Countersink	Nominal	Hi-Kote
CN-4C19E	Carbon	Hi-Lite	Protruding	Nominal	Hi-Kote
HN-4C21C	Hybrid	Hi-Lite	Countersink	Nominal	Hi-Kote
HN-4C19D	Hybrid	Hi-Lite	Protruding	Nominal	Hi-Kote
CF5-4C20A	Carbon	Hi-Lite	Countersink	Composite drill breakout / Burr	
CF7-4C20A	Carbon	Hi-Lite	Countersink	Countersink too deep	
CF4-4C20A	Carbon	Hi-Lite	Countersink	Fuel tank coating scratch	
CN-4C20A	Carbon	Hi-Lite	Countersink	Nominal	
CN-4C20E	Carbon	Hi-Lite	Countersink	Nominal	
CF8-4C20A	Carbon	Hi-Lite	Countersink	Perpendicularity	

CF6-4C20A	Carbon	Hi-Lite	Countersink	Under torque	
CF5-4C18E	Carbon	Hi-Lite	Protruding	Composite drill breakout / Burr	
CF4-4C18E	Carbon	Hi-Lite	Protruding	Fuel tank coating scratch	
CN-4C18E	Carbon	Hi-Lite	Protruding	Nominal	
CF8-4C18E	Carbon	Hi-Lite	Protruding	Perpendicularity	
CF6-4C18E	Carbon	Hi-Lite	Protruding	Under torque	
HF5-4C20C	Hybrid	Hi-Lite	Countersink	Composite drill breakout / Burr	
HF7-4C20C	Hybrid	Hi-Lite	Countersink	Countersink too deep	
HF4-4C20C	Hybrid	Hi-Lite	Countersink	Fuel tank coating scratch	
HN-4C20C	Hybrid	Hi-Lite	Countersink	Nominal	
HF8-4C20C	Hybrid	Hi-Lite	Countersink	Perpendicularity	
HF6-4C20C	Hybrid	Hi-Lite	Countersink	Under torque	
HF5-4C18D	Hybrid	Hi-Lite	Protruding	Composite drill breakout / Burr	
HF4-4C18D	Hybrid	Hi-Lite	Protruding	Fuel tank coating scratch	
HN-4C18D	Hybrid	Hi-Lite	Protruding	Nominal	
HF8-4C18D	Hybrid	Hi-Lite	Protruding	Perpendicularity	
HF6-4C18D	Hybrid	Hi-Lite	Protruding	Under torque	

Table 2: Test Article Naming Convention: AB#-#C#D-#

A	Joint Type	C-Carbon H-Hybrid
B	Nominal or Faulted	N-Nominal F-Faulted
#	Fault Type	4-Scratch 5-Burr 6-Undertorque 7-Countersink Too Deep 8-Perpendicularity 9-Substitute Hi-Kote
#	No. of Fasteners per Joint	4-All joints in this study had 4 fasteners per joint.
C	Fit Type	C-Clearance
#	Unique Pin/Collar Combination	18- HST10BJ8-5/ HST79CY8 19- HST10AG8-5/ HST79CY8 20- HST11BJ8-5/HST79CY8 21- HST11AG8-5/ HST79CY8
D	Coupon Type	A-ECF carbon to plain carbon C-ECF carbon with fiberglass to aluminum D-plain carbon with fiberglass to aluminum E-plain carbon to plain carbon
#	Instance	1-First instance of the configuration 2- Second instance of the configuration 3- Third instance of the configuration 4-Last instance of the configuration

Testing

1.1 Fuel Tank Conducted Current Test Procedure

The non-sparking threshold is defined as the highest test level where no sparking occurs. To find this threshold, begin by testing at 25.981 generator for the 1-10 kA tests.

1. Verify the 25.981 generator waveforms meet requirements by using a dummy test article (Nichrome strip).
2. Measure pre-test DC resistance across each fastener joint prior to testing.
3. Ensure cameras are set to the calibrated settings and focused on the test article.

4. Install test article into copper clamps. Cover edges of the clamping surface with clay or tape to prevent sparking from escaping from this region. Power on and connect all measurement probes to the test article.
5. Begin conducted current testing at 10 kA for the first test article instance (one of the four duplicate test articles) of each configuration. Only the first shot per test article counts toward a threshold to limit the effects of conditioning due to damage resulting from the test.
    a. If no spark occurs at 10 kA, the next test level should be increased. The remaining test articles for that configuration will be tested at the DEL generator.
    b. If a spark occurs at 10 kA, the next test level should be decreased. Move on to the next instance of that test article configuration. Decrease the test amplitude by half and test again. If no spark is observed, replace the test article with the next instance of the configuration and increase the test level to 7 kA. Continue to increase or decrease the current based on the presence of a spark until a maximum non-sparking threshold is obtained.
6. Measure the post-test DC resistance across each fastener joint before and after each shot.

Once all configurations have been tested at the 25.981 generator, those that did not spark at or below 10 kA will be tested at the DEL generator at increased current amplitudes.

1. Verify the DEL generator waveforms meet requirements.
2. Measure pre-test DC resistance across each fastener joint prior to testing.
3. Ensure cameras are set to the calibrated settings and focused on the test article.
4. Install test article into copper clamps. Cover edges of the clamping surface with clay or tape to prevent sparking from escaping from this region. Power on and connect all measurement probes to the test article.
5. Begin conducted current testing on the next untested instance at 60 kA.

   a. If no spark is observed at 60 kA, test the next instance at 100 kA. If no spark is observed at 100kA, testing is complete. If there is a spark at 100kA, test the next instance at 80 kA.
   b. If a spark is observed at 60 kA, test the next instance at 30 kA. If no spark is observed at 30kA, test the next instance at 40 kA. If a spark is observed at 30 kA, test the next instance at 20 kA.
6. Measure the post-test DC resistance across each fastener joint before and after each shot.

Test Image Analysis

Sparking from countersink fasteners was evaluated differently than sparking from protruding fasteners.

- For test articles with countersink fasteners, sparking was considered a failure (counted towards the threshold) only if it occurred on the tail side or between the plates of the test article.
- For test articles with protruding fasteners, all sparking – tail side, between the plates, and head side – is considered a failure (counts to the threshold).

The difference in spark evaluation is due to the location of the fastener head types in the fuel tank. Countersink fasteners are typically installed on skin surfaces, for which the fastener heads are external to the fuel tank environment. Sparking on the external side of the tank is not considered a threat of ignition. Sparking at the fastener tail side, as well as sparks escaping from between the plates are both located inside the fuel tank environment and are considered ignition sources for countersink fasteners.

Protruding fasteners are typically installed in internal structure locations and thus any sparking from the head or tail of these fasteners can act as an ignition source. All following analysis will separate the data for the protruding and countersink head fasteners, as the non-sparking threshold criteria for the two types were different.

Table 3 - Equipment Used For Conducted Current Testing

Description	Manufacturer	Model Number	Serial Number	Cal Due Date
Mixed Signal Oscilloscope-LIMITED CAL	Agilent	MSO6104A	MY44004620	9/30/2021
4 Channel 500 MHz 20 GSPS Oscilloscope	Tektronix	DPO7054C	C302445	2/28/2022
Current Monitor Probe 100:1	Pearson Electronics Inc.	101	157914	2/28/2022
Milliohm Meter	Hioki	RM3548	160526787	9/30/2021
High Current Generator	NIAR	HC1	001	N/A
Current Monitor Probe	Pearson Electronics Inc.	301X	147836	8/28/2021
HV Power Supply	Spellman	SL8PN2000X4 874	102151349-A00001	N/A
Oscilloscope	Yokogawa	DL850E	91P313729	9/30/2021
Current Probe 1:1500	Danisense	DS600IDSA	14170020014	12/12/2021
Current Monitor Probe	Pearson Electronics Inc.	1423	147997	8/28/2021
Analog Voltage Input Module	Yokogawa	701250	91P321170	9/30/2021
HV Power Supply	Spellman	STR70N6/200/ 3PHASE	102186808-A00003	N/A
Analog Voltage Input Module	Yokogawa	701250	91P321166	9/30/2021
#3 EOS Rebel 18-55mm Camera Lens	Canon	EFS 18-55mm	1446092416	N/A
#3 EOS Rebel	Canon	DS126311	402077002849	N/A
#8 EOS Rebel T3i Camera	Canon	DS126311	402077002846	N/A
#8 EOS Rebel 18-55mm Camera Lens	Canon	EFS 18-55mm	1446092413	N/A
#6 EOS Rebel 18-55mm Camera Lens	Canon	EFS 18-55mm	610204005366	N/A
#6 EOS Rebel T6i Camera	Canon	DS126571	352072015432	N/A
#7 EOS Rebel 18-55mm Camera Lens	Canon	EFS 18-55mm	610204005502	N/A
#7 EOS Rebel T6i Camera	Canon	DS126571	352072015496	N/A

1.2 <u>Results/Discussion</u>

Thickness measurements of the fuel tank coating primer were taken in three locations across each test article. This was done to ensure that the paint thickness was reasonably uniform and would not impact the testing. The paint thickness averages of the three measurements per test article for the four test article instances of each configuration are shown in Figure 7. From this graph, it is clear that the paint thickness is reasonably uniform. Figure 8 shows the average paint thickness of the specific test article that the non-sparking threshold was obtained on for each configuration. From this graph, it is clear that there is no trend between paint thickness and the non-sparking threshold.

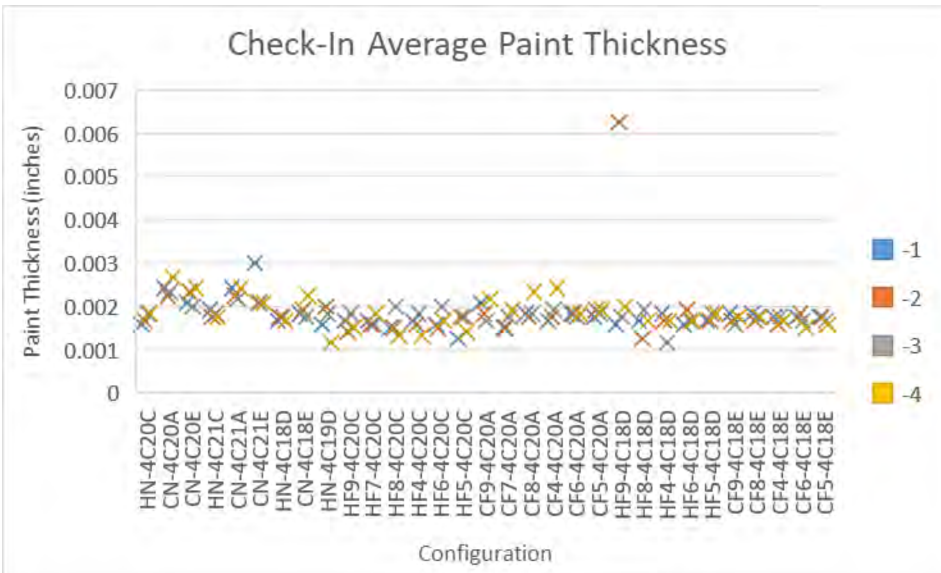


Figure 7: Average Paint Thickness at Check In

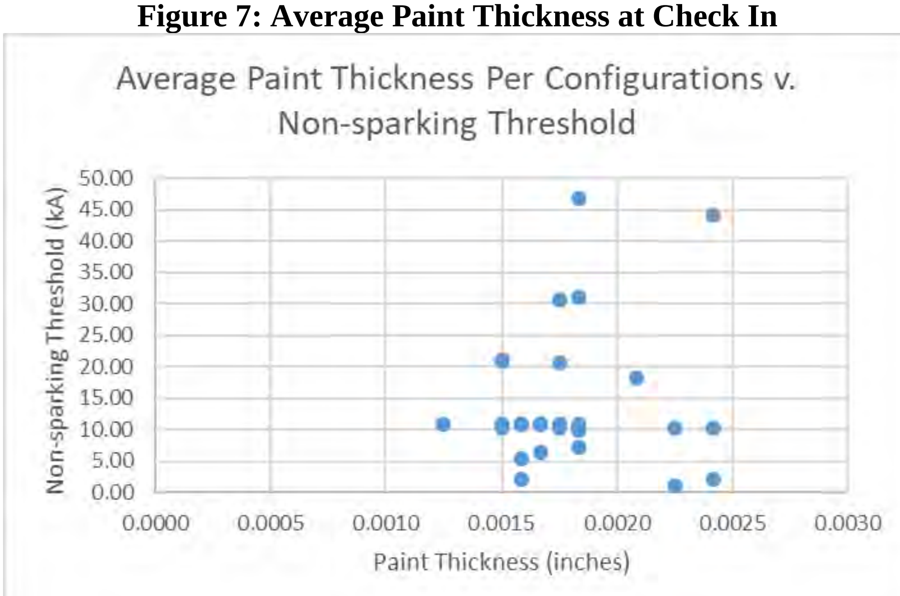


Figure 8: Paint Thicknesses v. Non-sparking Threshold

DC resistance measurements were taken across each joint for each test article instance both before and after testing. These measurements were used to determine if the pre-test measurements could be correlated with the maximum non-sparking threshold levels. Average DC resistance measurements were also compared between the pre-test and post-test measurements to determine whether conditioning took place as a result of the test. In Figure 9 below are the pre-test DC measurements for the specific test article instance that resulted in the threshold for each configuration, plotted against said threshold for protruding head fasteners. The complimentary graph for the countersink fasteners is in Figure 10. No clear trend emerged between the pre-test DC resistance measurements and the non-sparking thresholds.

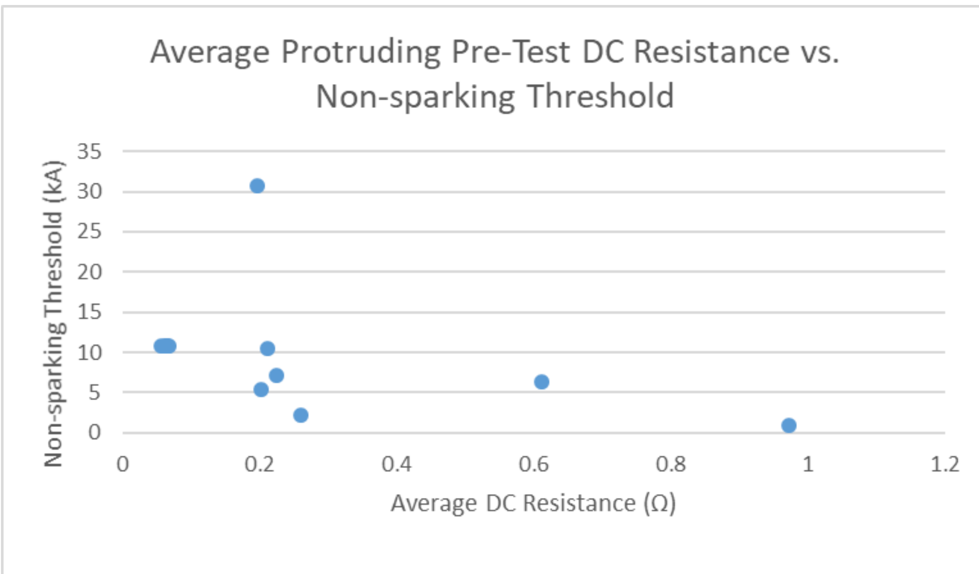


Figure 9: Average Protruding Pre-test DC Resistance vs. Non-sparking Threshold

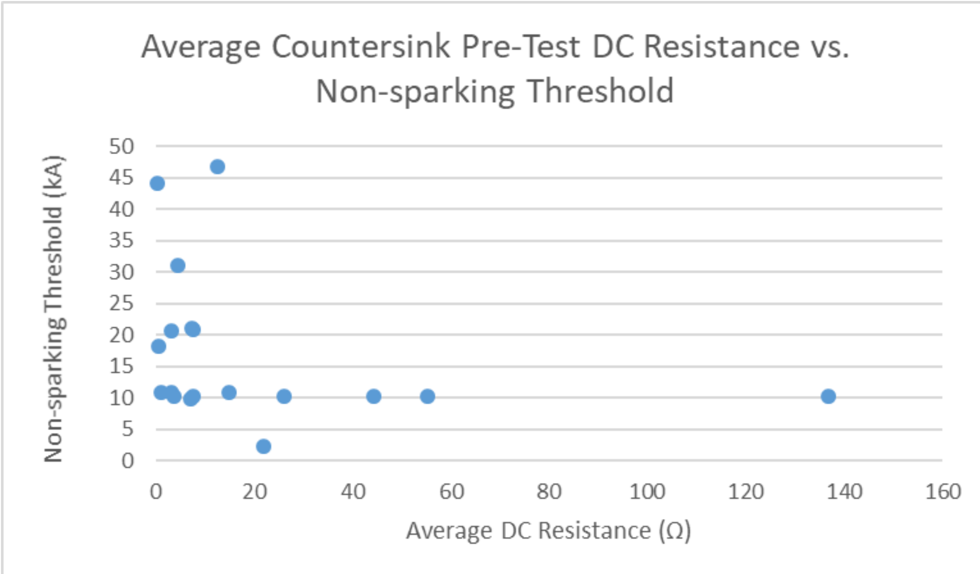


Figure 10: Average Countersink Pre-test DC Resistance vs. Non-sparking Threshold

The pre and post-test DC measurements were plotted against each other to study the conditioning effects of the lightning events in Figure 11 for the protruding fasteners and Figure 12 for the countersink fasteners. The DC resistance decreased after testing protruding head configurations 61% of the time, and 100% of the time for countersink configurations. The decrease in DC resistance after testing was not by a consistent or predictable amount. The 39% of protruding fasteners which had an increase in DC resistance after testing were all faulted configurations. Of those faulted configurations, two were composite joints and five were hybrid joint configurations.

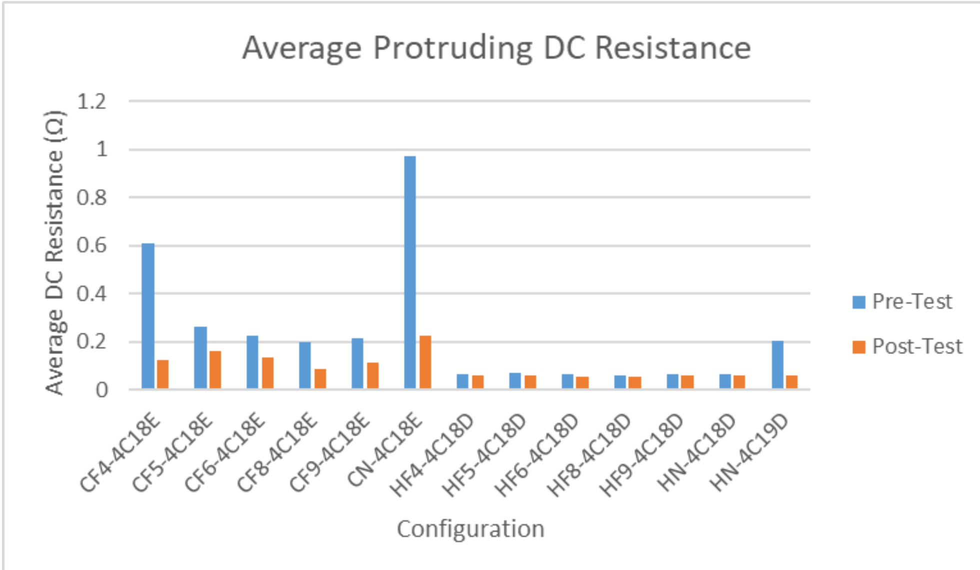


Figure 11: Average DC Resistance for Protruding Head Fasteners

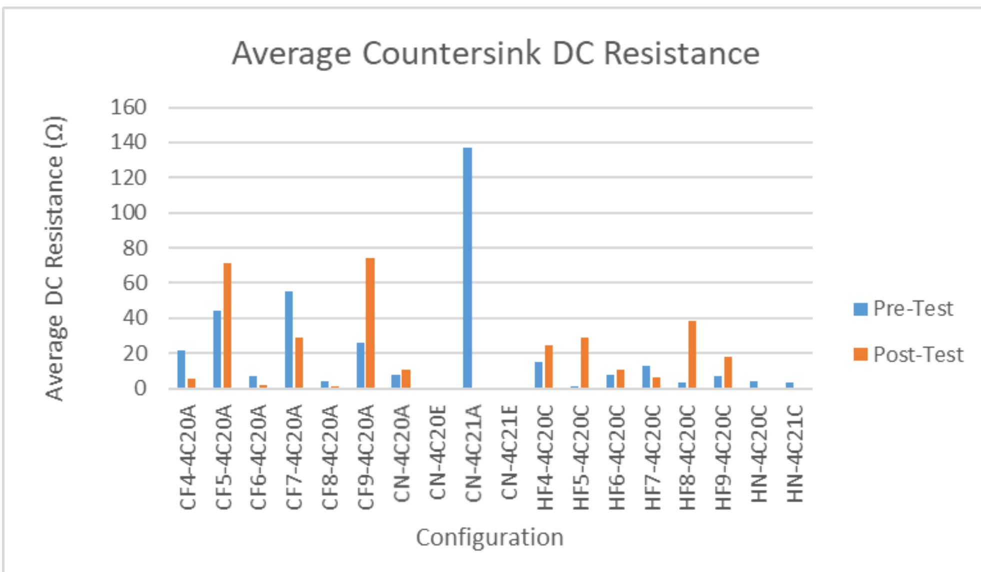


Figure 12: Average DC Resistance for Countersink Head Fasteners

The non-sparking thresholds that resulted from this work can be found in Figure 13 and Figure 14 for protruding head and countersink head fasteners respectively. To minimize the effects of conditioning, only the first shot on each test article is valid. Of those, the shot with the highest peak current value that did not result in a sparking event is considered the non-sparking threshold. The only configuration for which no threshold was obtained was the non-conductive, protruding, composite test article configuration (CN-4C19E). This particular test article sparked at every test level, including the lower limit of testing of 1 kA, and thus no threshold could be determined. Specific factors were selected for test article configurations to determine which affected the non-sparking threshold. The following discussion considers each of these factors. The factors that were considered in testing were:

1. Fastener Coatings
2. Fault Type
3. Joint Type

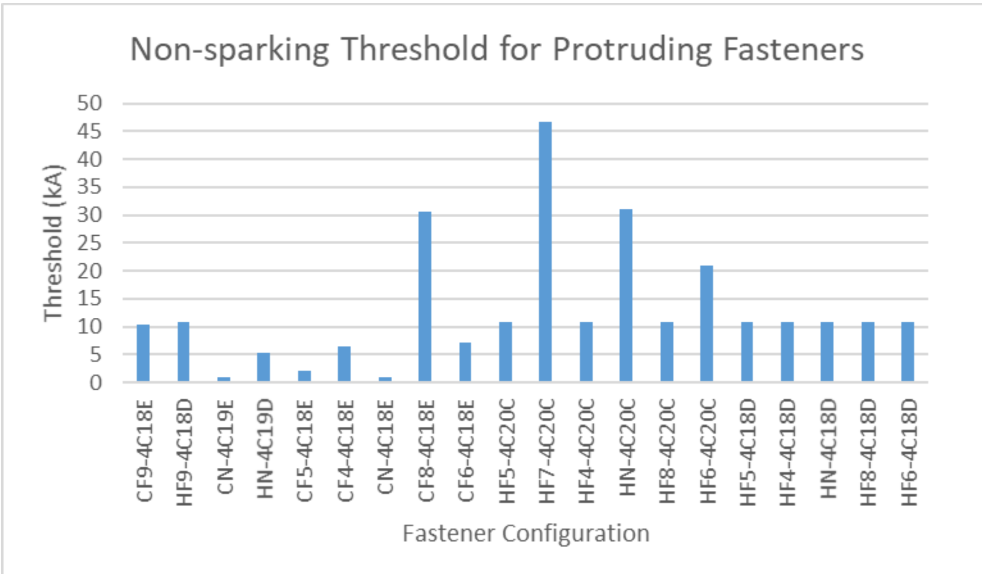


Figure 13: Non-sparking Threshold for Protruding Fasteners

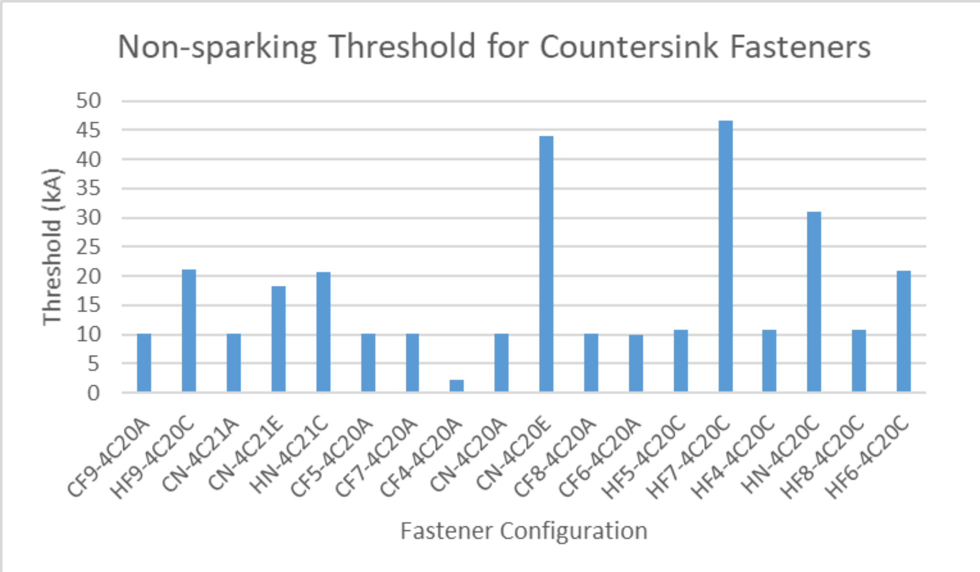


Figure 14: Non-sparking Threshold for Countersink Fasteners

Factor 1 – Fastener Coating

Two types of fastener coatings were evaluated:

1. Conductive – aluminum ion vapor deposition (IVD) layer.
2. Non-conductive: Hi-Kote phenolic-based aluminum coating.

Overall, the hybrid configurations had higher non-sparking thresholds than composite configurations for both protruding and countersink fasteners. The non-conductive fasteners reduced the threshold for hybrid joints when compared to the conductive fasteners in hybrid joints. The composite joints had lower non-sparking thresholds overall, though it appears that the nonconductive fasteners did not further reduce the non-sparking threshold when compared to the conductive fasteners. This is likely because the resistive nature of the composite-composite joints had more of an effect than the fastener coating. Similar results were seen in both the protruding and countersink fasteners, seen in Figure 15 and Figure 16 below.

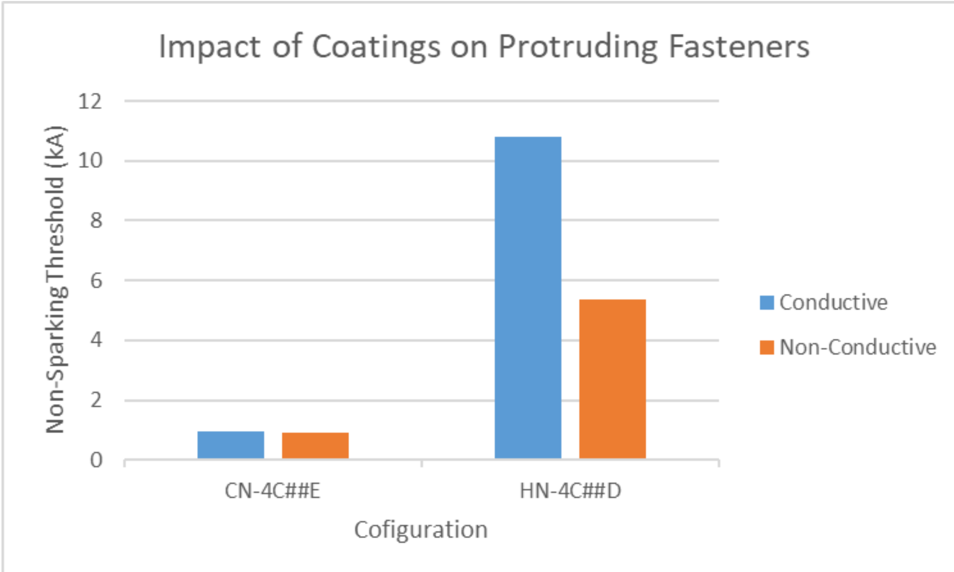


Figure 15: Impact of Fastener Coatings on Protruding Fasteners

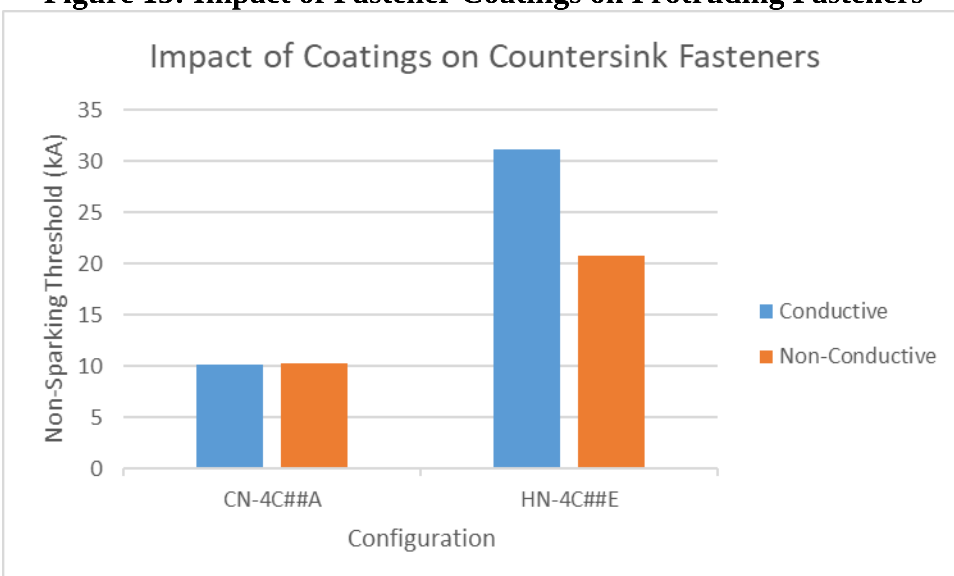


Figure 16: Impact of Fastener Coatings on Countersink Fasteners

Factor 2 – Fault Type

Of the configurations with a conductive protruding head fastener, on average, those with the perpendicularity fault had a higher non-sparking threshold than any other configuration (21 ± 14 kA), including the nominal installations (6 ± 7 kA). The under torque and scratch faults also had slightly higher non-sparking thresholds than the nominal configurations did at 9 ± 3 kA. In fact, the only conductive faulted configuration that performed similarly to the conductive nominal installations was the burr fault (6 ± 6 kA).

There were two types of configurations containing nonconductive protruding fasteners: a nominal configuration and the faulted substitute Hi-Kote installations. The nominal configurations included four Hi-Kote fasteners per joint, while the faulted installation included one Hi-Kote fastener per joint, along with three conductive IVD coated fasteners. The faulted configuration had a higher average non-sparking threshold (10.6 ± 0.3 kA) than the nominal nonconductive configuration (3 ± 3 kA).

On average for protruding head fasteners, the nominal configurations, regardless of fastener coating, had lower non-sparking thresholds than some of the faulted configurations. This result may be due to manufacturing variability and/or the small sample size of comparable configurations, since the faulted configurations were expected to have the lower non-sparking thresholds then their nominal counterparts.

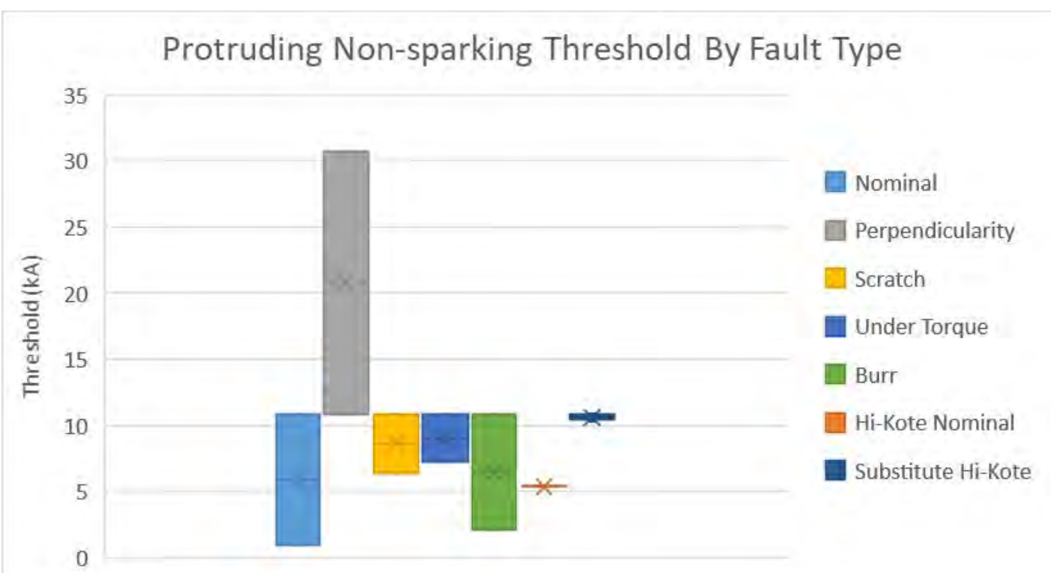


Figure 17: Protruding Conductive Non-sparking Threshold by Fault Type

Of the configurations with conductive countersink head fasteners, on average, those with the countersink too deep fault had a higher non-sparking threshold than any other configuration (28 ± 26 kA), including the nominal installations (14 ± 19 kA). The perpendicularity and burr faults both had average thresholds of 10 ± 0.5 kA. The under torque and scratch faults had average thresholds of 15 ± 8 kA, and 6 ± 6 kA.

There were two configurations with nonconductive countersink fasteners: nominal Hi-Kote and the faulted substitute Hi-Kote installations. The nominal installation included four Hi-Kote fasteners per joint, and the faulted installation included one Hi-Kote fastener per joint, along with three conductive IVD coated fasteners. The faulted nonconductive configuration had a lower average threshold (15 ± 8 kA) than the nominal nonconductive configuration (16 ± 5 kA), though not by a significant amount.

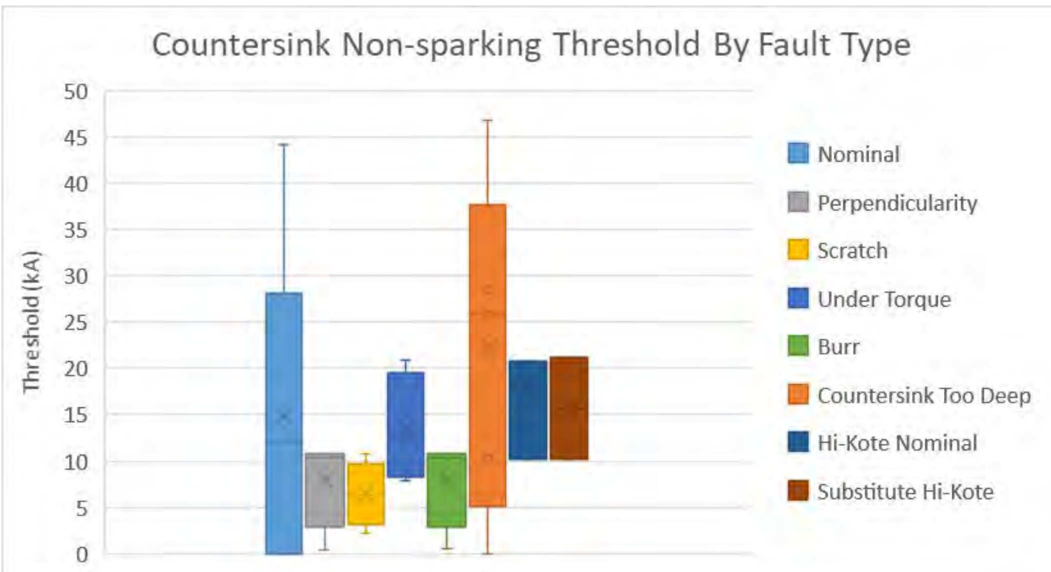


Figure 18: Countersink Conductive Non-sparking Threshold by Fault Type

Factor 3 – Joint Type

Hybrid joints had higher non-sparking thresholds than composite joints, as seen in Figure 15 and Figure 16, and Figure 19 and Figure 20. This was expected, as the aluminum coupon conductivity is higher than the carbon fiber coupon conductivity. The only configuration where the composite joint had a higher non-sparking threshold than the corresponding hybrid joint was for protruding head fasteners installed with a perpendicularity fault.

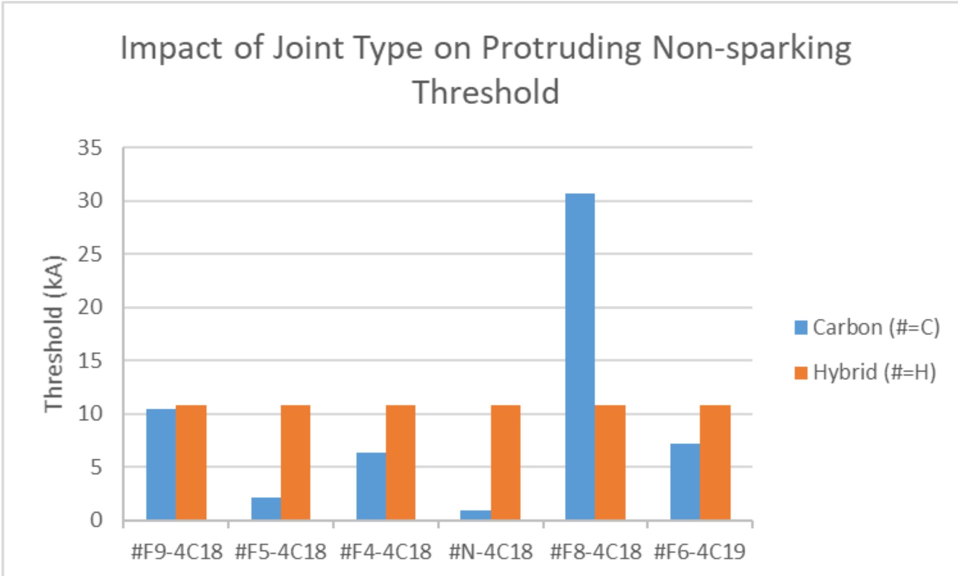


Figure 19: Impact of Joint Type on Protruding Non-sparking Threshold

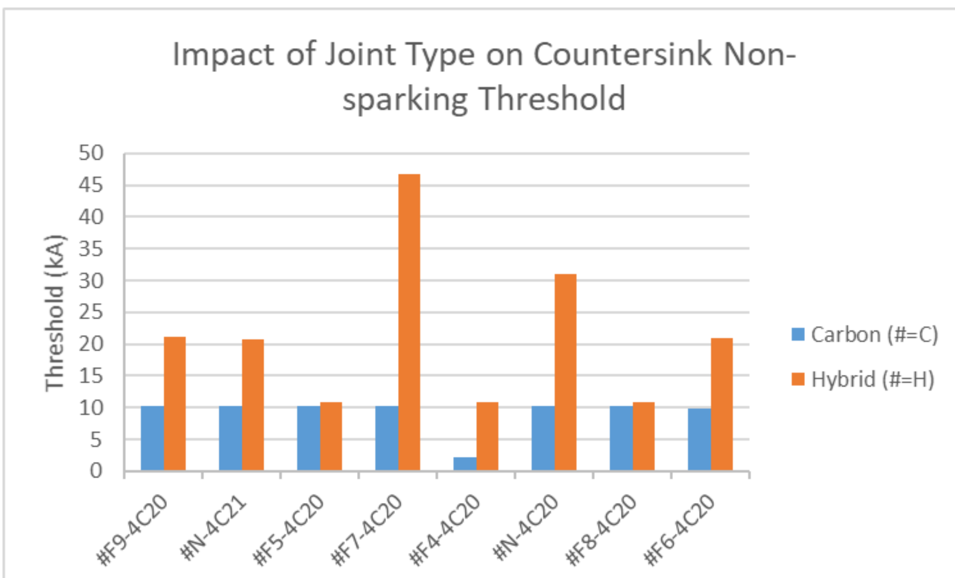


Figure 20: Impact of Joint Type on Countersink Non-sparking Threshold

Anomalies

The all composite, protruding head fastener test article with nonconductive Hi-Kote fasteners configuration, CN-4C19E, resulted in anomalous data. The CN-4C19E-1 test article was tested at 10 kA. This protruding configuration had head side sparking at all three joints and failed the 10 kA test level. The CN-4C19E-2 test article was tested at 3 kA and failed due to head side sparking at joint 3. The CN-4C19E-3 test article was tested at 1 kA – which is the lowest test level – and failed due to head side sparking at joint 1. No threshold was obtained because the lightning generator could not be reduced to lower test levels than 1 kA. The very low undiscovered threshold for this configuration was likely due to the non-conductive coating on the protruding fasteners. This configuration was the only non-conductive protruding configuration that was tested. The only other nonconductive protruding configuration was a hybrid (5 kA) which almost always had higher thresholds than the carbon configurations.

Conclusions

- Only taking into account instances which resulted in a threshold, average DC resistance values per configuration decreased after lightning testing for all countersink configurations and 61% of protruding configurations.
- Fasteners with nonconductive Hi-Kote coating have lower non-sparking thresholds in hybrid configurations than fasteners with aluminum IVD coating.
- Faulted protruding head fasteners had higher non-sparking thresholds than the nominal protruding head installations on average.
- The countersink too deep faulted configuration had the highest average non-sparking threshold (28 kA) of any conductive countersink configuration.
- The countersink “substitute Hi-Kote” faulted installations had higher non-sparking thresholds than the nominal Hi-Kote installations. This was expected as there was only one nonconductive Hi-Kote fastener and three conductive IVD fasteners per joint in the faulted configuration, but four Hi-Kote fasteners per joint in the nominal configuration.
- Hybrid joints (aluminum to carbon fiber composite) had higher non-sparking thresholds than composite to composite joints in every configuration except for one (protruding head fasteners with a perpendicularity fault).
- On average, protruding head fasteners had lower non-sparking thresholds than configurations with countersink fasteners, primarily because sparking at the head side of the fastener was considered in determining non-sparking thresholds for

protruding head fasteners (internal fuel tank configurations) but was not considered for countersink head fasteners (fastener heads external to fuel tank).

Appendix A – Waveforms and Test Data

Scaled Down 25.981 Generator

A scaled-down conducted-current lightning generator, purposely constructed for this KART project, was utilized during testing. The generator was built having a 1-to-20 target ratio with respect to full-threat generator characteristics per ARP 5412A. The scaled waveforms are shown in Figure 1 and Figure 2. The rationale for the design was based on scaling down the action integral parameter of the full-threat current Component A, while the total charge transferred was scaled to obtain the reduced Component B current (Charge = Current x Time). Finally, the scaled Component B waveform was extended beyond its designated 5-ms duration in order to account for the charge transfer contributed by the scaled C*.

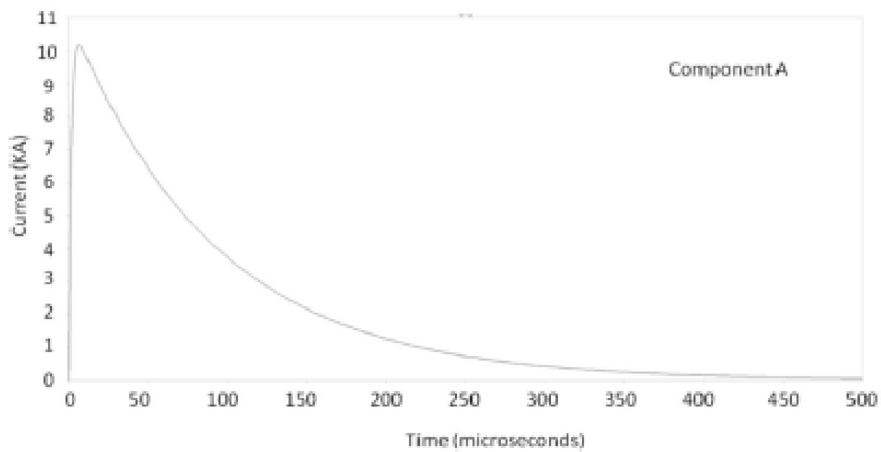


Figure 1: Scaled Down Component A Waveform

The characteristics for the scaled current **Component A** include:

- Unidirectional waveform
- $5.0 \cdot 10^3$ A^2s (±20%) action integral within 500 µs
- 10 kA (±10%) peak current amplitude
- ≤ 50 µs rise time between 10% and 90% of peak amplitude
- 70 µs time to 50% decay
- Total time to 1% peak not exceeding 500 µs.

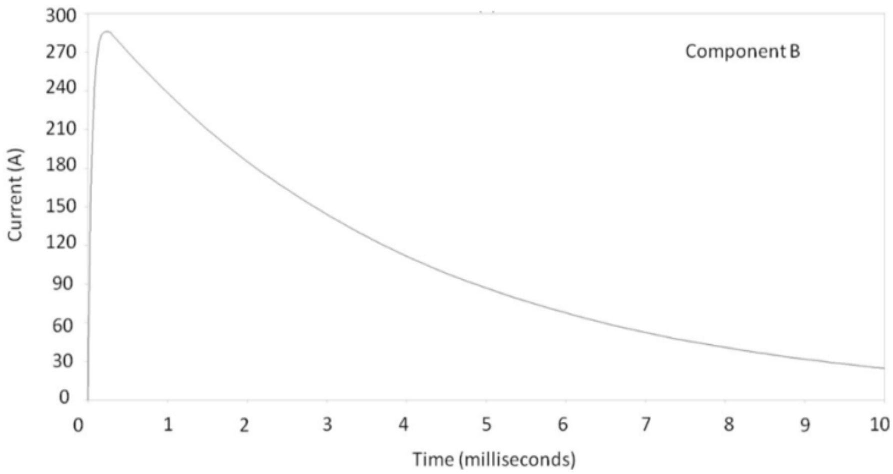


Figure 2: Scaled Down Component B/C* Waveform

The characteristics for the scaled current **Component B/C*** include:

- Unidirectional waveform
- 171 A (±20%) average current
- 290 A peak current
- 1.4 C (±10%) total charge transfer.

DEL Generator

A full-scale direct effects of lightning generator was also used for testing at increased current amplitudes ranging from 20kA to 60kA. Sample waveforms are shown below in **Error! Reference source not found.** and **Error! Reference source not found.**.

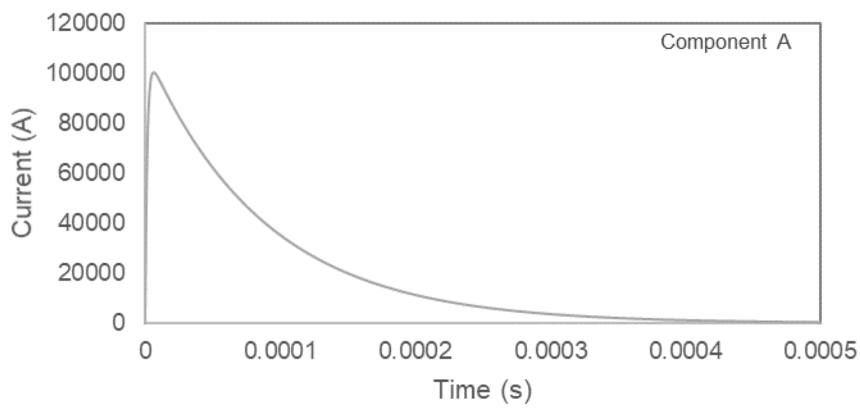


Figure 3: Full Scale Component A Waveform

The characteristics for the scaled current component A include:

- Unidirectional waveform
- 250 kA^2s±20% action integral in 500 µs
- Peak current of 100 kA
- 6.4 µs rise time, 70 µs to 50% decay
- Total time ≤ 500µs

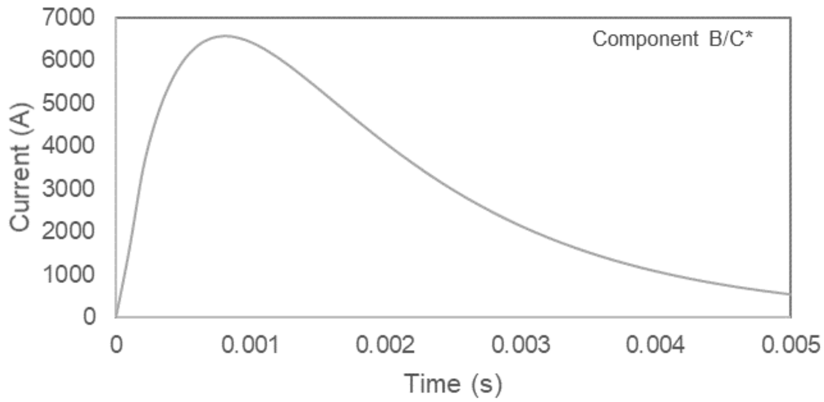


Figure 4: Full Scale Component B/C* Waveform

The characteristics for the current component B/C* include:

- Unidirectional waveform
- 3 kA average current
- 6.5 kA peak current
- 0.8 ms rise time
- 14 C total charge transfer

The tables below contain data from testing, including the measured and expected waveform parameters and all relevant sparking events. All configurations and test levels are included. The test point which resulted in the threshold level for each configuration is in bold text.

Table 1: Test Data

Configuration	Shot #	Charge Transfer (As)		Current (kA)		Action Integral (kAAs)		Sparking	Pass/Fail	Head Type
		Measured	Expected (± 10%)	Measured	Expected (± 10%)	Measured	Expected (± 20%)			
HN-4C20C-1	1	1.3	1.4	10.48	10	4.571	5.0000	No	Pass	Countersink
HN-4C20C-1	2	N/A	2.29	15.01	15	8.5	10.8183	No	Pass	Countersink
HN-4C20C-1	3	2.68	2.86	20.53	20	16.03	20.2034	No	Pass	Countersink
HN-4C20C-1	4	4.48	4.59	30.4	30	38.8	46.3033	No	Pass	Countersink
HN-4C20C-1	5	5.95	5.95	41	40	69.13	88.3645	No	Pass	Countersink
HN-4C20C-1	6	7.07	7.12	47.8	50	94.47	120.9416	No	Pass	Countersink
HN-4C20C-1	7	8.58	8.72	57.33	60	136.52	179.7895	No	Pass	Countersink
HN-4C20C-2	1	8.55	8.72	62.13	60	155.83	179.7895	No	Pass	Countersink
HN-4C20C-3	1	8.54	8.72	62.3	60	157.4	179.7895	Tail J3	Fail	Countersink
HN-4C20C-4	**1**	**4.41**	**4.59**	**31.1**	**30**	**39.18**	**46.3033**	**No**	Pass	**Countersink**
CN-4C20A-1	1	0.67	0.7	5.04	5	1.091	1.2500	No	Pass	Countersink
CN-4C20A-1	2	0.35	0.42	3.04	3	393.8	0.4590	No	Pass	Countersink
CN-4C20A-1	3	0.85	0.98	7.28	7	2.212	2.5000	No	Pass	Countersink
CN-4C20A-1	4	1.24	1.4	10.16	10	4.442	5.0000	Tail J1	Fail	Countersink
CN-4C20A-2	**1**	**1.26**	**1.4**	**10.16**	**10**	**4.436**	**5.0000**	**No**	Pass	**Countersink**
CN-4C20A-3	1	8.5	8.72	57	60	111.7	179.7895	Tail J1, J3	Fail	Countersink
CN-4C20A-4	1	4.39	4.59	29.67	30	29.18	46.3033	Tail J1, J2	Fail	Countersink
CN-4C20E-1	1	1.3	1.4	10.16	10	4.414	5.0000	No	Pass	Countersink
CN-4C20E-2	1	8.47	8.72	55.27	60	102.1	179.7895	Tail J2	Fail	Countersink
CN-4C20E-3	1	4.49	4.59	32.67	30	34.56	46.3033	No	Pass	Countersink
CN-4C20E-4	**1**	**5.63**	**5.95**	**44.1**	**40**	**63.4**	**88.3645**	**No**	Pass	**Countersink**
HN-4C21C-1	1	1.3	1.4	10.24	10	4.448	5.0000	No	Pass	Countersink
HN-4C21C-2	1	8.59	8.72	61.87	60	152.38	179.7895	Tail J1, J2, J3	Fail	Countersink
HN-4C21C-3	1	4.41	4.59	32.2	30	39.8	46.3033	Tail J2	Fail	Countersink
HN-4C21C-4	**1**	**2.94**	**2.86**	**20.73**	**20**	**15.78**	**20.2034**	**No**	**Pass**	**Countersink**
CN-4C21A-1	**1**	**N/A**	**1.4**	**10.24**	**10**	**4.43**	**5.0000**	**No**	**Pass**	**Countersink**
CN-4C21A-2	1	N/A	8.72	56.27	60	105.25	179.7895	Tail J1, J2, J3	Fail	Countersink
CN-4C21A-3	1	3.07	2.86	18.67	20	10.74	20.2034	Tail J2	Fail	Countersink
CN-4C21E-1	1	1.33	1.4	10.08	10	4.406	5.0000	No	Pass	Countersink
CN-4C21E-2	1	8.34	8.72	55.93	60	105.03	179.7895	Tail J1, J2, J3	Fail	Countersink
CN-4C21E-3	**1**	**3.2**	**2.86**	**18.2**	**20**	**10.2**	**20.2034**	**No**	**Pass**	**Countersink**
CN-4C21E-4	1	5.89	5.95	44.3	40	64.85	88.3645	Tail J1, J2	Fail	Countersink
HN-4C18D-1	1	N/A	0.7	5.6	5	1.258	1.2500	No	Pass	Protrouding
HN-4C18D-1	2	1.32	1.4	10.8	10	4.703	5.0000	No	Pass	Protrouding
HN-4C18D-2	**1**	**1.34**	**1.4**	**10.8**	**10**	**4.743**	**5.0000**	**No**	**Pass**	**Protrouding**
HN-4C18D-3	1	4.63	4.59	31.47	30	37.57	46.3033	Head J1, J2, J3	Fail	Protrouding
HN-4C18D-4	1	3.21	2.86	20.47	20	14.87	20.2034	Head J2, J3	Fail	Protrouding
CN-4C18E-1	1	N/A	1.4	10.16	10	4.397	5.0000	Head J1, J2, J3	Fail	Protrouding
CN-4C18E-1	2	N/A	1.4	10.24	10	4.422	5.0000	No	Pass	Protrouding
CN-4C18E-2	1	0.67	0.7	5	5	1.086	1.2500	Tail J3	Fail	Protrouding
CN-4C18E-3	1	N/A	0.28	2.16	2	0.1873	0.2000	Head J3	Fail	Protrouding
CN-4C18E-4	**1**	**N/A**	**0.14**	**0.96**	**1**	**41.2**	**0.0500**	**No**	**Pass**	**Protrouding**
HN-4C19D-1	**1**	**0.66**	**0.7**	**5.36**	**5**	**1.161**	**1.2500**	**No**	**Pass**	**Protrouding**
HN-4C19D-1	2	1.32	1.4	10.8	10	4.689	5.0000	No	Pass	Protrouding
HN-4C19D-2	1	1.32	1.4	10.6	10	4.645	5.0000	Head J1, J2, J3	Fail	Protrouding
HN-4C19D-3	1	0.94	0.98	7.6	7	2.326	2.5000	Head J3	Fail	Protrouding
HN-4C19D-4	1	0.8	0.84	6.6	6	1.75	1.8400	Head J2, J3	Fail	Protrouding
CN-4C19E-1	1	0.67	1.4	10	10	4.336	5.0000	Head J1, J2, J3	Fail	Protrouding
CN-4C19E-2	1	0.39	0.42	2.9	3	0.3781	0.4590	Head J3	Fail	Protrouding
CN-4C19E-3	1	0.11	0.14	0.92	1	39.76	0.0500	Head J1	Fail	Protrouding
HF9-4C20C-1	1	1.31	1.4	10.8	10	4.76	5.0000	No	Pass	Countersink
HF9-4C20C-2	1	8.52	8.72	61.33	60	155.98	179.7895	Tail J3	Fail	Countersink
HF9-4C20C-3	1	4.39	4.59	32.13	30	41.66	46.3033	Tail J3	Fail	Countersink
HF9-4C20C-4	**1**	**N/A**	**2.86**	**21.13**	**20**	**17.52**	**20.2034**	**No**	**Pass**	**Countersink**
HF7-4C20C-1	1	1.29	1.4	10.8	10	4.733	5.0000	No	Pass	Countersink
HF7-4C20C-2	1	8.39	8.72	61.47	60	156.67	179.7895	Tail J3	Fail	Countersink
HF7-4C20C-3	1	4.32	4.59	31.93	30	42.27	46.3033	No	Pass	Countersink
HF7-4C20C-4	**1**	**5.93**	**5.95**	**46.73**	**40**	**91.54**	**88.3645**	**No**	**Pass**	**Countersink**
HF8-4C20C-1	**1**	**1.34**	**1.4**	**10.8**	**10**	**4.765**	**5.0000**	**No**	**Pass**	**Countersink**
HF8-4C20C-2	1	8.44	8.72	62.07	60	157.26	179.7895	Tail J3	Fail	Countersink
HF8-4C20C-3	1	5.77	5.95	43.6	40	80.29	88.3645	Tail J3	Fail	Countersink
HF8-4C20C-4	1	3.14	2.86	20.87	20	17.02	20.2034	Tail J2	Fail	Countersink
HF4-4C20C-1	**1**	**1.31**	**1.4**	**10.8**	**10**	**4.77**	**5.0000**	**No**	**Pass**	**Countersink**
HF4-4C20C-2	1	N/A	8.72	60.93	60	158.47	179.7895	Tail J2, J3	Fail	Countersink
HF4-4C20C-3	1	4.48	4.59	32.73	30	43.68	46.3033	Tail J3	Fail	Countersink
HF4-4C20C-4	1	2.92	2.86	20.87	20	17.56	20.2034	Tail J3	Fail	Countersink

Configuration	Shot #	Charge Transfer (As)		Current (kA)		Action Integral (kAAs)		Sparking	Pass/Fail	Head Type
		Measured	Expected (± 10%)	Measured	Expected (± 10%)	Measured	Expected (± 20%)			
HF5-4C20C-1	**1**	**1.3**	**1.4**	**10.8**	**10**	**4.747**	**5.0000**	**No**	**Pass**	**Countersink**
HF5-4C20C-2	1	8.68	8.72	61.13	60	159.78	179.7895	Tail J1, J2, J3	Fail	Countersink
HF5-4C20C-3	1	4.5	4.59	32.05	30	42.62	46.3033	Tail J1, J3	Fail	Countersink
HF5-4C20C-4	1	3.16	2.86	21	20	17.78	20.2034	Tail J1, J3	Fail	Countersink
CF9-4C20A-1	**1**	**1.3**	**1.4**	**10.16**	**10**	**4.44**	**5.0000**	**No**	**Pass**	**Countersink**
CF9-4C20A-2	1	8.59	8.72	63.47	60	141.06	179.7895	Tail J3	Fail	Countersink
CF9-4C20A-3	1	4.38	4.59	32.67	30	37.22	46.3033	Tail J3	Fail	Countersink
CF9-4C20A-4	1	3.14	2.86	22.73	20	17.53	20.2034	Tail J2	Fail	Countersink
CF7-4C20A-1	**1**	**1.31**	**1.4**	**10.24**	**10**	**4.448**	**5.0000**	**No**	**Pass**	**Countersink**
CF7-4C20A-2	1	8.47	8.72	63	60	139.77	179.7895	Tail J1, J2, J3	Fail	Countersink
CF7-4C20A-3	1	4.51	4.59	32.67	30	37.12	46.3033	Tail J1, J3	Fail	Countersink
CF7-4C20A-4	1	3.18	2.86	22.8	20	18.02	20.2034	Tail J3	Fail	Countersink
CF8-4C20A-1	**1**	**1.32**	**1.4**	**10.24**	**10**	**4.493**	**5.0000**	**No**	**Pass**	**Countersink**
CF8-4C20A-2	1	8.55	8.72	63.47	60	141.97	179.7895	Tail J1, J2, J3	Fail	Countersink
CF8-4C20A-3	1	4.42	4.59	32.47	30	37.32	46.3033	Tail J1, J3	Fail	Countersink
CF8-4C20A-4	1	3.09	2.86	23.2	20	18.3	20.2034	Tail J2, J3	Fail	Countersink
CF4-4C20A-1	1	1.31	1.4	10.16	10	4.445	5.0000	Tail J2	Fail	Countersink
CF4-4C20A-1	2	0.65	0.7	5.16	5	1.123	1.2500	No	Pass	Countersink
CF4-4C20A-1	3	0.95	0.98	7.28	7	2.236	2.5000	No	Pass	Countersink
CF4-4C20A-2	1	1.18	1.26	9.2	9	3.603	4.1300	Tail J2	Fail	Countersink
CF4-4C20A-2	2	1.04	1.12	8.24	8	2.846	3.2000	No	Pass	Countersink
CF4-4C20A-3	1	N/A	0.7	5.2	5	1.118	1.2500	Tail J1, J2, J3	Fail	Countersink
CF4-4C2AC-3	2	N/A	0.14	1.16	1	50.88	0.0500	No	Pass	Countersink
CF4-4C20A-3	3	0.37	0.42	3.16	3	0.4091	0.4590	No	Pass	Countersink
CF4-4C20A-4	**1**	**0.27**	**0.28**	**2.16**	**2**	**0.184**	**0.2000**	**No**	**Pass**	**Countersink**
CF6-4C20A-1	**1**	**1.34**	**1.4**	**9.92**	**10**	**4.203**	**5.0000**	**No**	**Pass**	**Countersink**
CF6-4C20A-2	1	8.47	8.72	62.87	60	140.59	179.7895	Tail J1, J2, J3	Fail	Countersink
CF6-4C20A-3	1	4.45	4.59	32.67	30	36.98	46.3033	Tail J2, J3	Fail	Countersink
CF6-4C20A-4	1	3.09	2.86	22.7	20	17.56	20.2034	Tail J3	Fail	Countersink
CF5-4C20A-1	**1**	**1.29**	**1.4**	**10.16**	**10**	**4.398**	**5.0000**	**No**	**Pass**	**Countersink**
CF5-4C20A-2	1	8.27	8.72	62.87	60	139.48	179.7895	Tail J1, J2, J3	Fail	Countersink
CF5-4C20A-3	1	4.34	4.59	31.87	30	34.03	46.3033	Tail J1, J2, J3	Fail	Countersink
CF5-4C20A-4	1	3.01	2.86	22.6	20	17.17	20.2034	Tail J1, J2, J3	Fail	Countersink
HF9-4C18D-1	**1**	**1.34**	**1.4**	**10.8**	**10**	**4.746**	**5.0000**	**No**	**Pass**	**Protrouding**
HF9-4C18D-2	1	8.64	8.72	65.67	60	181.62	179.7895	Head and Tail J1, J2, J3	Fail	Protrouding
HF9-4C18D-3	1	4.54	4.59	32.8	30	42.97	46.3033	Head J1, J2, J3	Fail	Protrouding
HF9-4C18D-4	1	3.17	2.86	24.23	20	23.1	20.2034	Head J2, J3	Fail	Protrouding
HF8-4C18D-1	**1**	**1.35**	**1.4**	**10.8**	**10**	**4.774**	**5.0000**	**No**	**Pass**	**Protrouding**
HF8-4C18D-2	1	4.55	4.59	32.73	30	42.61	46.3033	Head J1, J2, J3	Fail	Protrouding
HF8-4C18D-3	1	3.23	2.86	21.93	20	18.79	20.2034	Head J3	Fail	Protrouding
HF4-4C18D-1	**1**	**1.34**	**1.4**	**10.8**	**10**	**4.68**	**5.0000**	**No**	**Pass**	**Protrouding**
HF4-4C18D-2	1	4.54	4.59	32.73	30	43.17	46.3033	Head J1, J2, J3	Fail	Protrouding
HF4-4C18D-3	1	3.21	2.86	22.07	20	18.72	20.2034	Head J1, J3	Fail	Protrouding
HF6-4C18D-1	**1**	**N/A**	**1.4**	**10.8**	**10**	**4.662**	**5.0000**	**No**	**Pass**	**Protrouding**
HF6-4C18D-2	1	8.6	8.72	59.67	60	142.18	179.7895	Head J1, J2, J3	Fail	Protrouding
HF6-4C18D-3	1	4.57	4.59	31.2	30	36.33	46.3033	Head J1, J2, J3	Fail	Protrouding
HF6-4C18D-4	1	3.18	2.86	20.4	20	14.99	20.2034	Head J3	Fail	Protrouding
HF5-4C18D-1	**1**	**1.34**	**1.4**	**10.8**	**10**	**4.713**	**5.0000**	**No**	**Pass**	**Protrouding**
HF5-4C18D-2	1	4.59	4.59	32.67	30	42.41	46.3033	Head J1, J2, J3, Tail J2	Fail	Protrouding
HF5-4C18D-3	1	3.26	2.86	22.07	20	18.44	20.2034	Tail J1, J3	Fail	Protrouding
CF9-4C18E-1	**1**	**1.33**	**1.4**	**10.4**	**10**	**4.609**	**5.0000**	**No**	**Pass**	**Protrouding**
CF9-4C18E-2	1	4.55	4.59	29.73	30	29.11	46.3033	Head J1, J2, J3, Tail J2	Fail	Protrouding
CF9-4C18E-3	1	3.11	2.86	19.6	20	12.25	20.2034	Head J3	Fail	Protrouding
CF8-4C18E-1	1	1.32	1.4	10.6	10	4.56	5.0000	No	Pass	Protrouding
CF8-4C18E-2	1	4.46	4.59	30.07	30	29.96	46.3033	No	Pass	Protrouding
CF8-4C18E-3	1	5.69	5.95	38.27	40	49.68	88.3645	Head J1	Fail	Protrouding
CF4-4C18E-1	1	0.64	0.7	5.2	5	1.127	1.2500	No	Pass	Protrouding
CF4-4C18E-1	2	1.33	1.4	10.6	10	4.636	5.0000	No	Pass	Protrouding
CF4-4C18E-2	1	1.33	1.4	10.6	10	4.594	5.0000	Head J3, Tail J2	Fail	Protrouding
CF4-4C18E-3	1	1.05	0.98	7.4	7	2.287	2.5000	Head J3	Fail	Protrouding
CF4-4C18E-4	**1**	**0.77**	**0.84**	**6.4**	**6**	**1.703**	**1.8400**	**No**	**Pass**	**Protrouding**
CF6-4C18E-1	1	1.34	1.4	10.6	10	4.587	5.0000	Head J3	Fail	Protrouding
CF6-4C18E-2	1	0.95	0.98	7.2	7	2.186	2.5000	No	Pass	Protrouding
CF6-4C18E-3	1	1.06	1.12	8.24	8	2.85	3.2000	Head J1, J3	Fail	Protrouding
CF5-4C18E-1	1	1.33	1.4	10.6	10	4.537	5.0000	Tail J2	Fail	Protrouding
CF5-4C18E-2	1	1.07	1.12	8.16	8	2.815	3.2000	Head J3, Tail J2	Fail	Protrouding
CF5-4C18E-3	1	N/A	0.56	4.16	4	0.7292	0.8000	Tail J2, J3	Fail	Protrouding
CF5-4C18E-4	**1**	**0.26**	**0.28**	**2.12**	**2**	**0.1861**	**0.2000**	**No**	**Pass**	**Protrouding**

Appendix B - Test Photos

Figure 1: CF4-4C18E-2-Head Side-Open Box-Shot 1-10 kA

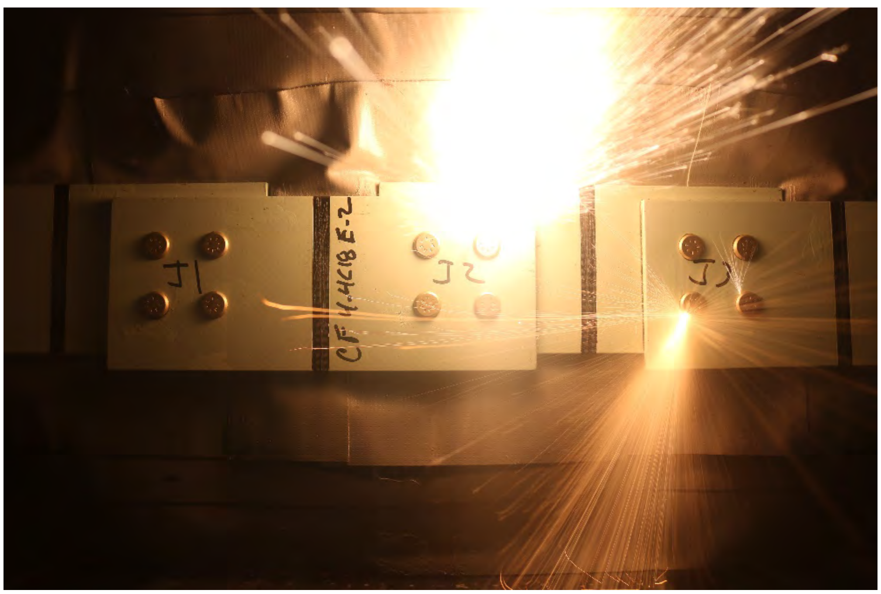


Figure 2: CF4-4C18E-2-Head Side-Test Photo-Shot 1-10 kA

Figure 3: CF4-4C18E-2-Tail Side-Open Box-Shot 1-10 kA

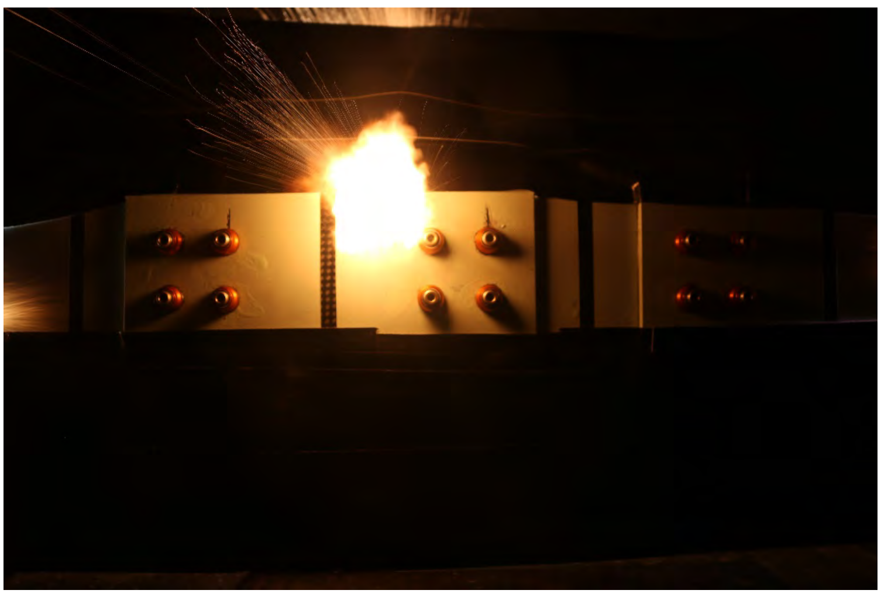


Figure 4: CF4-4C18E-2-Tail Side-Test Photo-Shot 1-10 kA

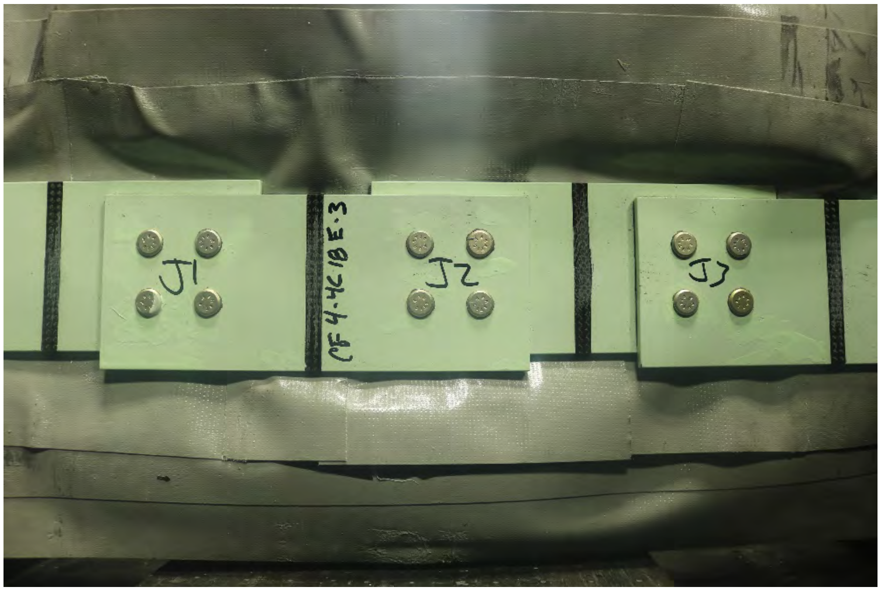


Figure 5: CF4-4C18E-3-Head Side-Open Box-Shot 1-7 kA

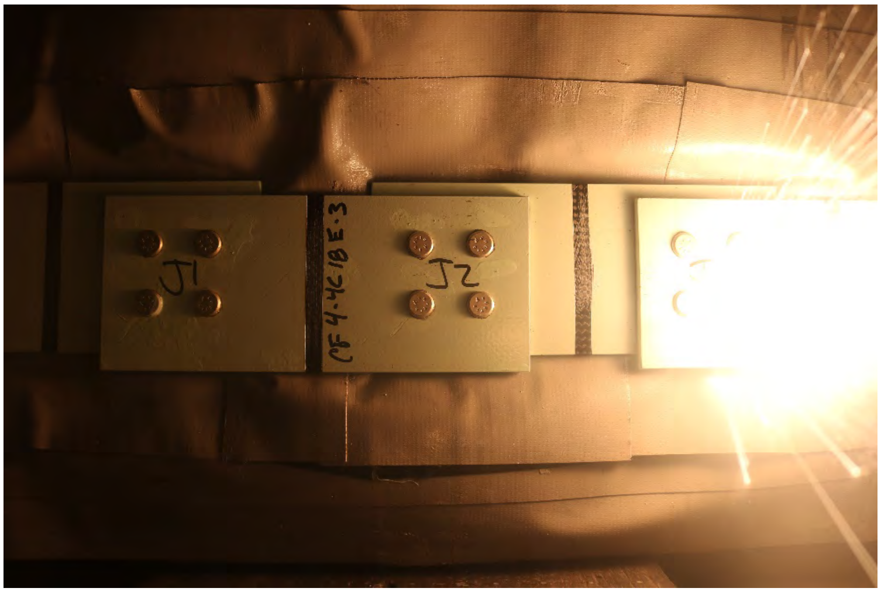


Figure 6: CF4-4C18E-3-Head Side-Test Photo-Shot 1-7 kA

Figure 7: CF4-4C18E-3-Tail Side-Open Box-Shot 1-7 kA

Figure 8: CF4-4C18E-3-Tail Side-Test Photo-Shot 1-7 kA

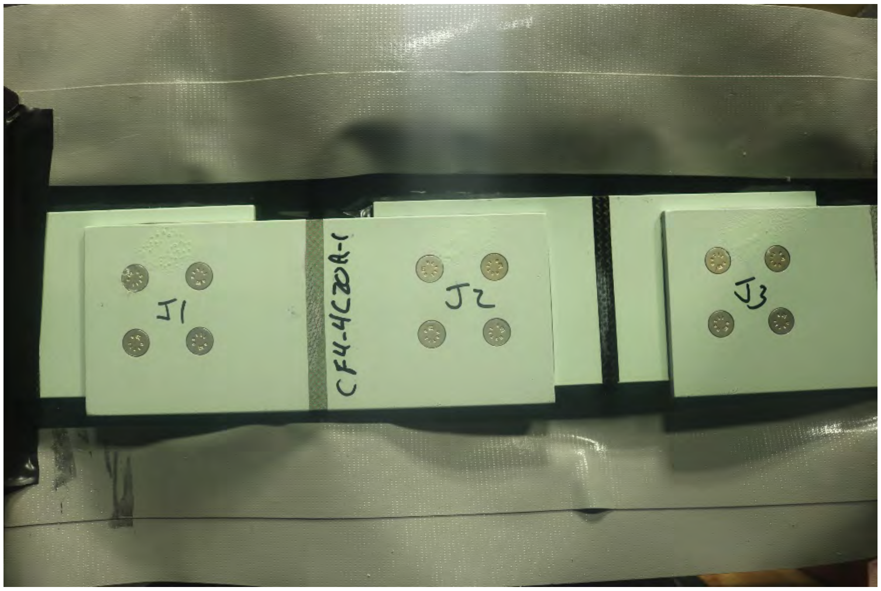


Figure 9: CF4-4C20A-1-Head Side-Open Box-Shot 1-10 kA

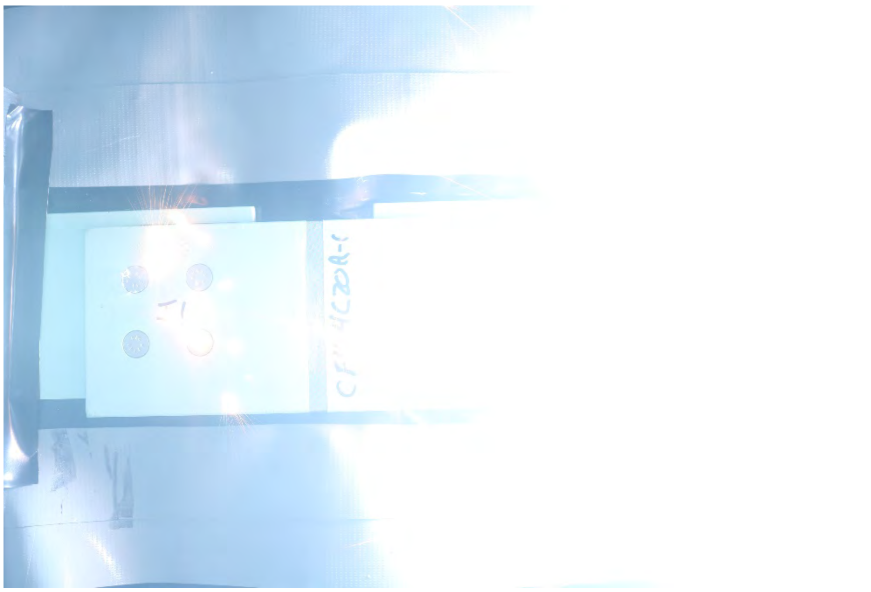


Figure 10: CF4-4C20A-1-Head Side-Test Photo-Shot 1-10 kA

Figure 11: CF4-4C20A-1-Tail Side-Open Box-Shot 1-10 kA

Figure 12: CF4-4C20A-1-Tail Side-Test Photo-Shot 1-10 kA

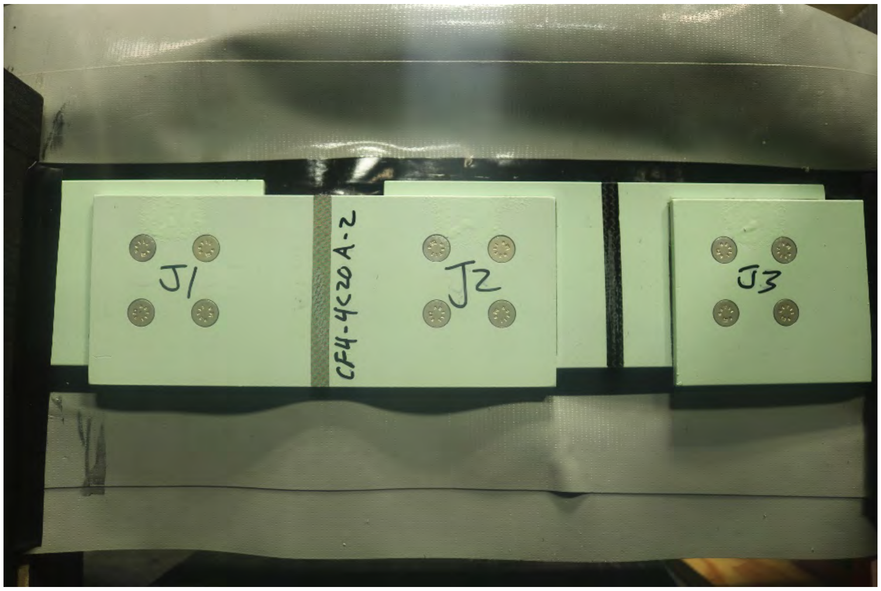


Figure 13: CF4-4C20A-2-Head Side-Open Box-Shot 1-9 kA

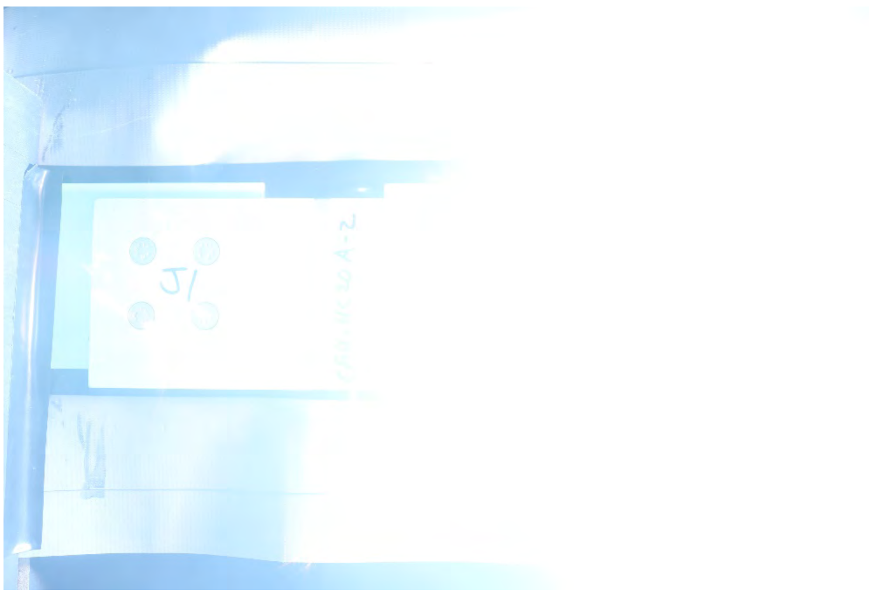


Figure 14: CF4-4C20A-2-Head Side-Test Photo-Shot 1-9 kA

Figure 15: CF4-4C20A-2-Tail Side-Open Box-Shot 1-9 kA

Figure 16: CF4-4C20A-2-Tail Side-Test Photo-Shot 1-9 kA

Figure 17: CF4-4C20A-3-Head Side-Open Box-Shot 1-5 kA

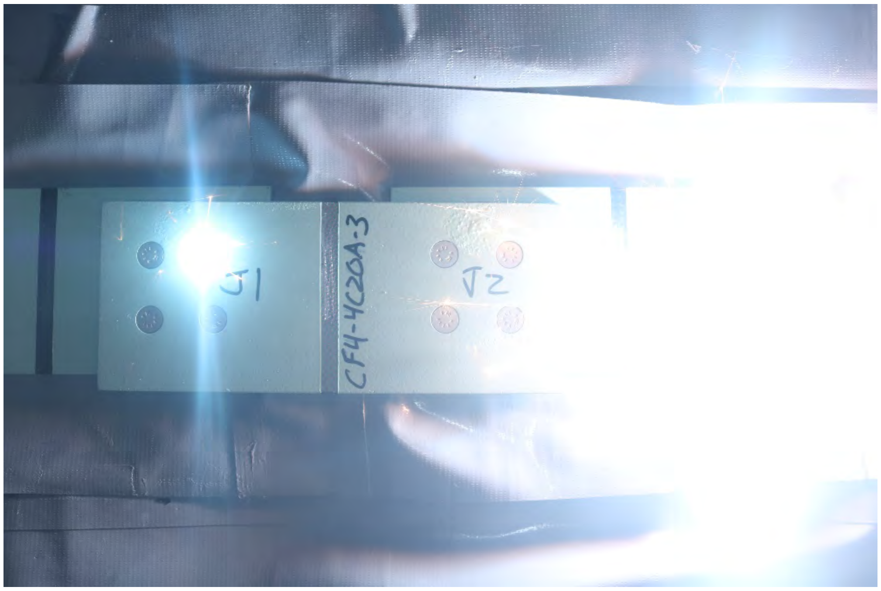


Figure 18: CF4-4C20A-3-Head Side-Test Photo-Shot 1-5 kA

Figure 19: CF4-4C20A-3-Tail Side-Open Box-Shot 1-5 kA

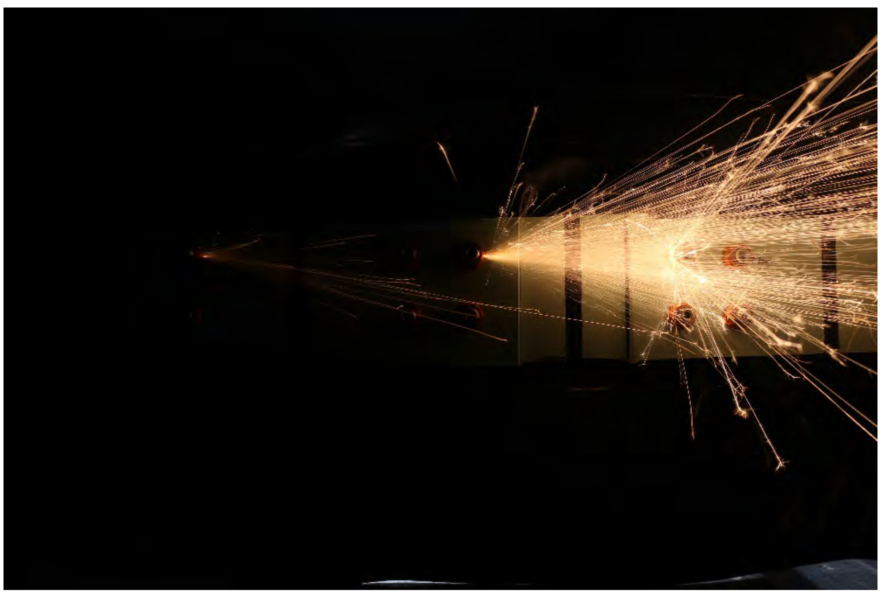


Figure 20: CF4-4C20A-3-Tail Side-Test Photo-Shot 1-5 kA

Figure 21: CF5-4C18E-1-Head Side-Open Box-Shot 1-10 kA

Figure 22: CF5-4C18E-1-Head Side-Test Photo-Shot 1-10 kA

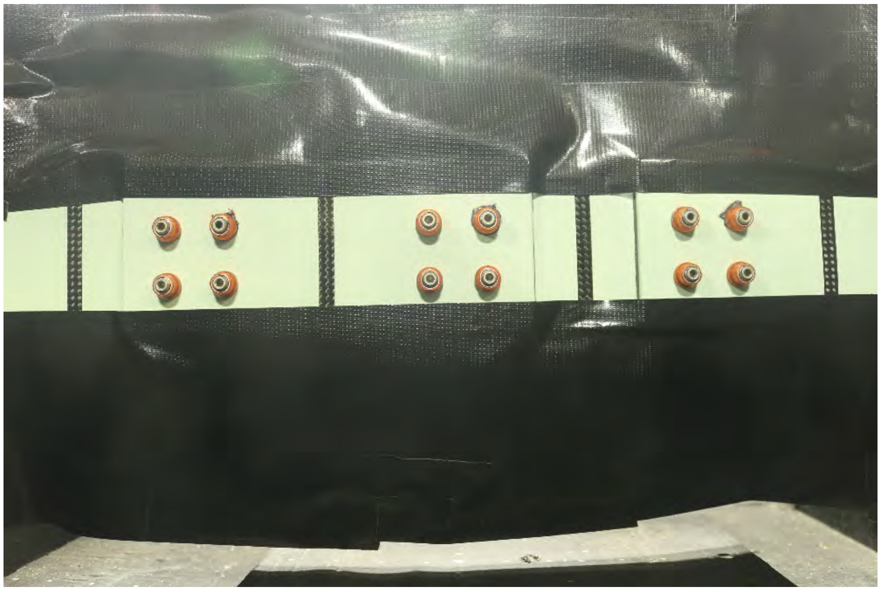


Figure 23: CF5-4C18E-1-Tail Side-Open Box-Shot 1-10 kA

Figure 24: CF5-4C18E-1-Tail Side-Test Photo-Shot 1-10 kA

Figure 25: CF5-4C18E-2-Head Side-Open Box-Shot 1-8 kA

Figure 26: CF5-4C18E-2-Head Side-Test Photo-Shot 1-8 kA

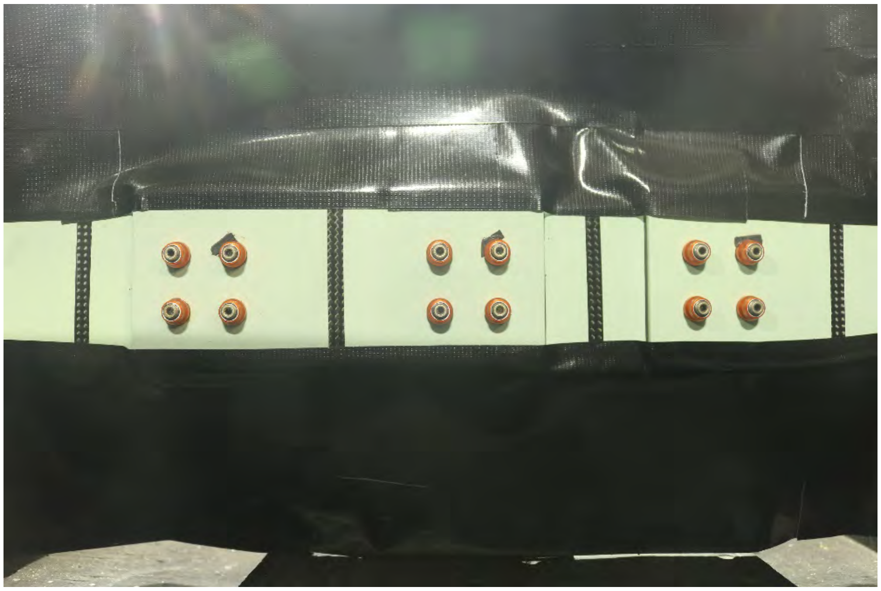


Figure 27: CF5-4C18E-2-Tail Side-Open Box-Shot 1-8 kA

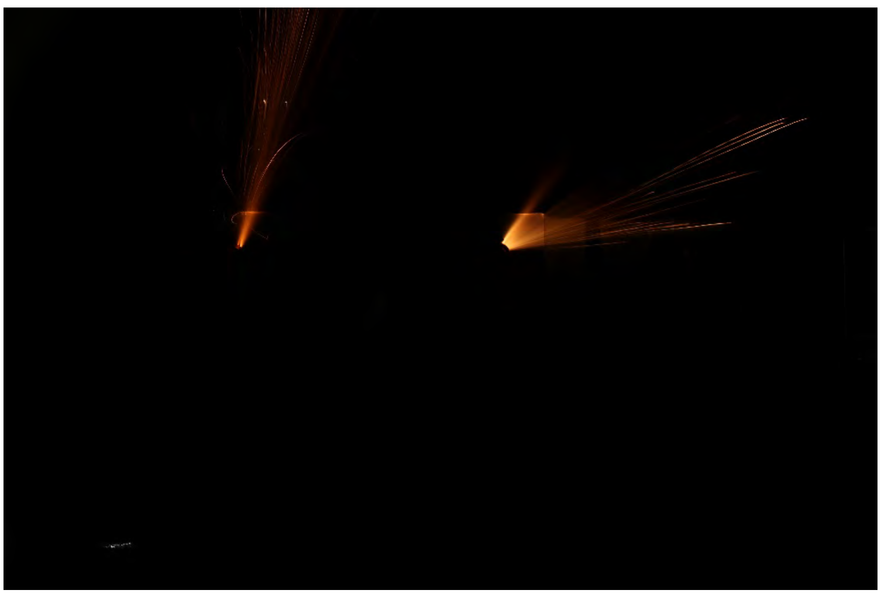


Figure 28: CF5-4C18E-2-Tail Side-Test Photo-Shot 1-8 kA

Figure 29: CF5-4C18E-3-Head Side-Open Box-Shot 1-4 kA

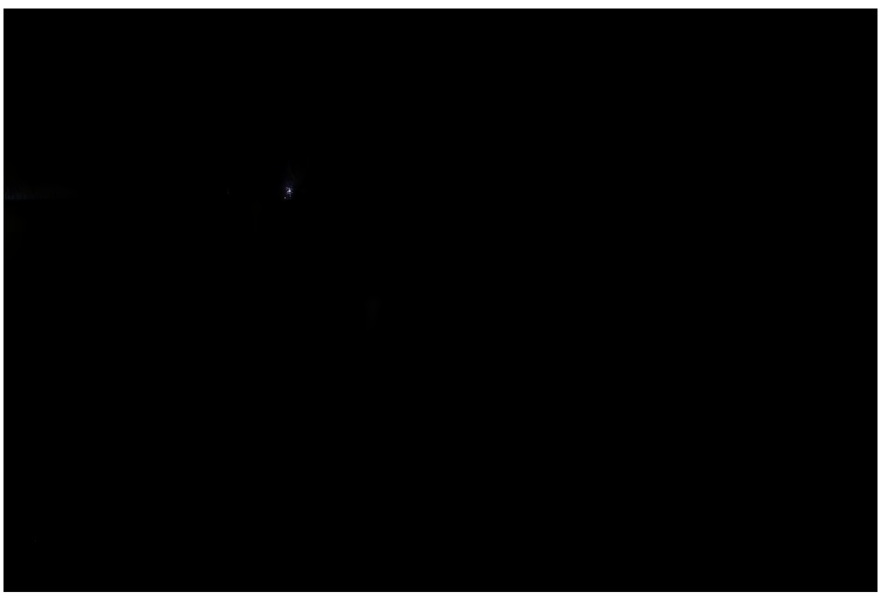


Figure 30: CF5-4C18E-3-Head Side-Test Photo-Shot 1-4 kA

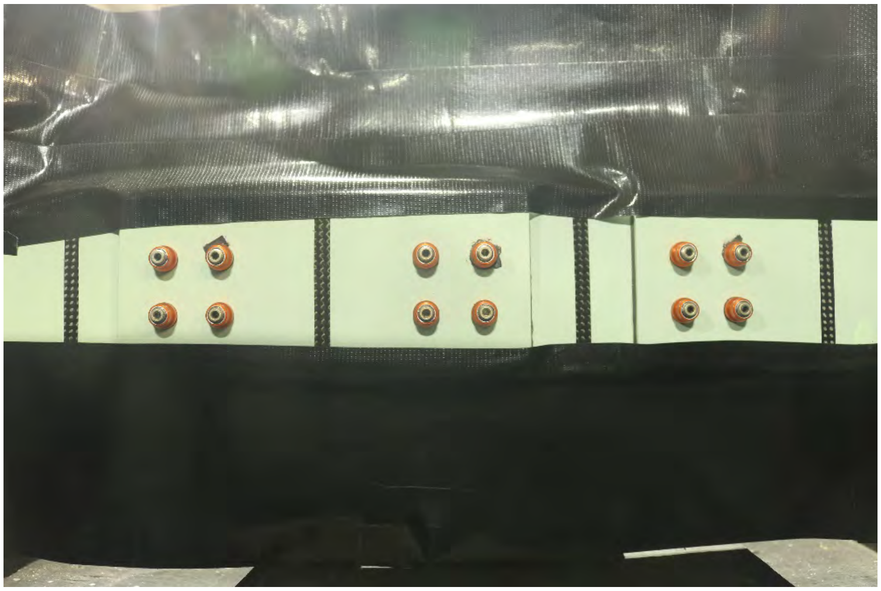


Figure 31: CF5-4C18E-3-Tail Side-Open Box-Shot 1-4 kA

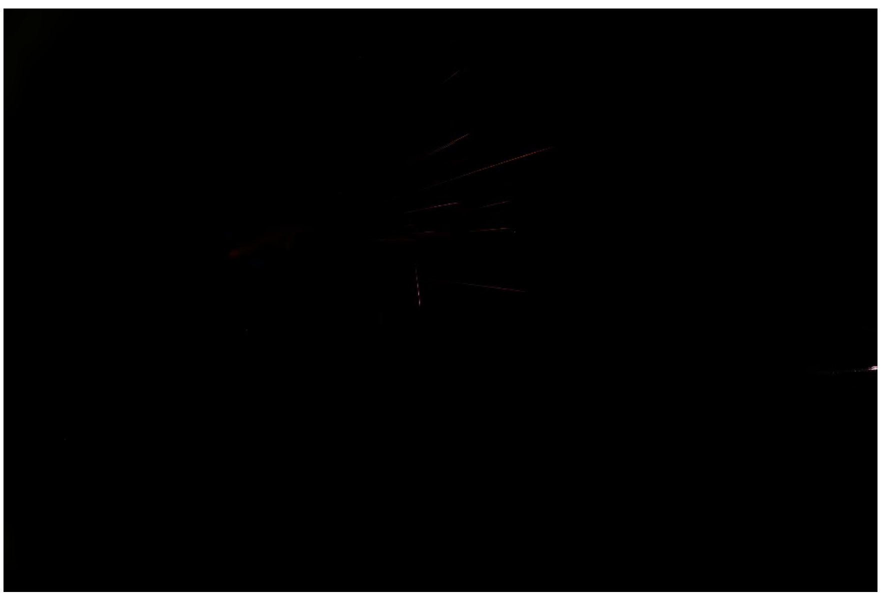


Figure 32: CF5-4C18E-3-Tail Side-Test Photo-Shot 1-4 kA

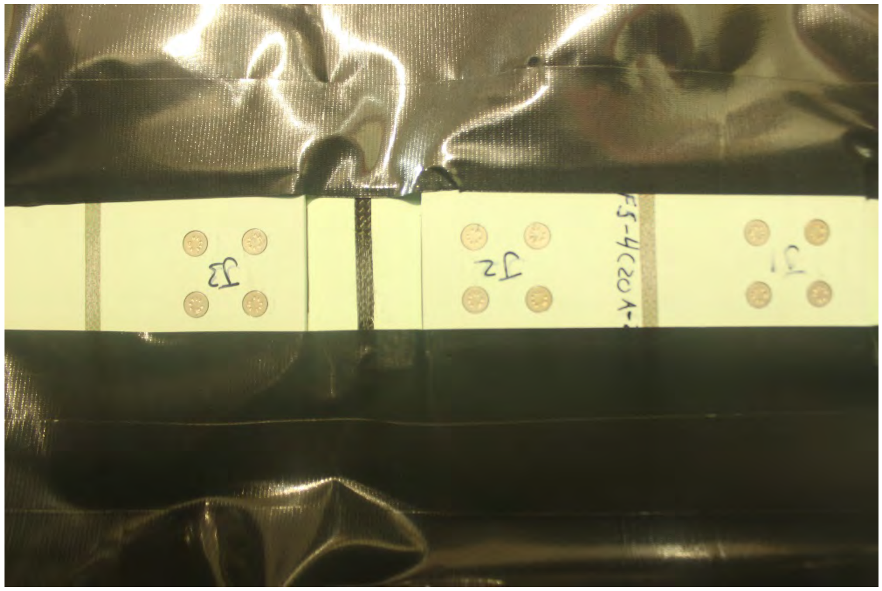


Figure 33: CF5-4C20A-2-Head Side-Open Box-Shot 1-60 kA

Figure 34: CF5-4C20A-2-Head Side-Test Photo-Shot 1-60 kA

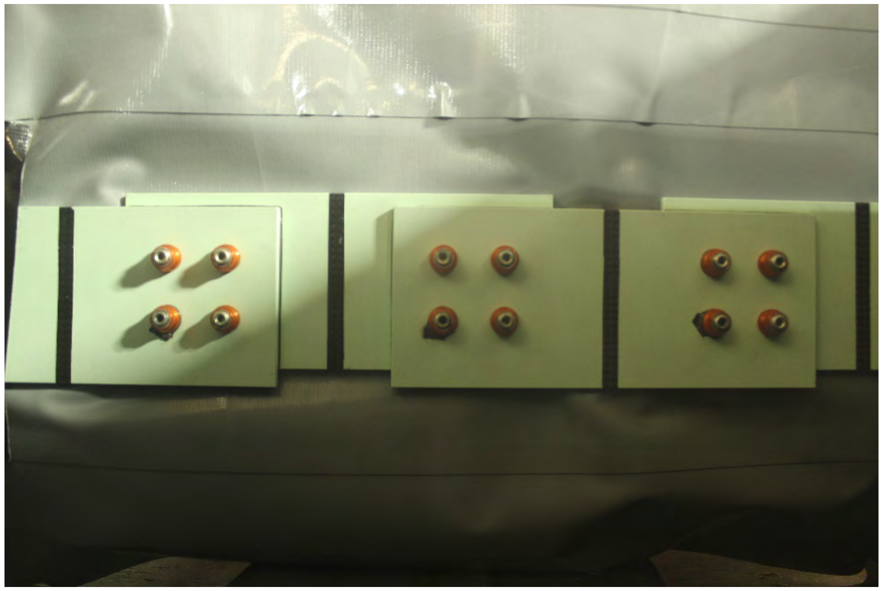


Figure 35: CF5-4C20A-2-Tail Side-Open Box-Shot 1-60 kA

Figure 36: CF5-4C20A-2-Tail Side-Test Photo-Shot 1-60 kA

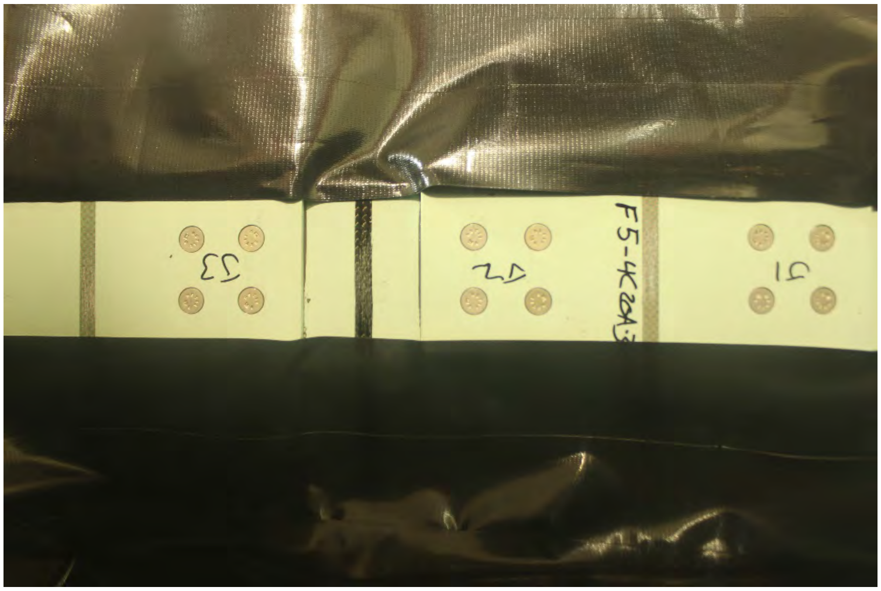


Figure 37: CF5-4C20A-3-Head Side-Open Box-Shot 1-30 kA

Figure 38: CF5-4C20A-3-Head Side-Test Photo-Shot 1-30 kA

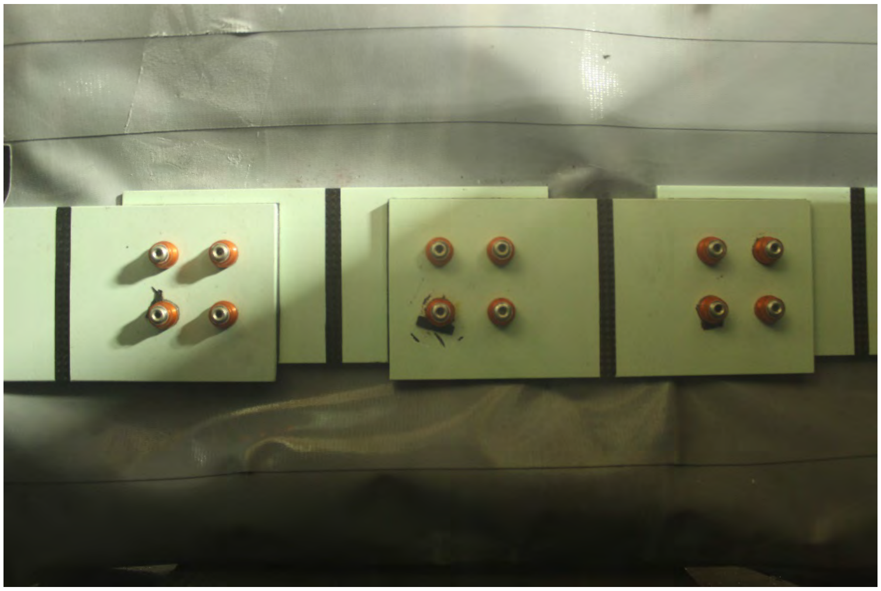


Figure 39: CF5-4C20A-3-Tail Side-Open Box-Shot 1-30 kA

Figure 40: CF5-4C20A-3-Tail Side-Test Photo-Shot 1-30 kA

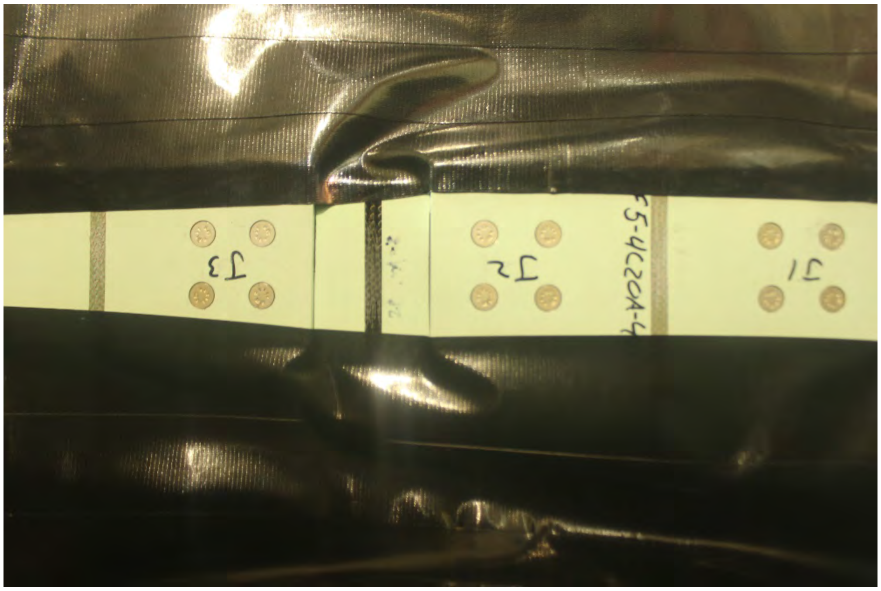


Figure 41: CF5-4C20A-4-Head Side-Open Box-Shot 1-20 kA

Figure 42: CF5-4C20A-4-Head Side-Test Photo-Shot 1-20 kA

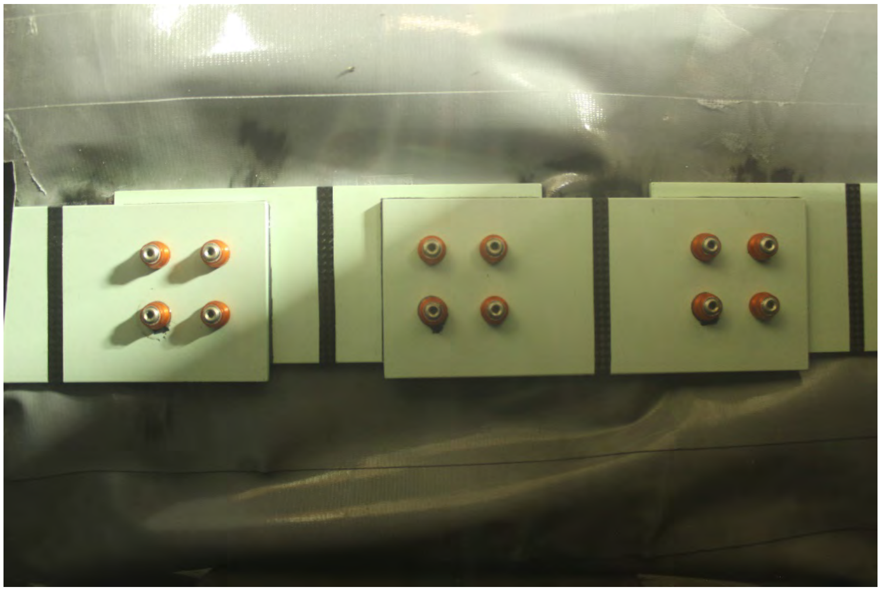


Figure 43: CF5-4C20A-4-Tail Side-Open Box-Shot 1-20 kA


Figure 44: CF5-4C20A-4-Tail Side-Test Photo-Shot 1-20 kA

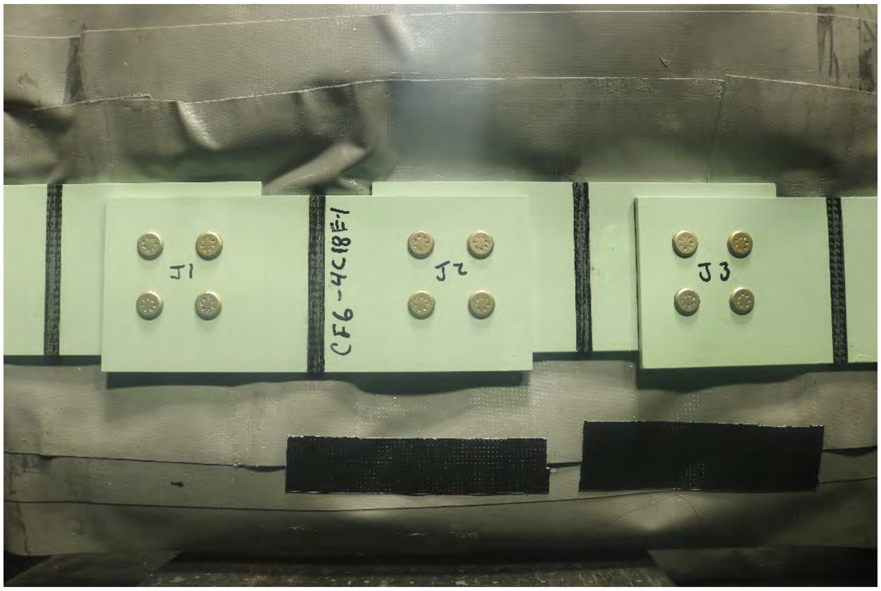


Figure 45: CF6-4C18E-1-Head Side-Open Box-Shot 1-10 kA


Figure 46: CF6-4C18E-1-Head Side-Test Photo-Shot 1-10 kA

Figure 47: CF6-4C18E-1-Tail Side-Open Box-Shot 1-10 kA

Figure 48: CF6-4C18E-1-Tail Side-Test Photo-Shot 1-10 kA

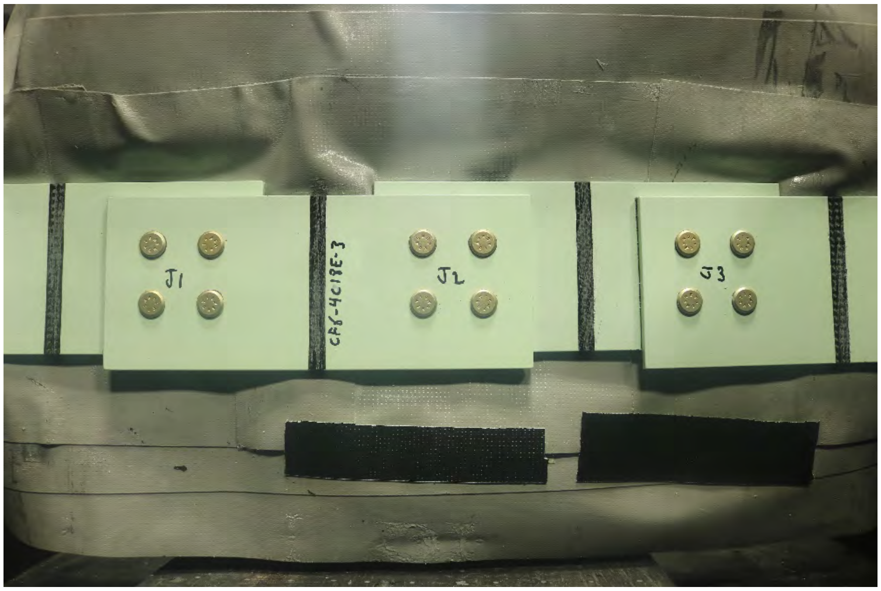


Figure 49: CF6-4C18E-3-Head Side-Open Box-Shot 1-8 kA


Figure 50: CF6-4C18E-3-Head Side-Test Photo-Shot 1-8 kA

Figure 51: CF6-4C18E-3-Tail Side-Open Box-Shot 1-8 kA

Figure 52: CF6-4C18E-3-Tail Side-Test Photo-Shot 1-8 kA

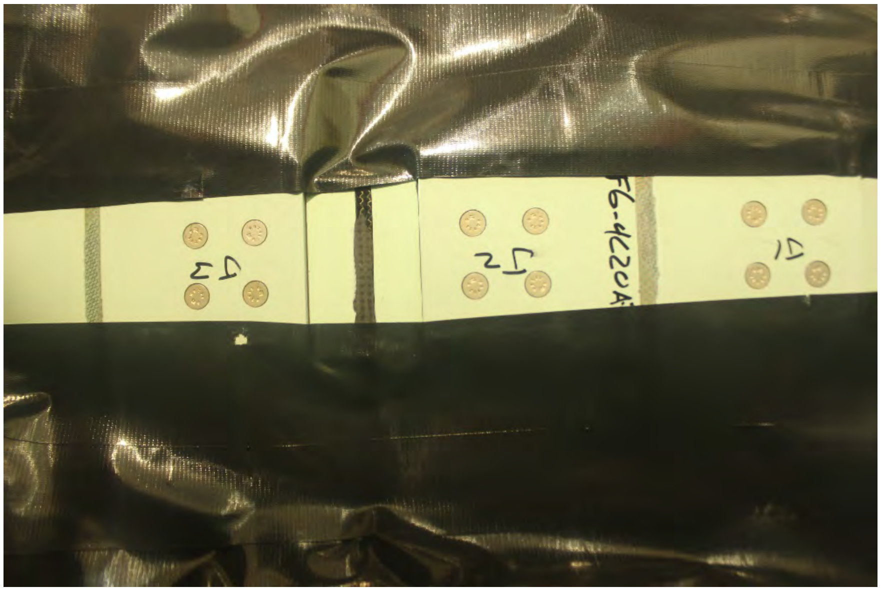


Figure 53: CF6-4C20A-2-Head Side-Open Box-Shot 1-60 kA

Figure 54: CF6-4C20A-2-Head Side-Test Photo-Shot 1-60 kA

Figure 55: CF6-4C20A-2-Tail Side-Open Box-Shot 1-60 kA

Figure 56: CF6-4C20A-2-Tail Side-Test Photo-Shot 1-60 kA

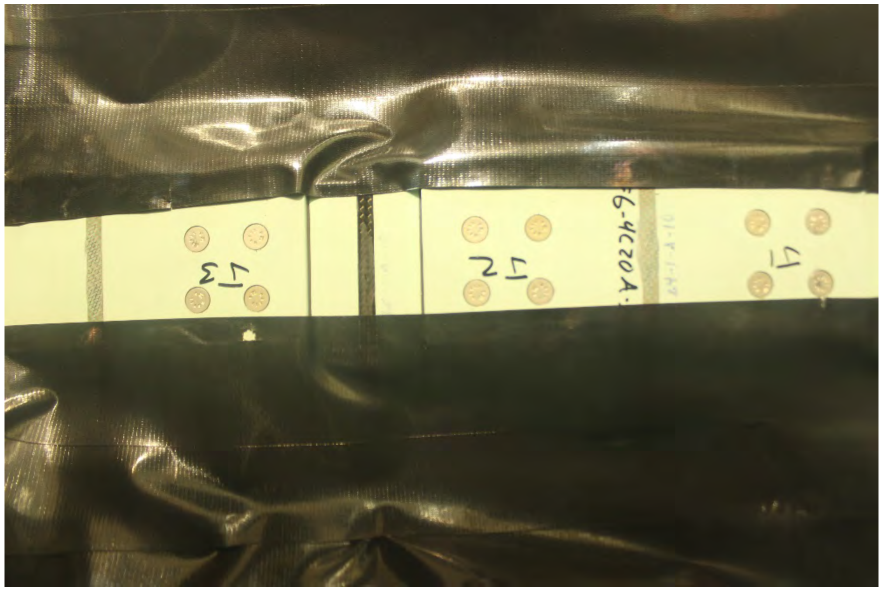


Figure 57: CF6-4C20A-3-Head Side-Open Box-Shot 1-30 kA

Figure 58: CF6-4C20A-3-Head Side-Test Photo-Shot 1-30 kA

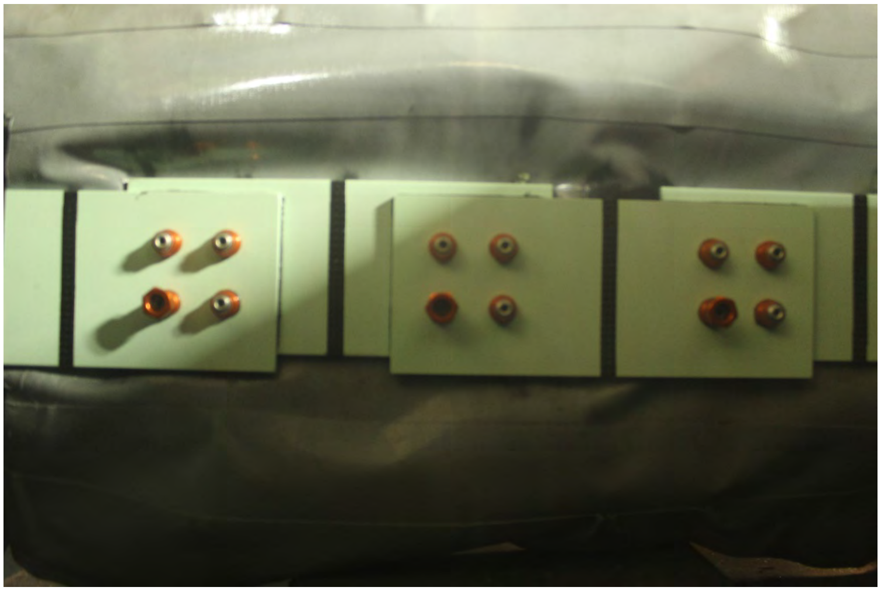


Figure 59: CF6-4C20A-3-Tail Side-Open Box-Shot 1-30 kA

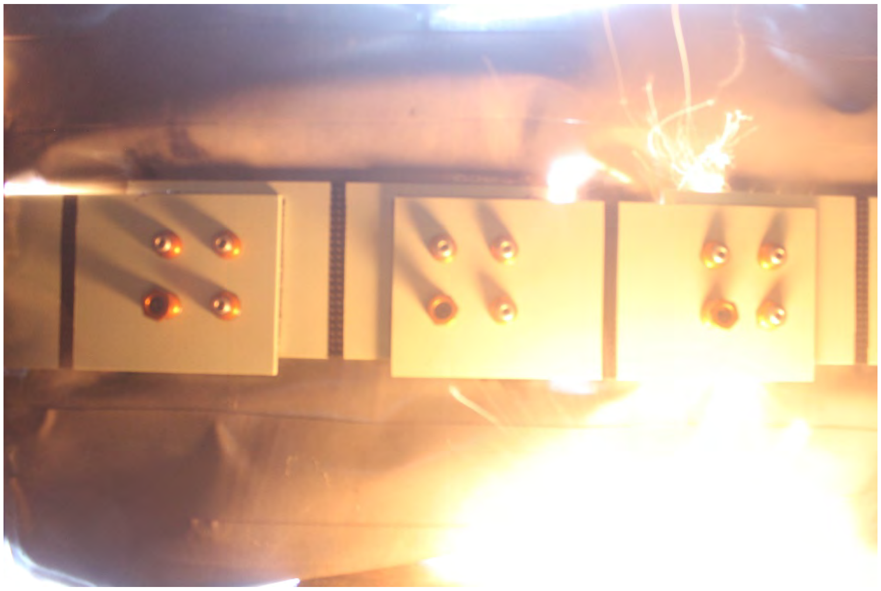


Figure 60: CF6-4C20A-3-Tail Side-Test Photo-Shot 1-30 kA

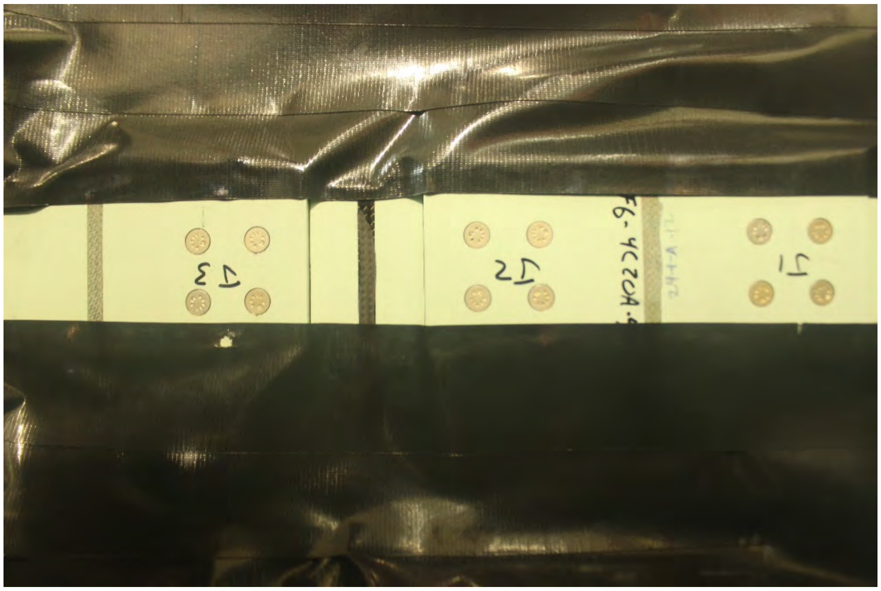


Figure 61: CF6-4C20A-4-Head Side-Open Box-Shot 1-20 kA

Figure 62: CF6-4C20A-4-Head Side-Test Photo-Shot 1-20 kA

Figure 63: CF6-4C20A-4-Tail Side-Open Box-Shot 1-20 kA

Figure 64: CF6-4C20A-4-Tail Side-Test Photo-Shot 1-20 kA

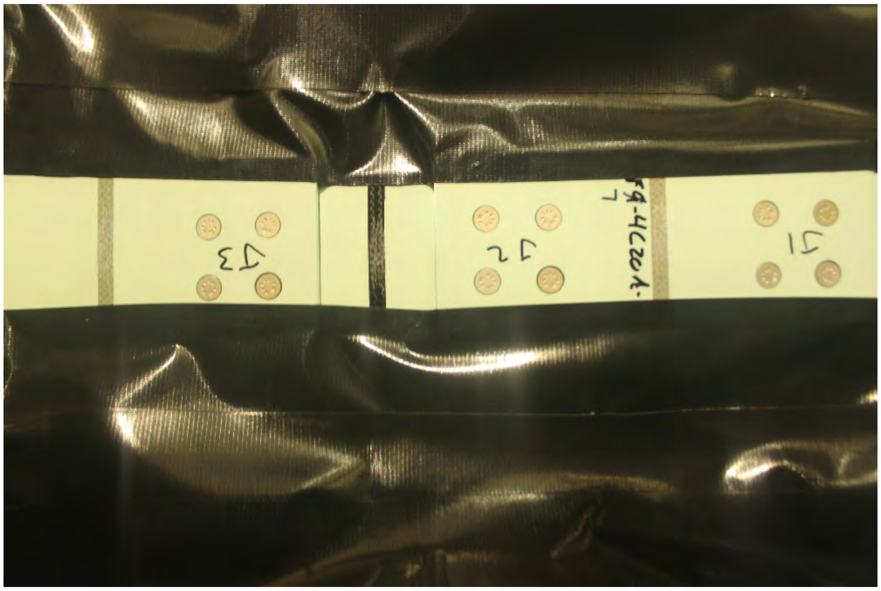


Figure 65: CF7-4C20A-2-Head Side-Open Box-Shot 1-60 kA

Figure 66: CF7-4C20A-2-Head Side-Test Photo-Shot 1-60 kA

Figure 67: CF7-4C20A-2-Tail Side-Open Box-Shot 1-60 kA

Figure 68: CF7-4C20A-2-Tail Side-Test Photo-Shot 1-60 kA

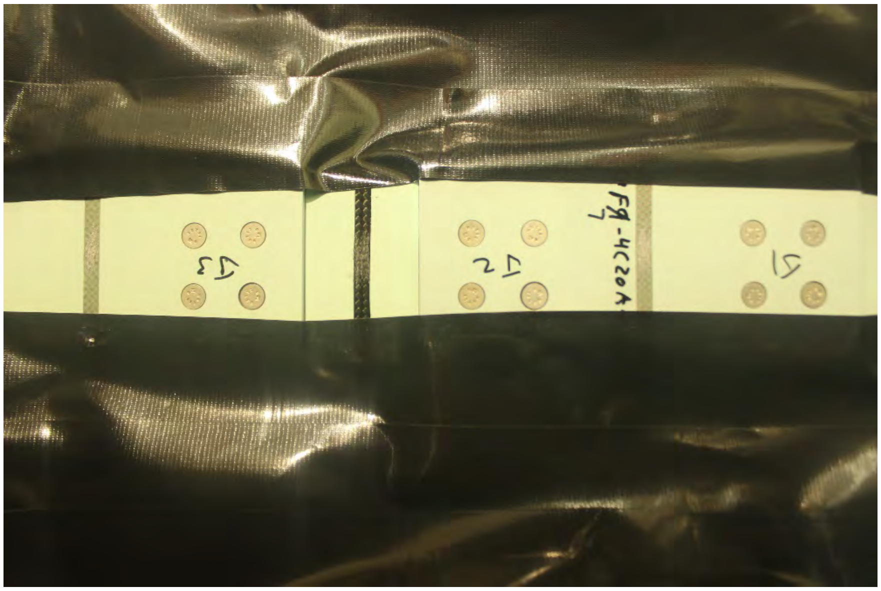


Figure 69: CF7-4C20A-3-Head Side-Open Box-Shot 1-30 kA

Figure 70: CF7-4C20A-3-Head Side-Test Photo-Shot 1-30 kA

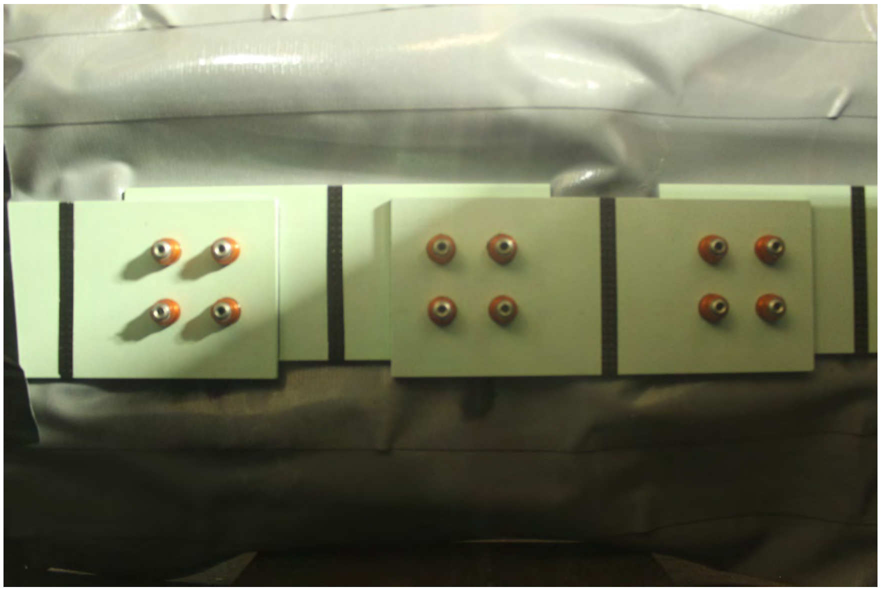


Figure 71: CF7-4C20A-3-Tail Side-Open Box-Shot 1-30 kA

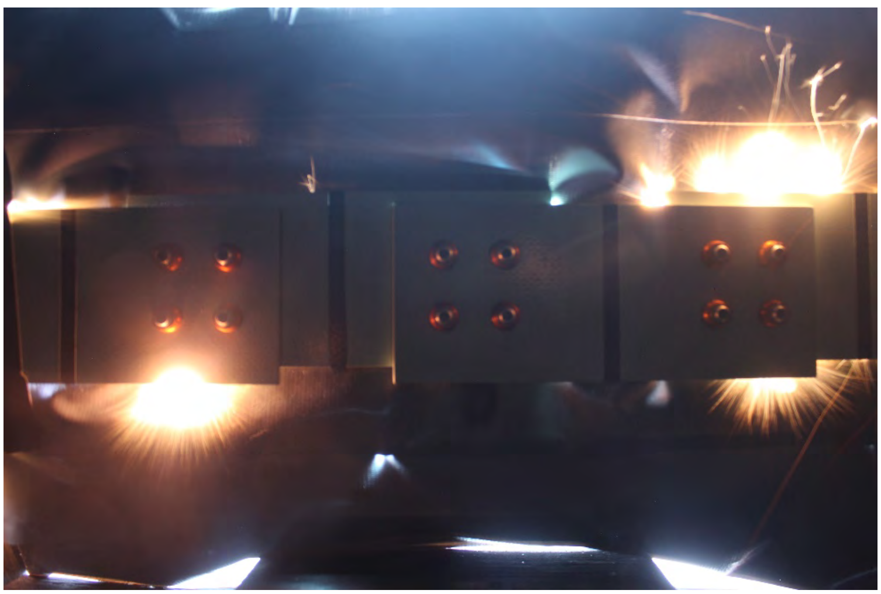


Figure 72: CF7-4C20A-3-Tail Side-Test Photo-Shot 1-30 kA

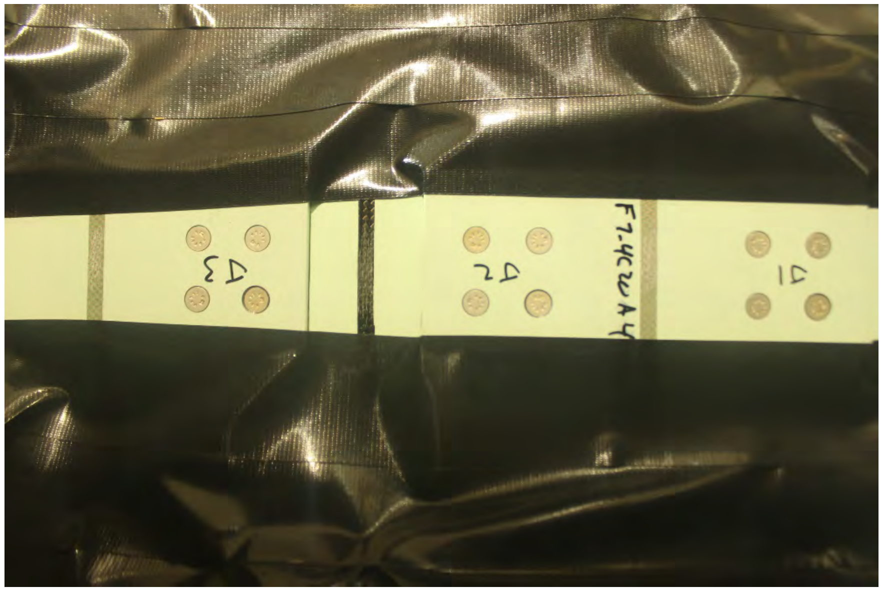


Figure 73: CF7-4C20A-4-Head Side-Open Box-Shot 1-20 kA

Figure 74: CF7-4C20A-4-Head Side-Test Photo-Shot 1-20 kA

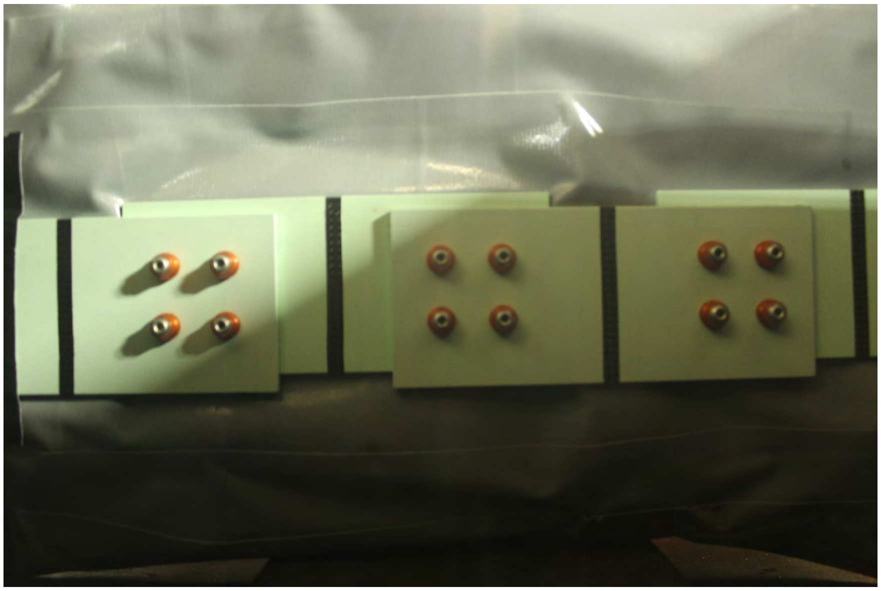


Figure 75: CF7-4C20A-4-Tail Side-Open Box-Shot 1-20 kA

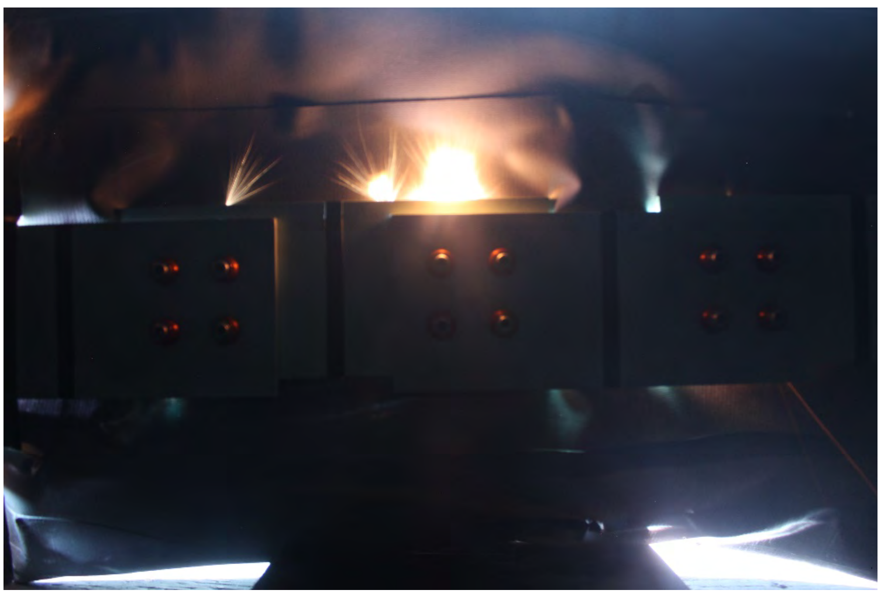


Figure 76: CF7-4C20A-4-Tail Side-Test Photo-Shot 1-20 kA

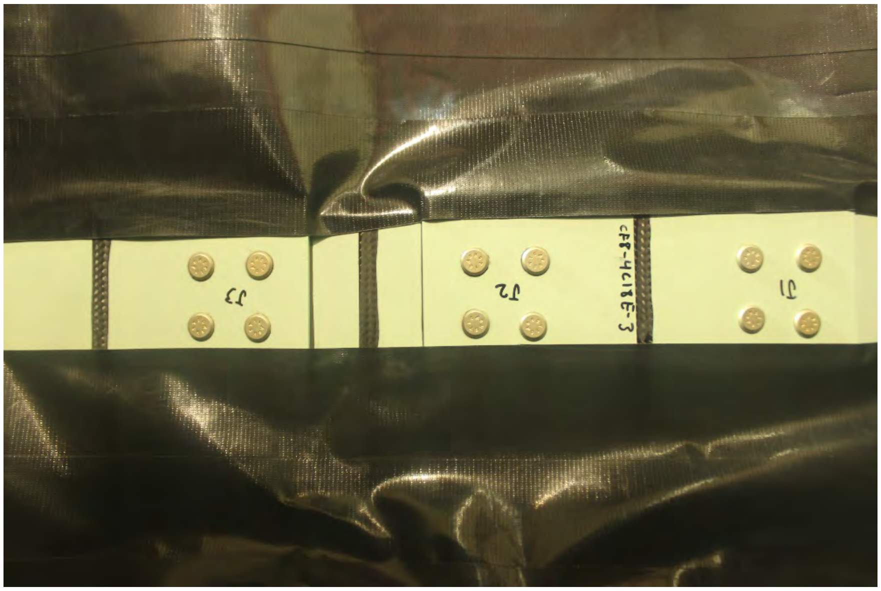


Figure 77: CF8-4C18E-3-Head Side-Open Box-Shot 1-20 kA

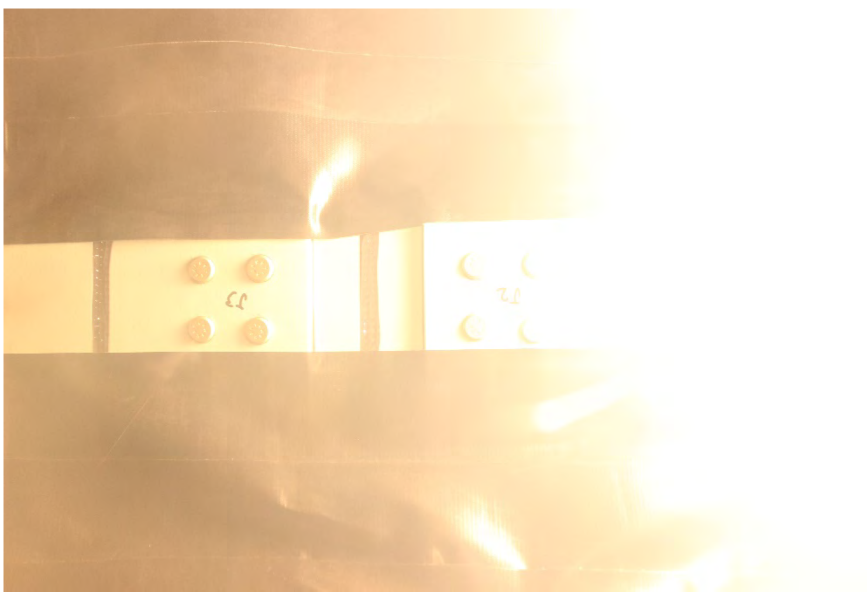


Figure 78: CF8-4C18E-3-Head Side-Test Photo-Shot 1-20 kA

Figure 79: CF8-4C18E-3-Tail Side-Open Box-Shot 1-20 kA

Figure 80: CF8-4C18E-3-Tail Side-Test Photo-Shot 1-20 kA

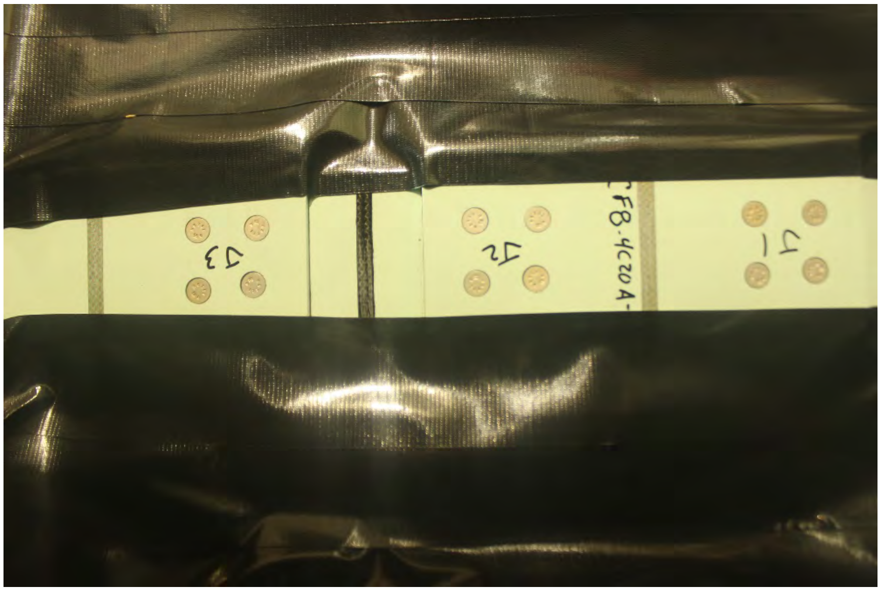


Figure 81: CF8-4C20A-2-Head Side-Open Box-Shot 1-60 kA

Figure 82: CF8-4C20A-2-Head Side-Test Photo-Shot 1-60 kA

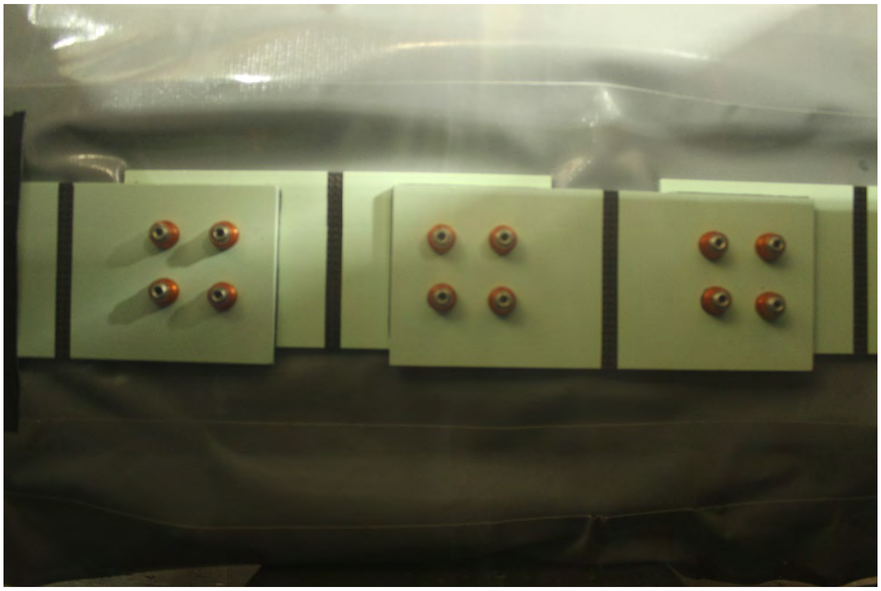


Figure 83: CF8-4C20A-2-Tail Side-Open Box-Shot 1-60 kA


Figure 84: CF8-4C20A-2-Tail Side-Test Photo-Shot 1-60 kA

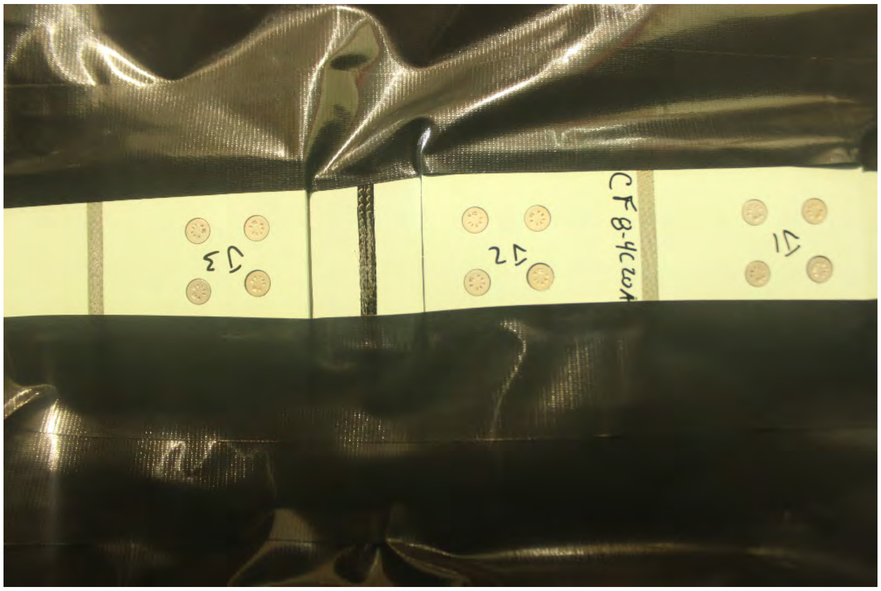


Figure 85: CF8-4C20A-3-Head Side-Open Box-Shot 1-30 kA

Figure 86: CF8-4C20A-3-Head Side-Test Photo-Shot 1-30 kA

Figure 87: CF8-4C20A-3-Tail Side-Open Box-Shot 1-30 kA

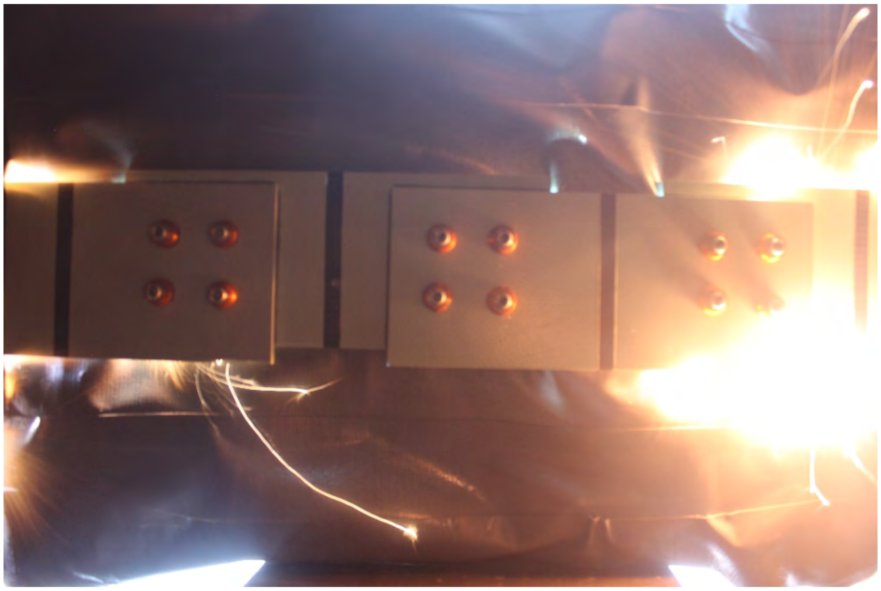


Figure 88: CF8-4C20A-3-Tail Side-Test Photo-Shot 1-30 kA

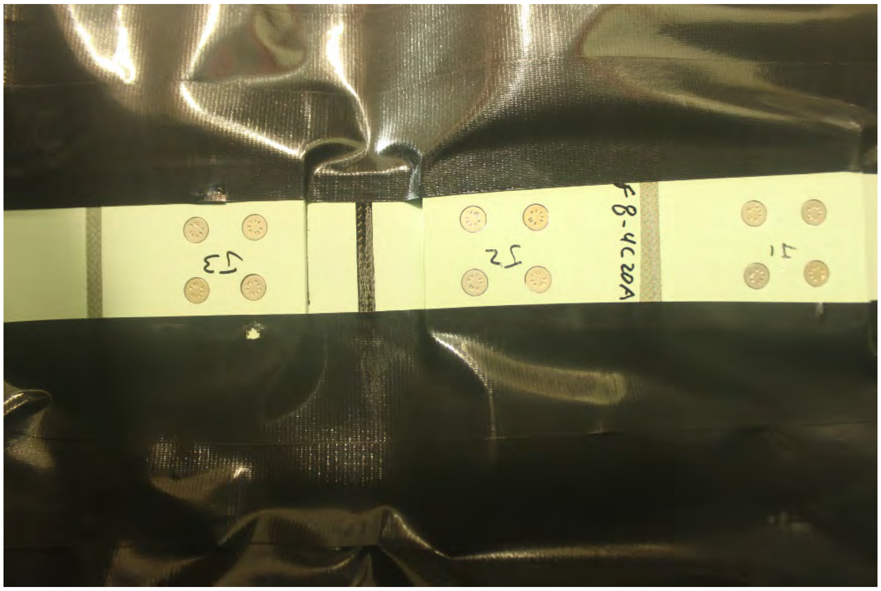


Figure 89: CF8-4C20A-4-Head Side-Open Box-Shot 1-20 kA

Figure 90: CF8-4C20A-4-Head Side-Test Photo-Shot 1-20 kA

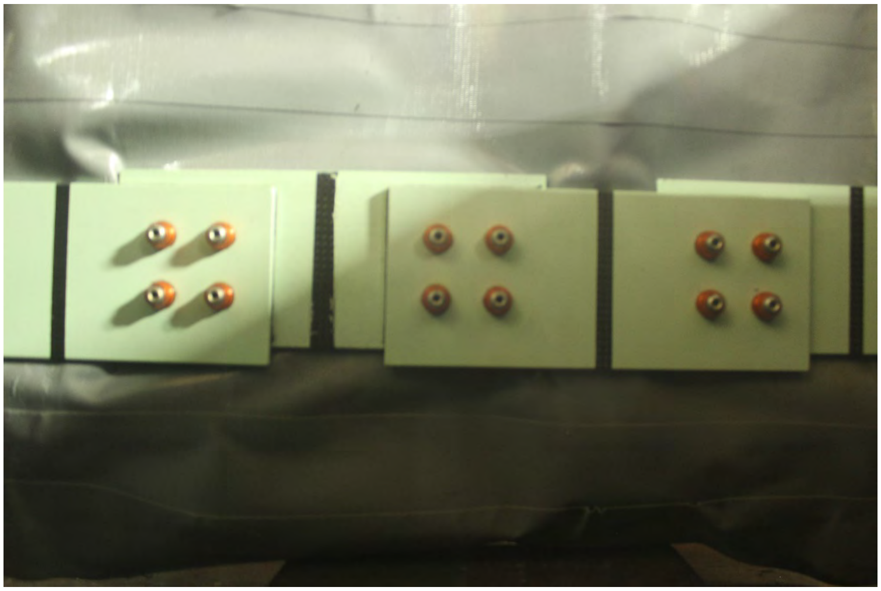


Figure 91: CF8-4C20A-4-Tail Side-Open Box-Shot 1-20 kA

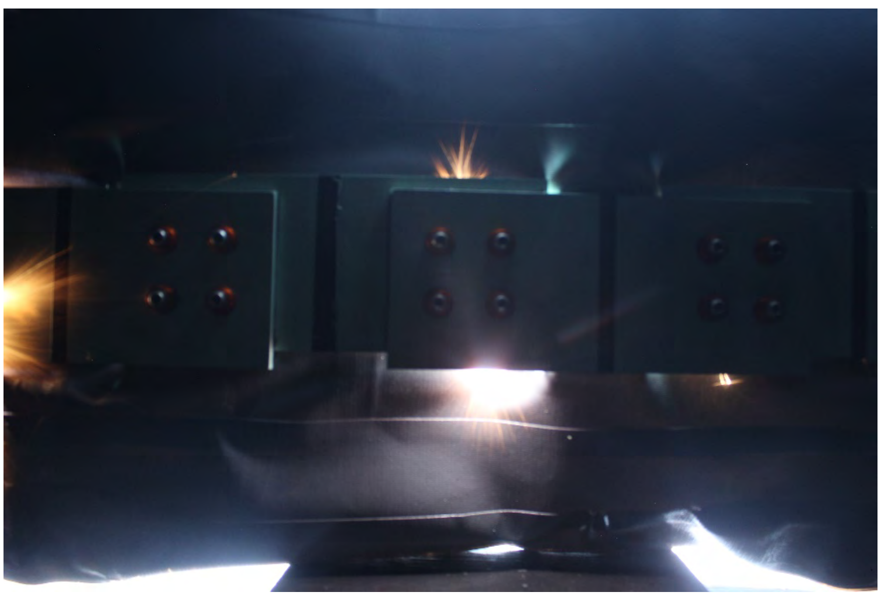


Figure 92: CF8-4C20A-4-Tail Side-Test Photo-Shot 1-20 kA

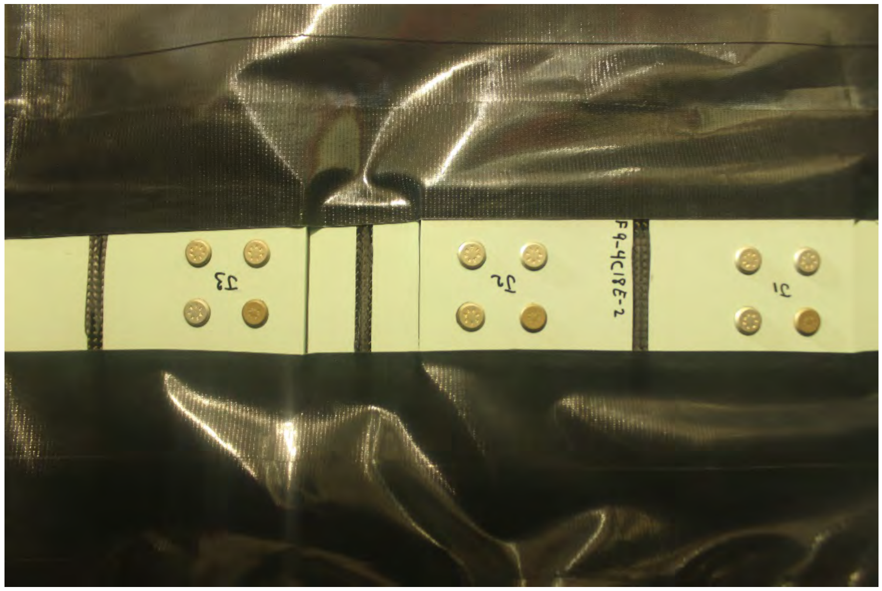


Figure 93: CF9-4C18E-2-Head Side-Open Box-Shot 1-30 kA

Figure 94: CF9-4C18E-2-Head Side-Test Photo-Shot 1-30 kA

Figure 95: CF9-4C18E-2-Tail Side-Open Box-Shot 1-30 kA

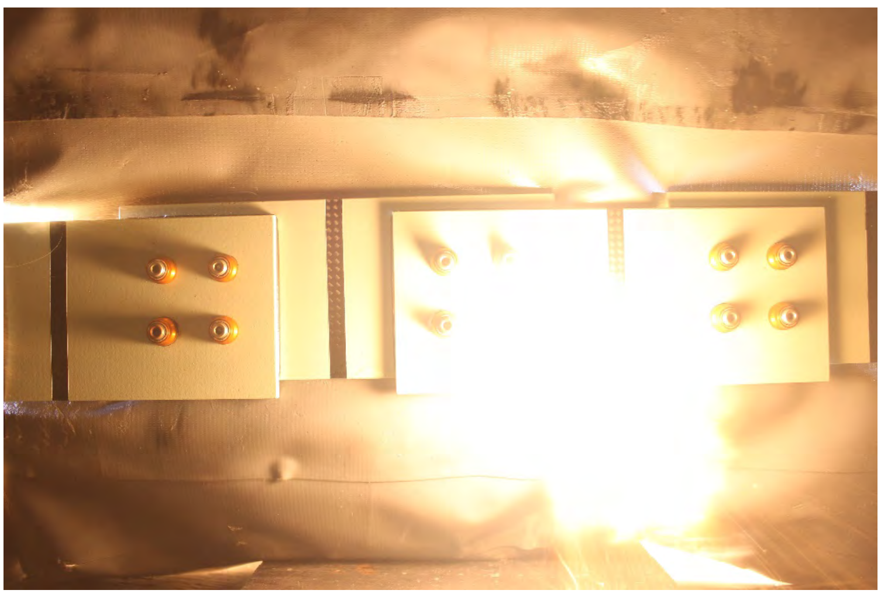


Figure 96: CF9-4C18E-2-Tail Side-Test Photo-Shot 1-30 kA

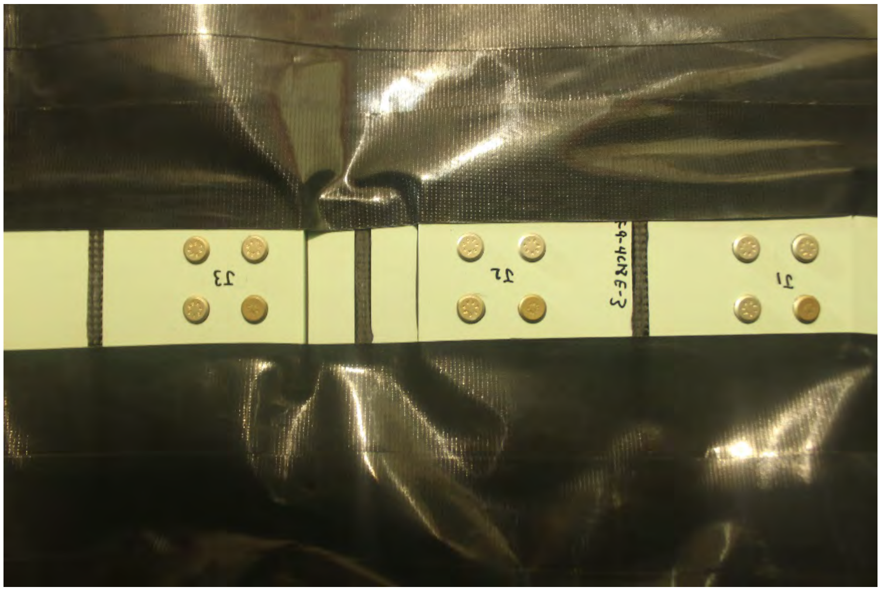


Figure 97: CF9-4C18E-3-Head Side-Open Box-Shot 1-20 kA

Figure 98: CF9-4C18E-3-Head Side-Test Photo-Shot 1-20 kA

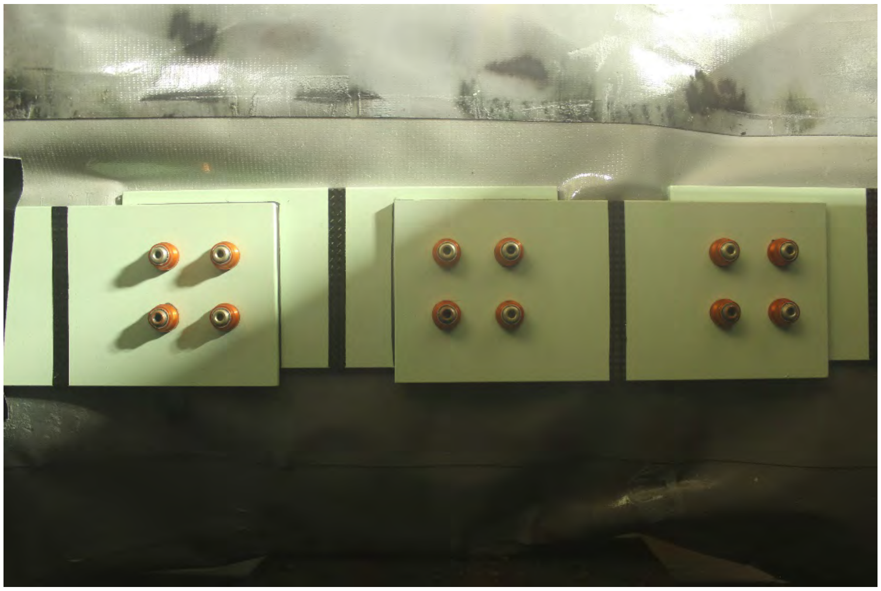


Figure 99: CF9-4C18E-3-Tail Side-Open Box-Shot 1-20 kA

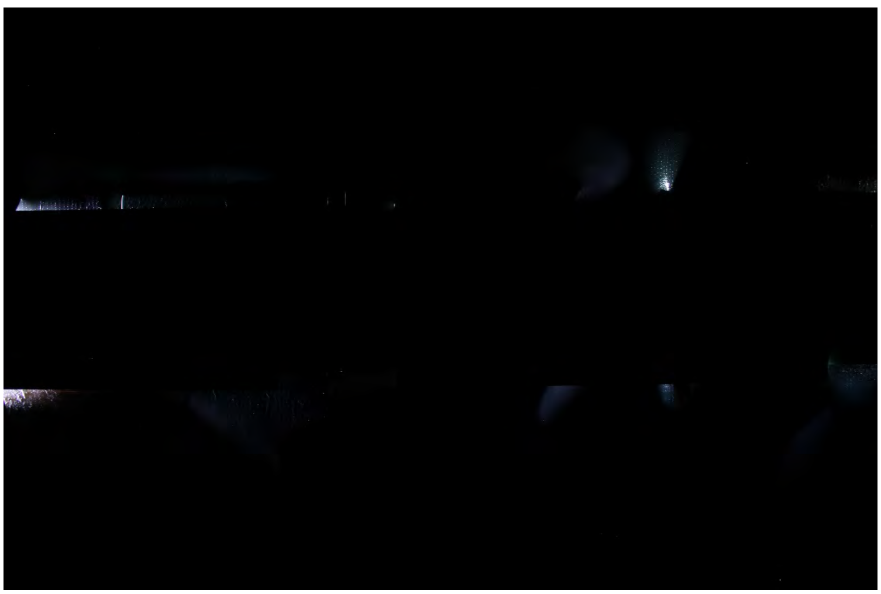


Figure 100: CF9-4C18E-3-Tail Side-Test Photo-Shot 1-20 kA

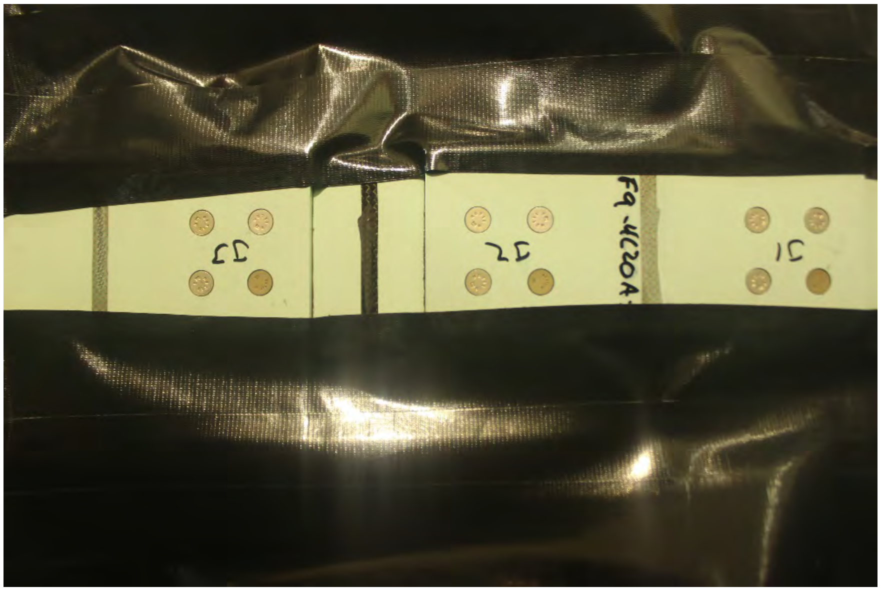


Figure 101: CF9-4C20A-2-Head Side-Open Box-Shot 1-60 kA

Figure 102: CF9-4C20A-2-Head Side-Test Photo-Shot 1-60 kA

Figure 103: CF9-4C20A-2-Tail Side-Open Box-Shot 1-60 kA

Figure 104: CF9-4C20A-2-Tail Side-Test Photo-Shot 1-60 kA

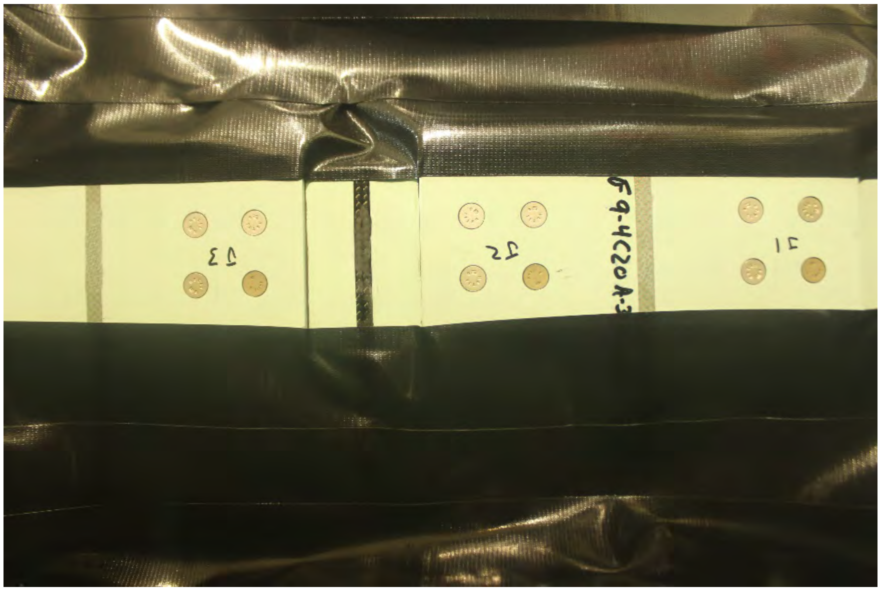


Figure 105: CF9-4C20A-3-Head Side-Open Box-Shot 1-30 kA

Figure 106: CF9-4C20A-3-Head Side-Test Photo-Shot 1-30 kA

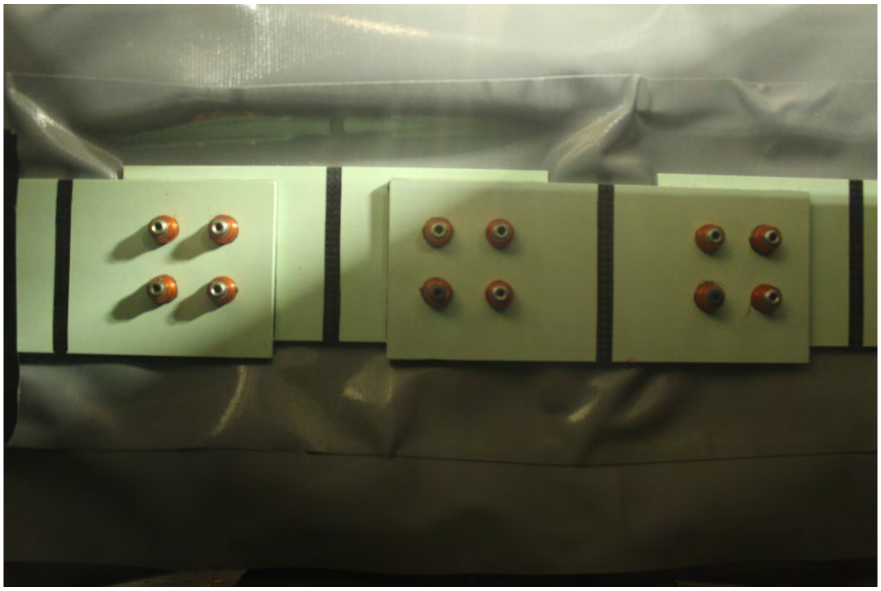


Figure 107: CF9-4C20A-3-Tail Side-Open Box-Shot 1-30 kA

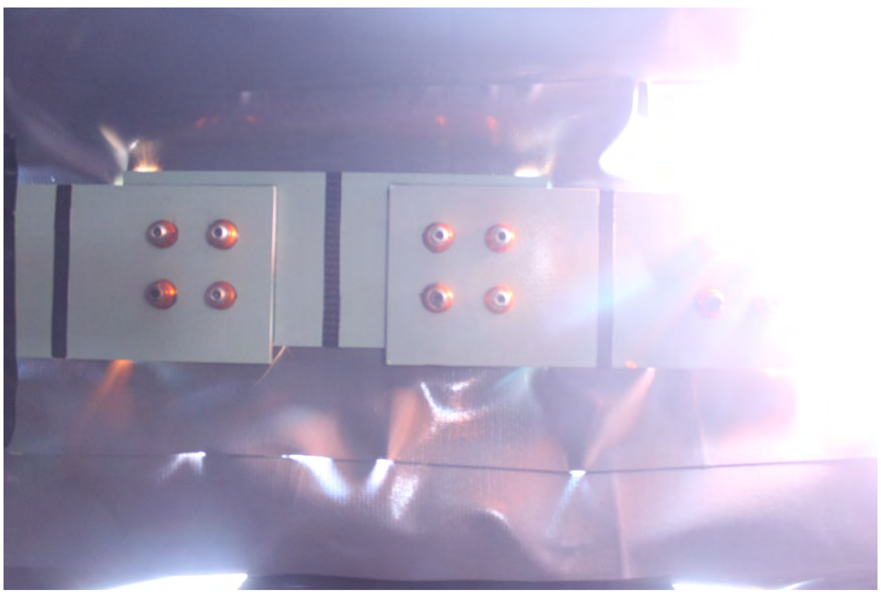


Figure 108: CF9-4C20A-3-Tail Side-Test Photo-Shot 1-30 kA

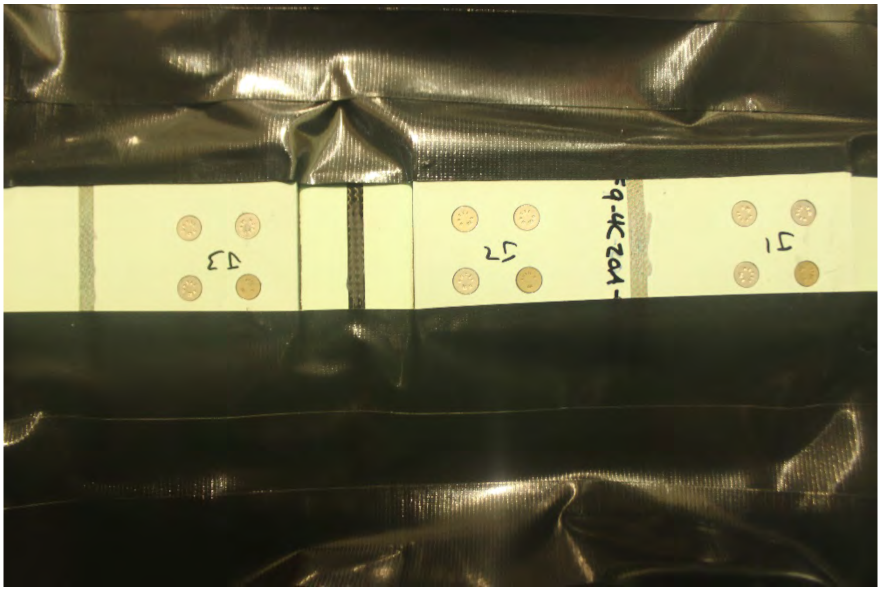


Figure 109: CF9-4C20A-4-Head Side-Open Box-Shot 1-20 kA

Figure 110: CF9-4C20A-4-Head Side-Test Photo-Shot 1-20 kA

Figure 111: CF9-4C20A-4-Tail Side-Open Box-Shot 1-20 kA

Figure 112: CF9-4C20A-4-Tail Side-Test Photo-Shot 1-20 kA

Figure 113: CN-4C18E-1-Head Side-Open Box-Shot 1-10 kA

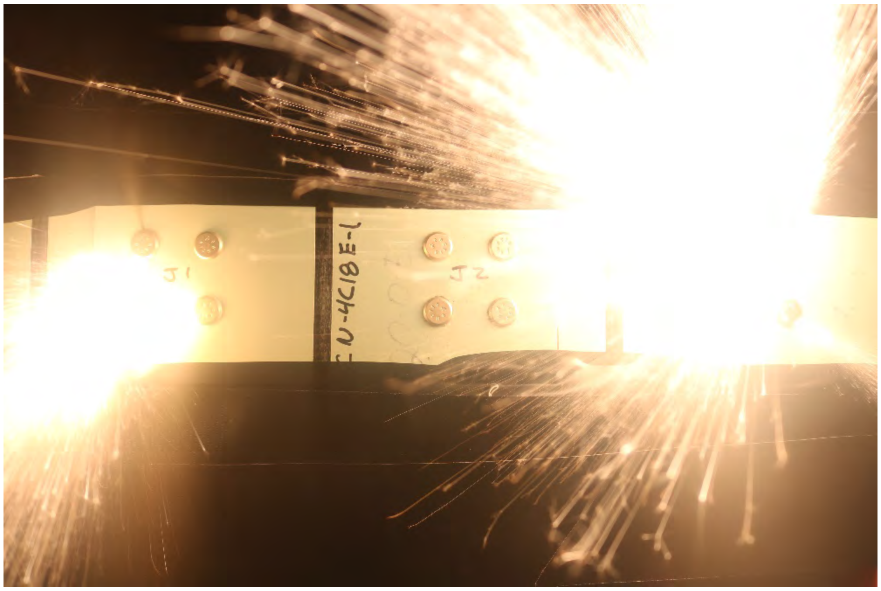


Figure 114: CN-4C18E-1-Head Side-Test Photo-Shot 1-10 kA

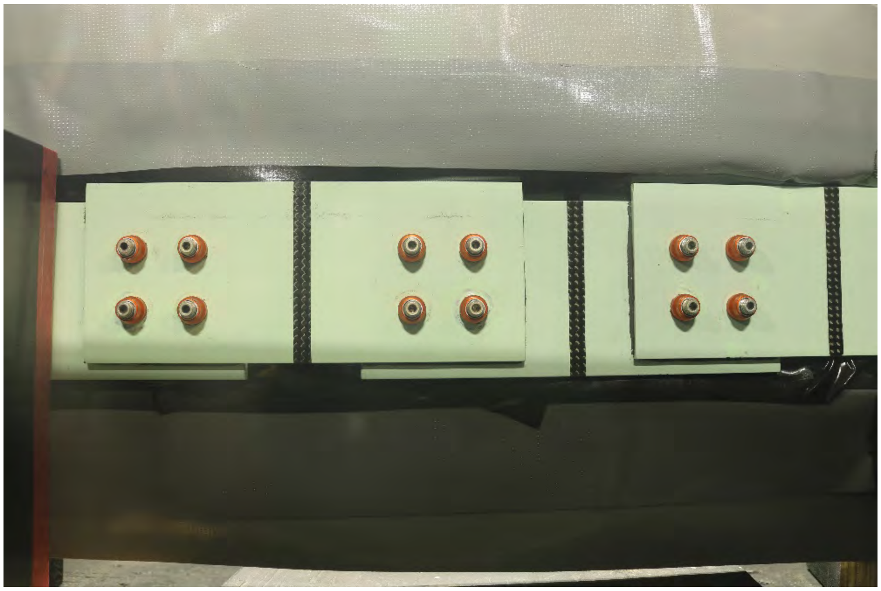


Figure 115: CN-4C18E-1-Tail Side-Open Box-Shot 1-10 kA

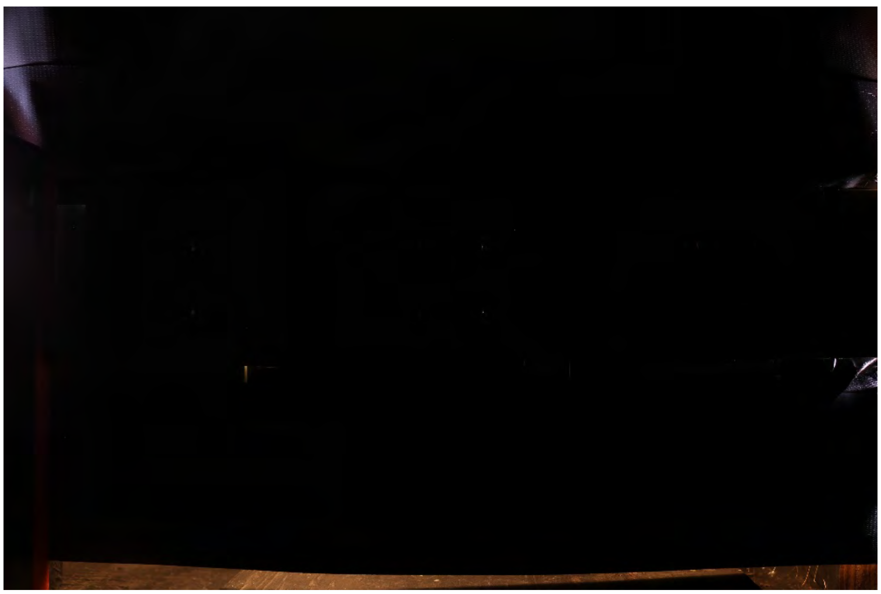


Figure 116: CN-4C18E-1-Tail Side-Test Photo-Shot 1-10 kA

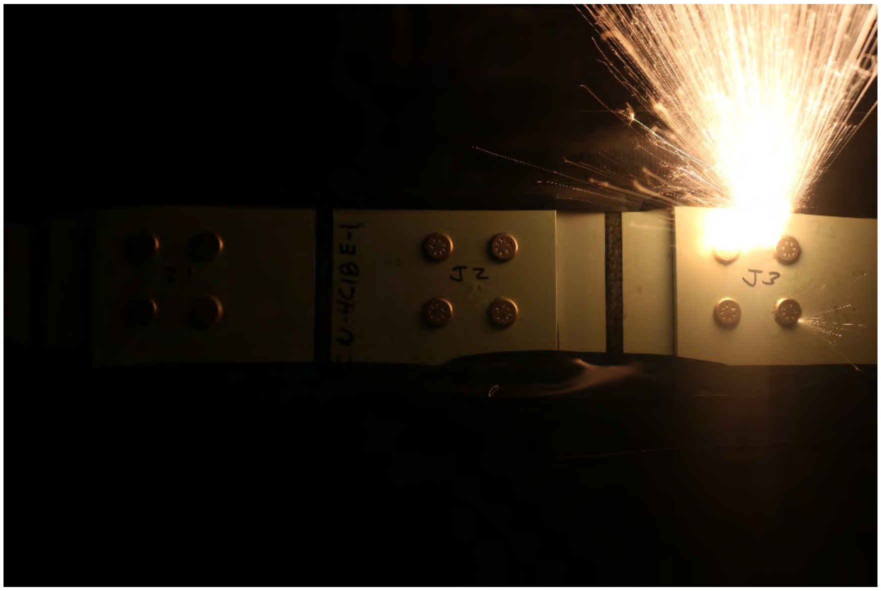


Figure 117: CN-4C18E-1-Head Side-Test Photo-Shot 2-10 kA


Figure 118: CN-4C18E-1-Tail Side-Test Photo-Shot 2-10 kA

Figure 119: CN-4C18E-2-Head Side-Open Box-Shot 1-5 kA

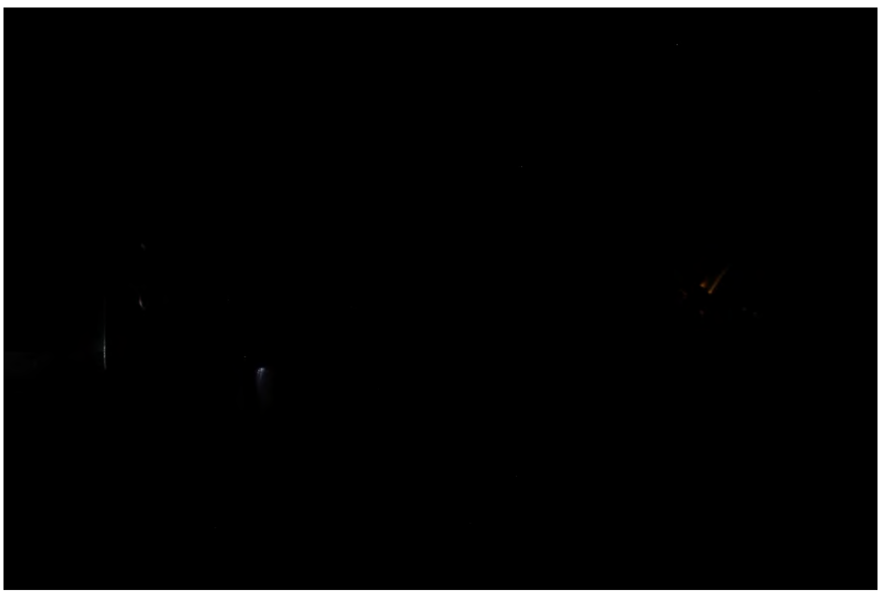


Figure 120: CN-4C18E-2-Head Side-Test Photo-Shot 1-5 kA

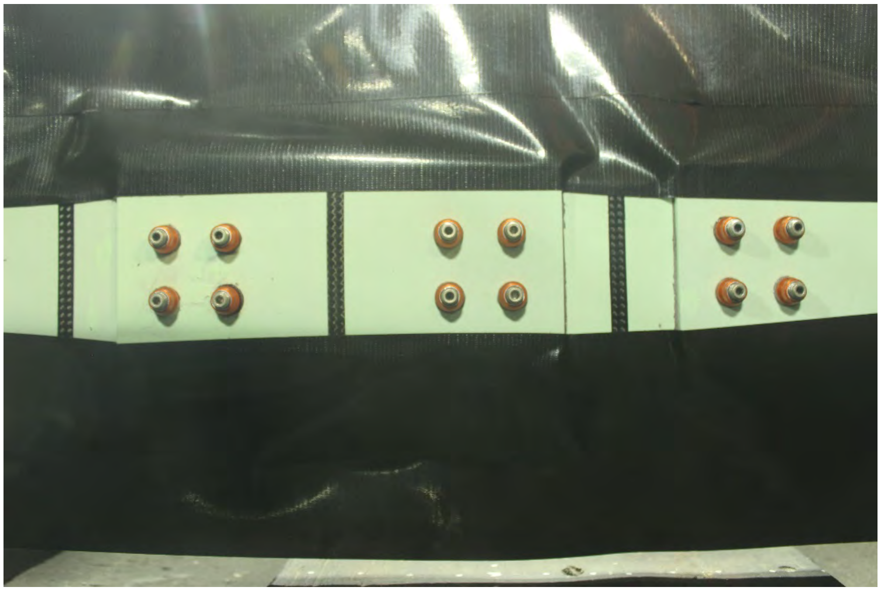


Figure 121: CN-4C18E-2-Tail Side-Open Box-Shot 1-5 kA

Figure 122: CN-4C18E-2-Tail Side-Test Photo-Shot 1-5 kA

Figure 123: CN-4C18E-3-Head Side-Open Box-Shot 1-2 kA

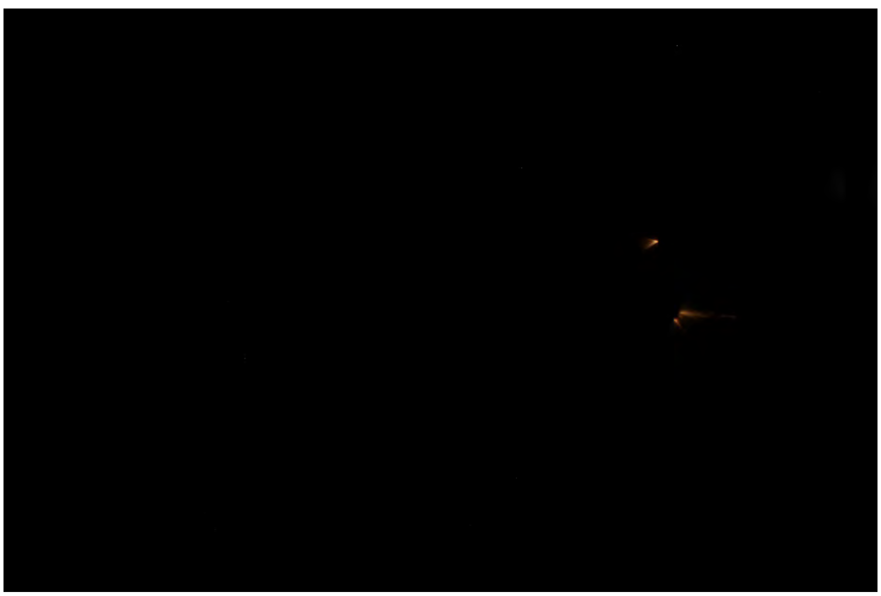


Figure 124: CN-4C18E-3-Head Side-Test Photo-Shot 1-2 kA

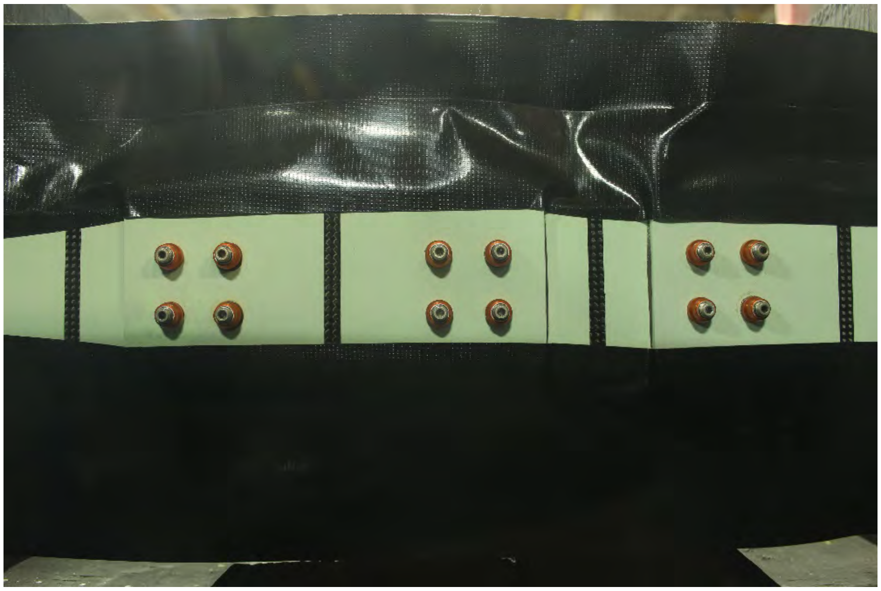


Figure 125: CN-4C18E-3-Tail Side-Open Box-Shot 1-2 kA

Figure 126: CN-4C18E-3-Tail Side-Test Photo-Shot 1-2 kA

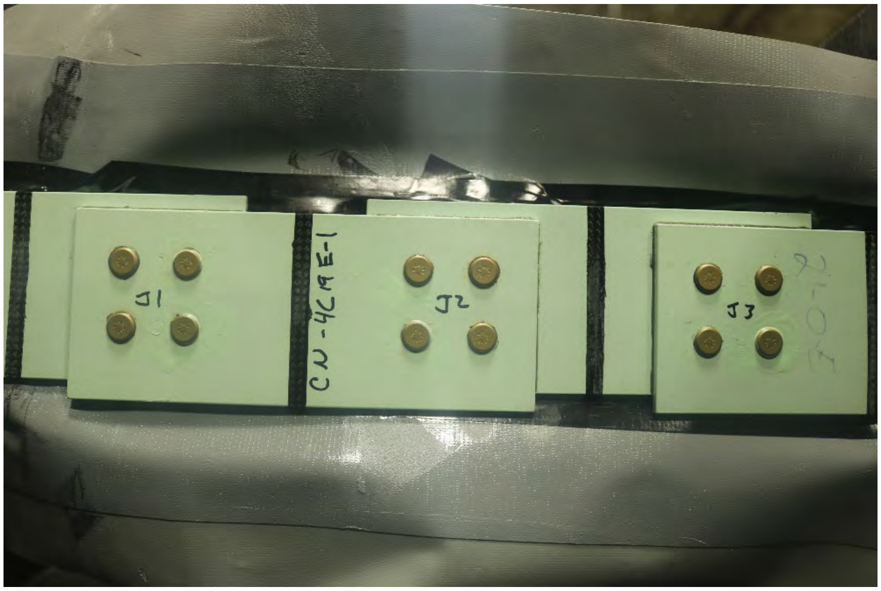


Figure 127: CN-4C19E-1-Head Side-Open Box-Shot 1-10 kA

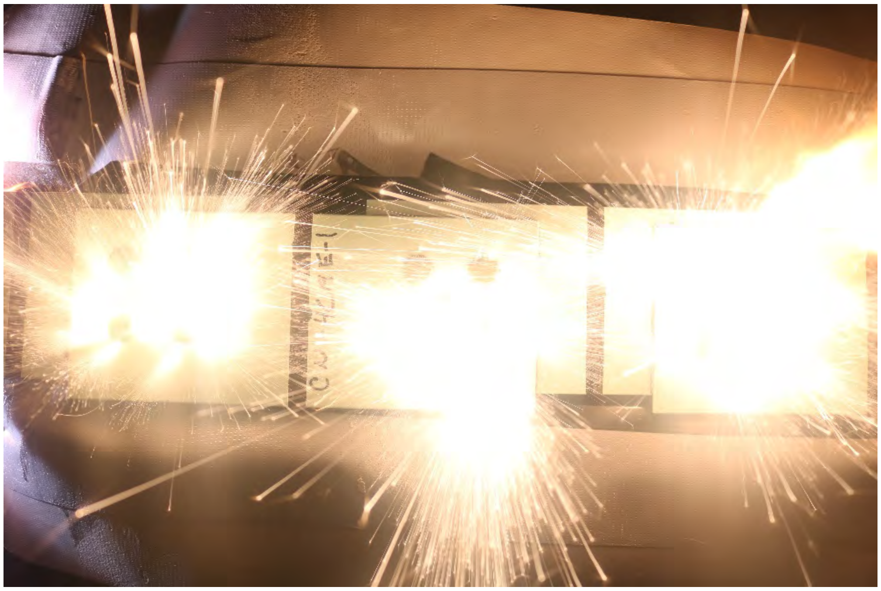


Figure 128: CN-4C19E-1-Head Side-Test Photo-Shot 1-10 kA

Figure 129: CN-4C19E-1-Tail Side-Open Box-Shot 1-10 kA

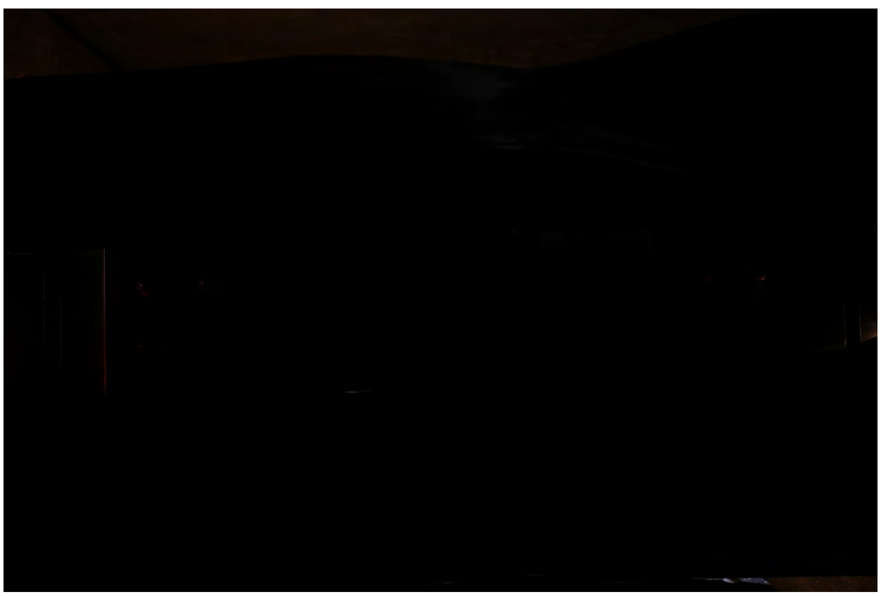


Figure 130: CN-4C19E-1-Tail Side-Test Photo-Shot 1-10 kA

Figure 131: CN-4C19E-2-Head Side-Open Box-Shot 1-3 kA

Figure 132: CN-4C19E-2-Head Side-Test Photo-Shot 1-3 kA


Figure 133: <u>CN-4C19E-2-Tail Side-Open Box-Shot 1-3 kA</u>


Figure 134: <u>CN-4C19E-2-Tail Side-Test Photo-Shot 1-3 kA</u>

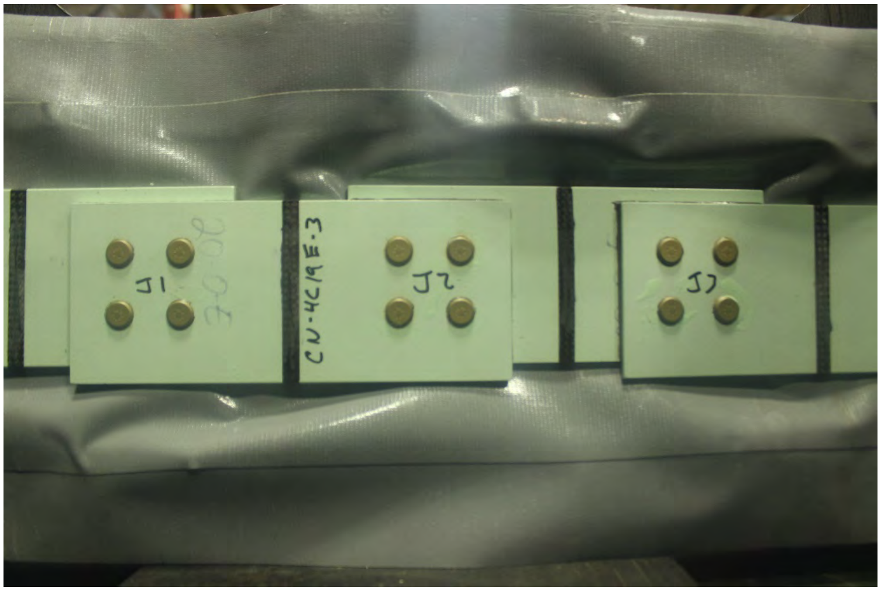


Figure 135: CN-4C19E-3-Head Side-Open Box-Shot 1-1 kA

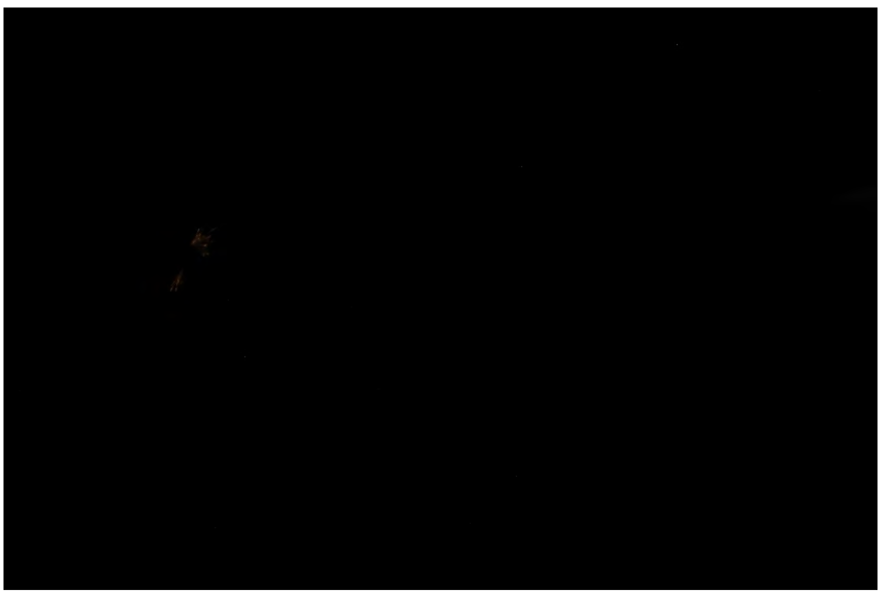


Figure 136: CN-4C19E-3-Head Side-Test Photo-Shot 1-1 kA

Figure 137: CN-4C19E-3-Tail Side-Open Box-Shot 1-1 kA

Figure 138: CN-4C19E-3-Tail Side-Test Photo-Shot 1-1 kA

Figure 139: CN-4C20A-1-Head Side-Test Photo-Shot 4-10 kA

Figure 140: CN-4C20A-1-Tail Side-Test Photo-Shot 4-10 kA

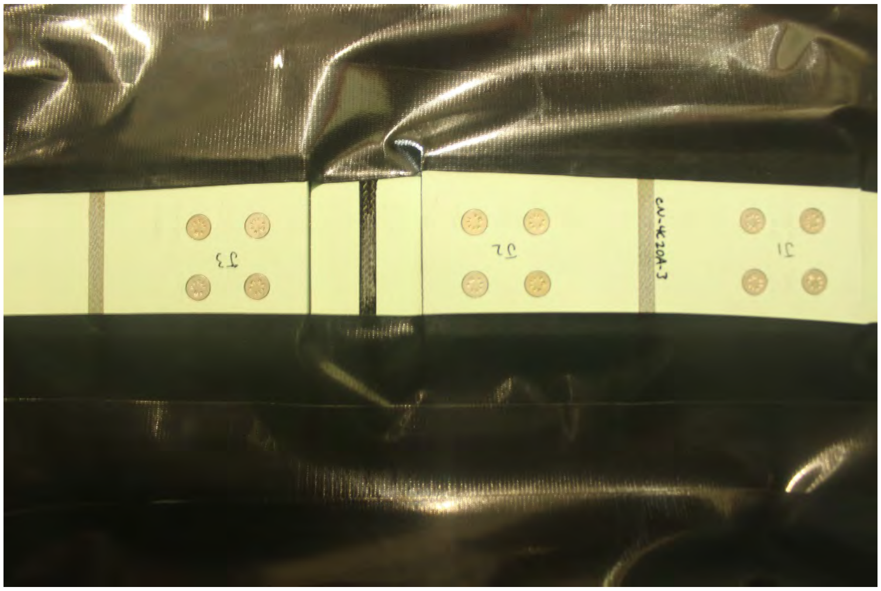


Figure 141: CN-4C20A-3-Head Side-Open Box-Shot 1-60 kA

Figure 142: CN-4C20A-3-Head Side-Test Photo-Shot 1-60 kA

Figure 143: CN-4C20A-3-Tail Side-Open Box-Shot 1-60 kA

Figure 144: CN-4C20A-3-Tail Side-Test Photo-Shot 1-60 kA

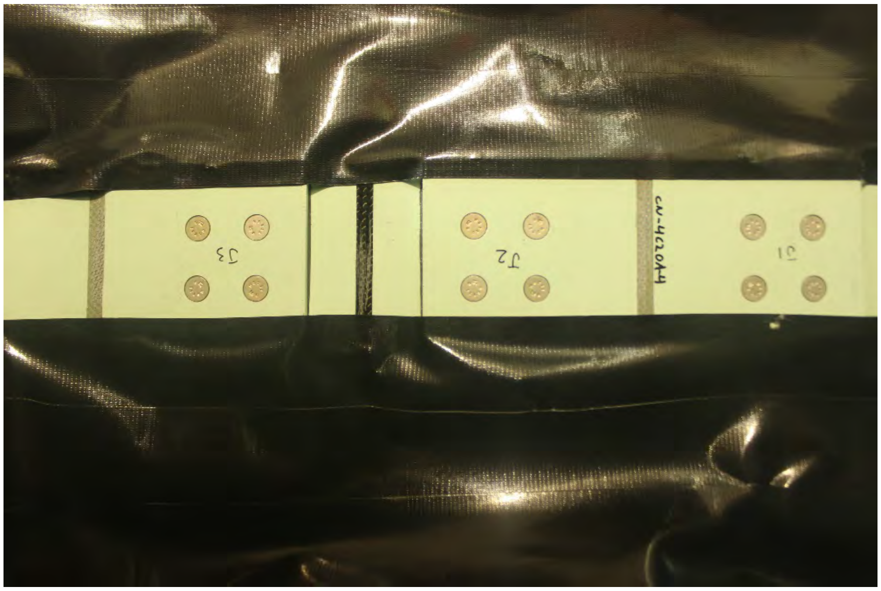


Figure 145: CN-4C20A-4-Head Side-Open Box-Shot 1-30 kA

Figure 146: CN-4C20A-4-Head Side-Test Photo-Shot 1-30 kA

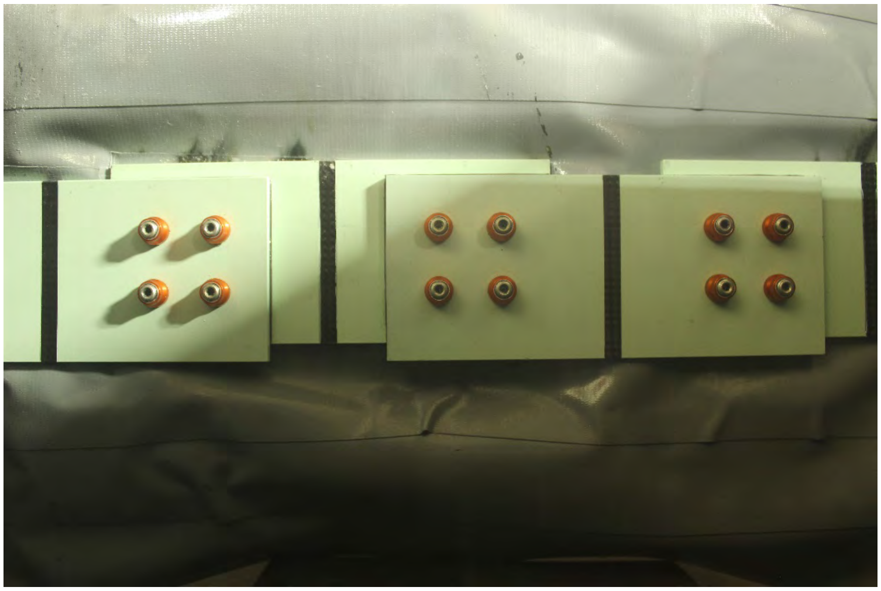


Figure 147: CN-4C20A-4-Tail Side-Open Box-Shot 1-30 kA

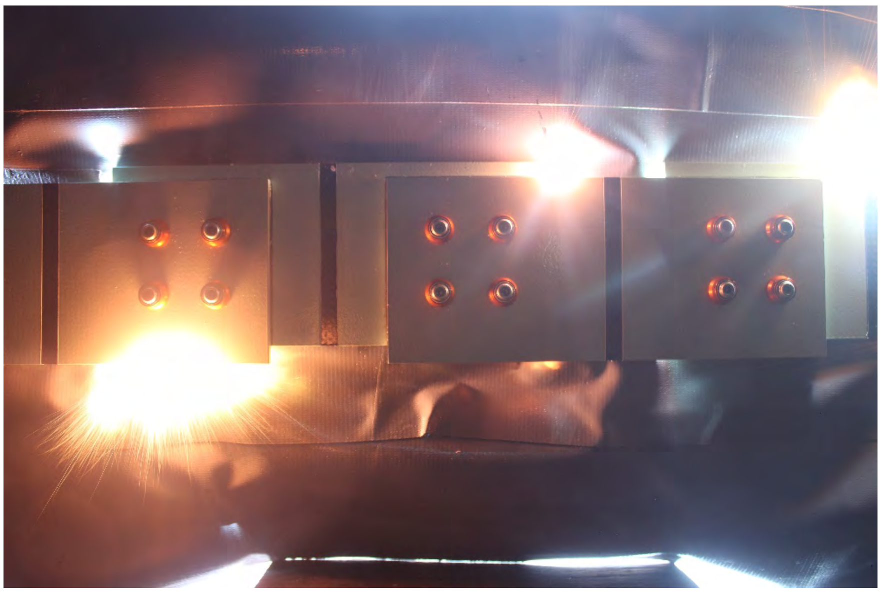


Figure 148: CN-4C20A-4-Tail Side-Test Photo-Shot 1-30 kA

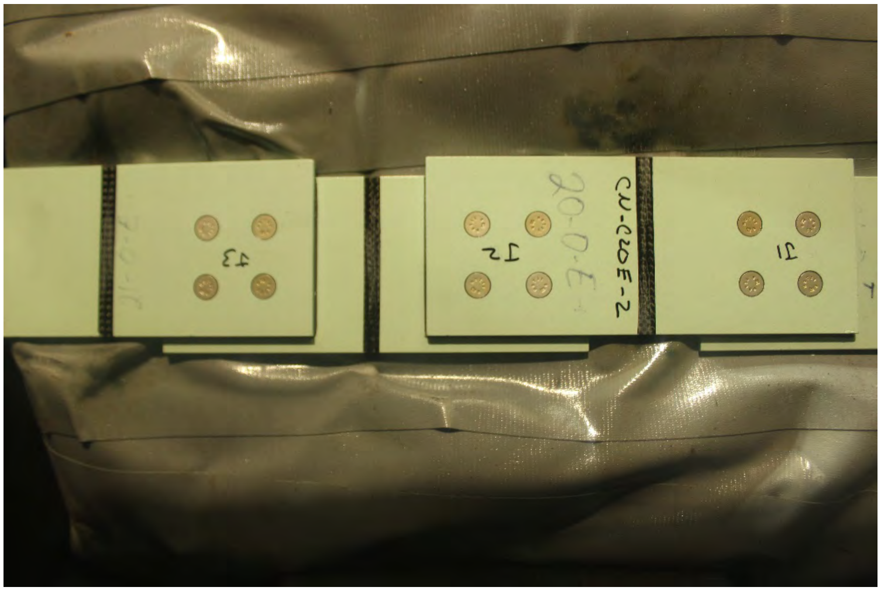


Figure 149: CN-4C20E-2-Head Side-Open Box-Shot 1-60 kA

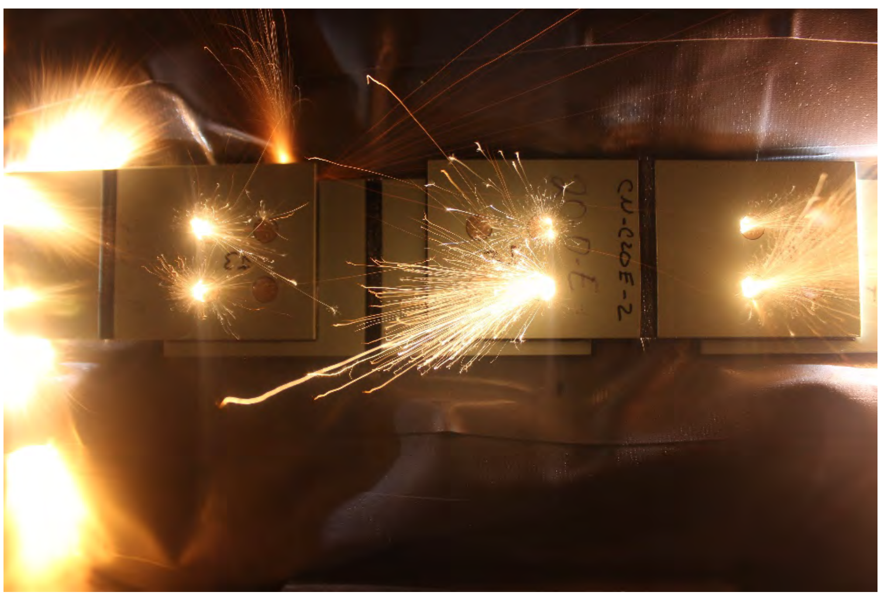


Figure 150: CN-4C20E-2-Head Side-Test Photo-Shot 1-60 kA

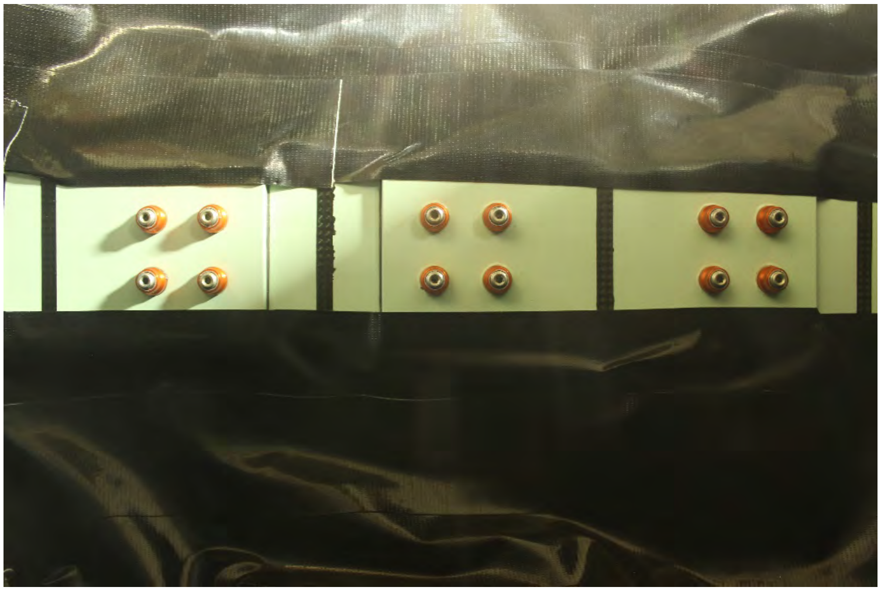


Figure 151: CN-4C20E-2-Tail Side-Open Box-Shot 1-60 kA

Figure 152: CN-4C20E-2-Tail Side-Test Photo-Shot 1-60 kA

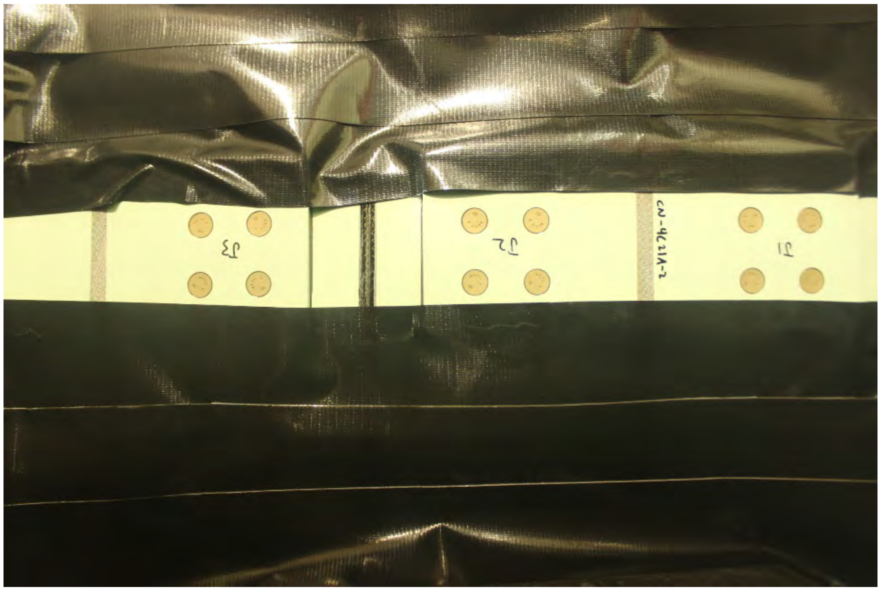


Figure 153: CN-4C21A-2-Head Side-Open Box-Shot 1-60 kA

Figure 154: CN-4C21A-2-Head Side-Test Photo-Shot 1-60 kA

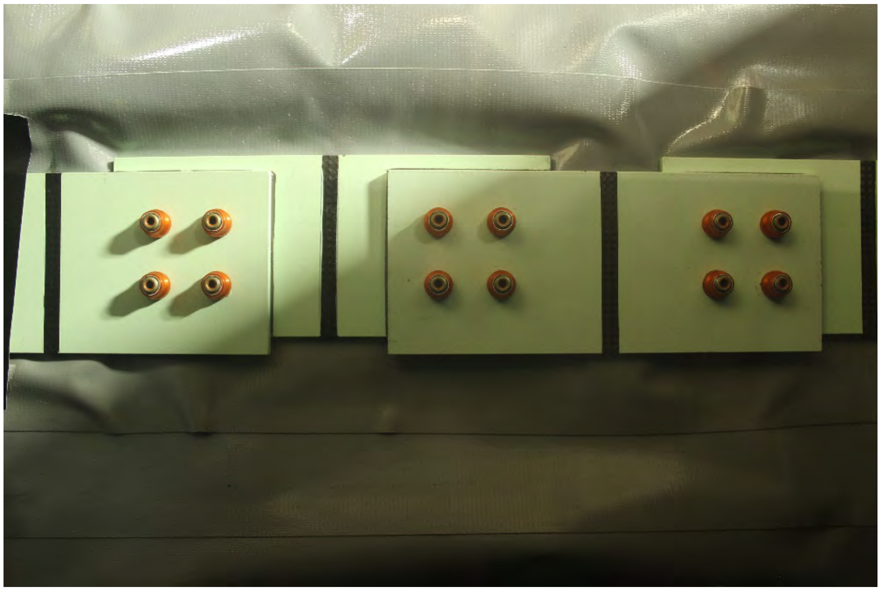


Figure 155: CN-4C21A-2-Tail Side-Open Box-Shot 1-60 kA

Figure 156: CN-4C21A-2-Tail Side-Test Photo-Shot 1-60 kA

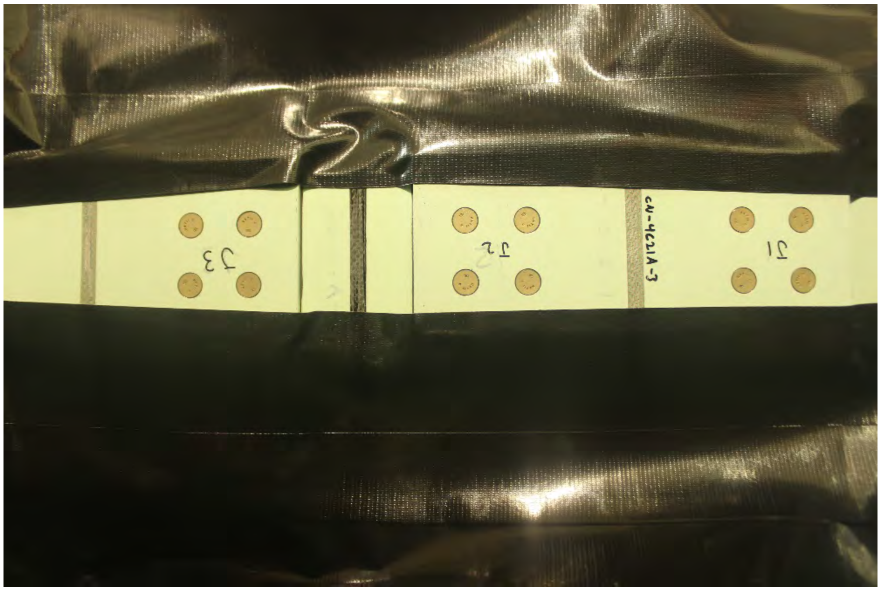


Figure 157: CN-4C21A-3-Head Side-Open Box-Shot 1-20 kA

Figure 158: CN-4C21A-3-Head Side-Test Photo-Shot 1-20 kA

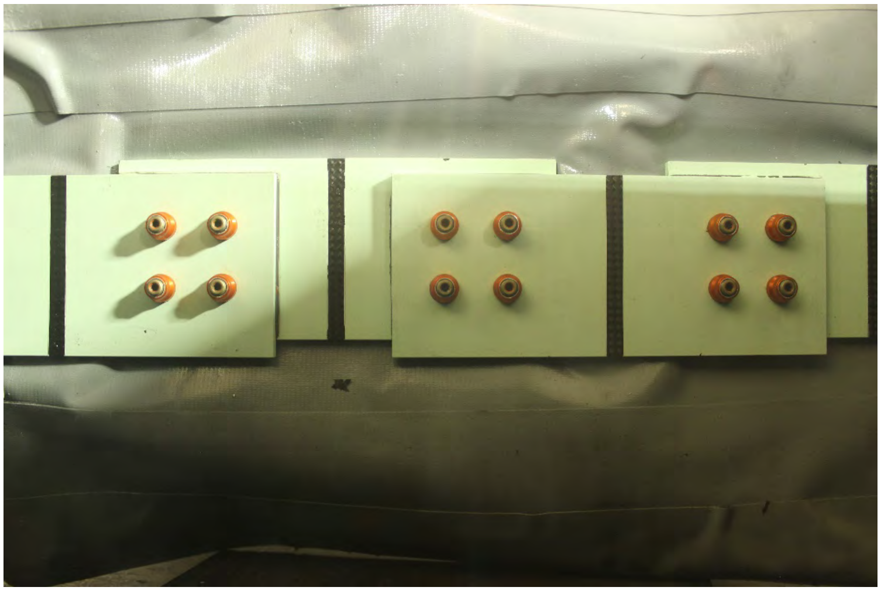


Figure 159: CN-4C21A-3-Tail Side-Open Box-Shot 1-20 kA

Figure 160: CN-4C21A-3-Tail Side-Test Photo-Shot 1-20 kA

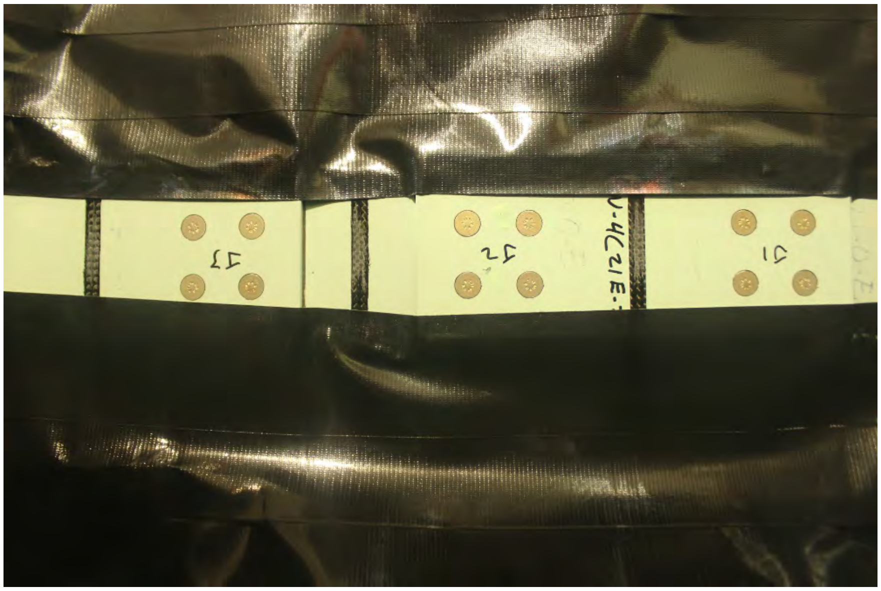


Figure 161: CN-4C21E-2-Head Side-Open Box-Shot 1-60 kA

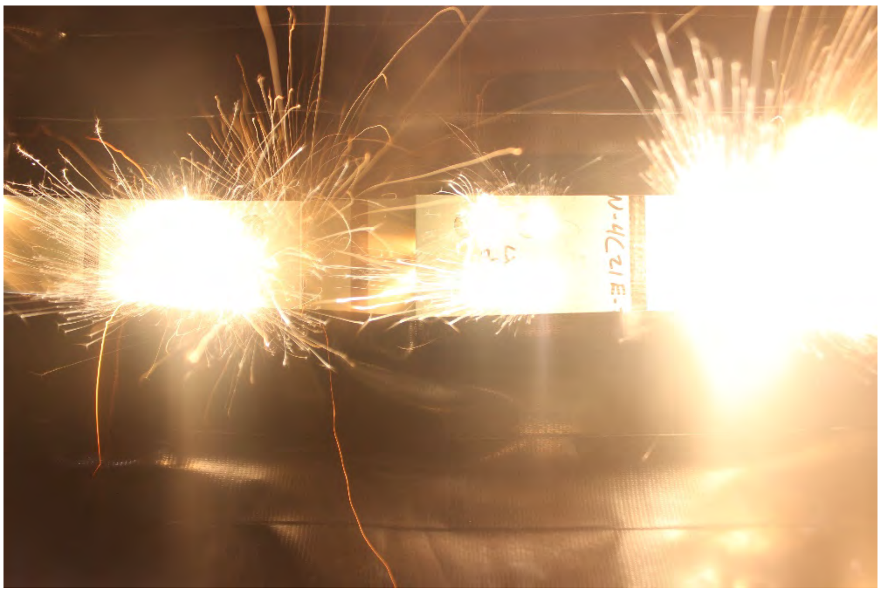


Figure 162: CN-4C21E-2-Head Side-Test Photo-Shot 1-60 kA

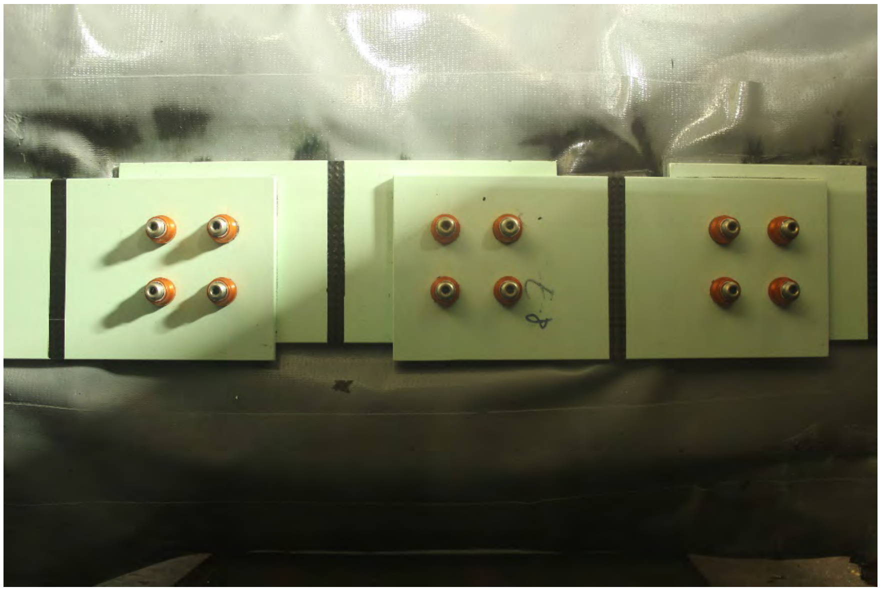


Figure 163: CN-4C21E-2-Tail Side-Open Box-Shot 1-60 kA

Figure 164: CN-4C21E-2-Tail Side-Test Photo-Shot 1-60 kA

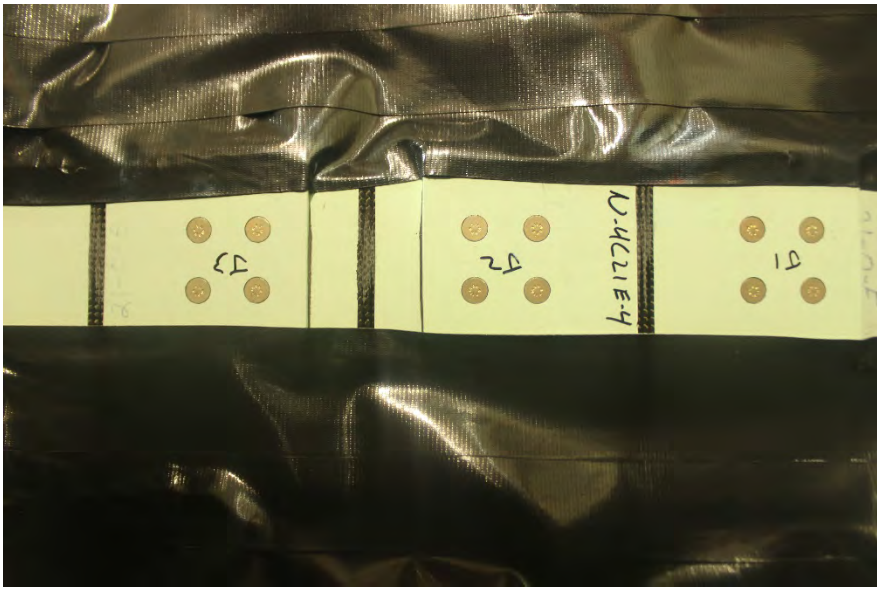


Figure 165: CN-4C21E-4-Head Side-Open Box-Shot 1-40 kA

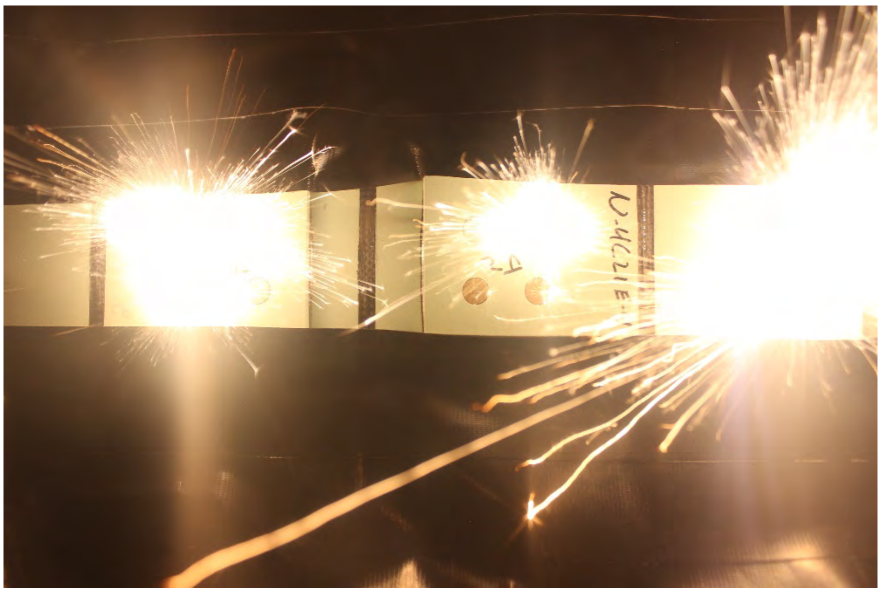


Figure 166: CN-4C21E-4-Head Side-Test Photo-Shot 1-40 kA

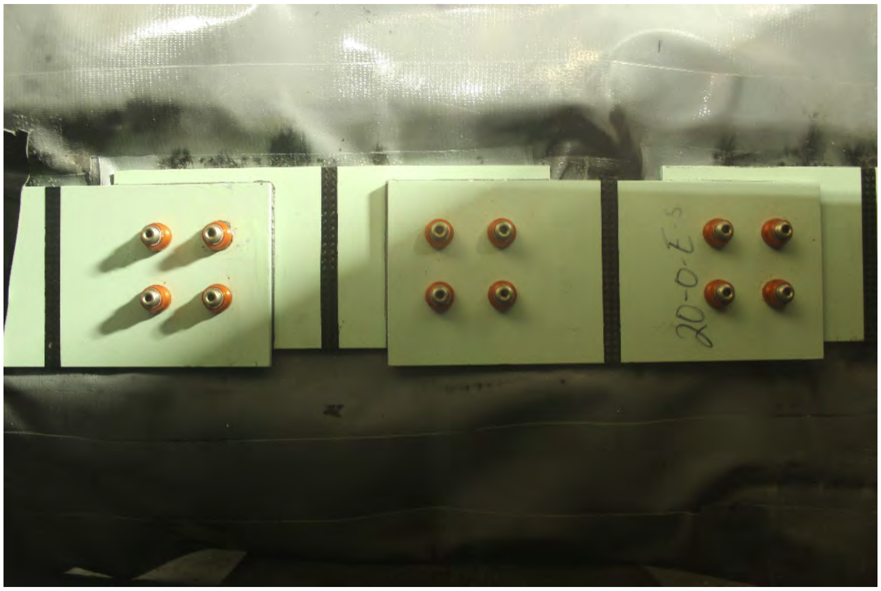


Figure 167: CN-4C21E-4-Tail Side-Open Box-Shot 1-40 kA

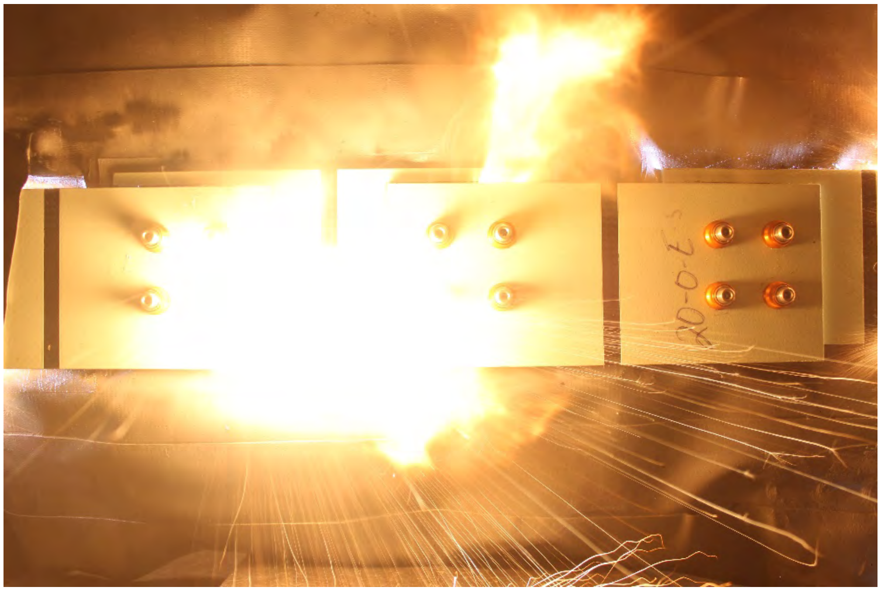


Figure 168: CN-4C21E-4-Tail Side-Test Photo-Shot 1-40 kA

Figure 169: HF4-4C18D-2-Head Side-Open Box-Shot 1-30 kA

Figure 170: HF4-4C18D-2-Head Side-Test Photo-Shot 1-30 kA


Figure 171: HF4-4C18D-2-Tail Side-Open Box-Shot 1-30 kA

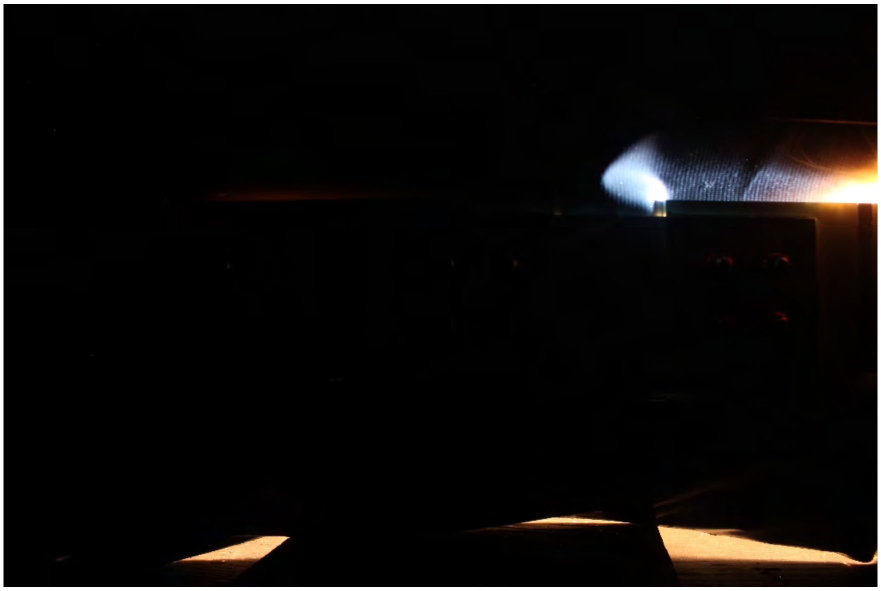


Figure 172: HF4-4C18D-2-Tail Side-Test Photo-Shot 1-30 kA

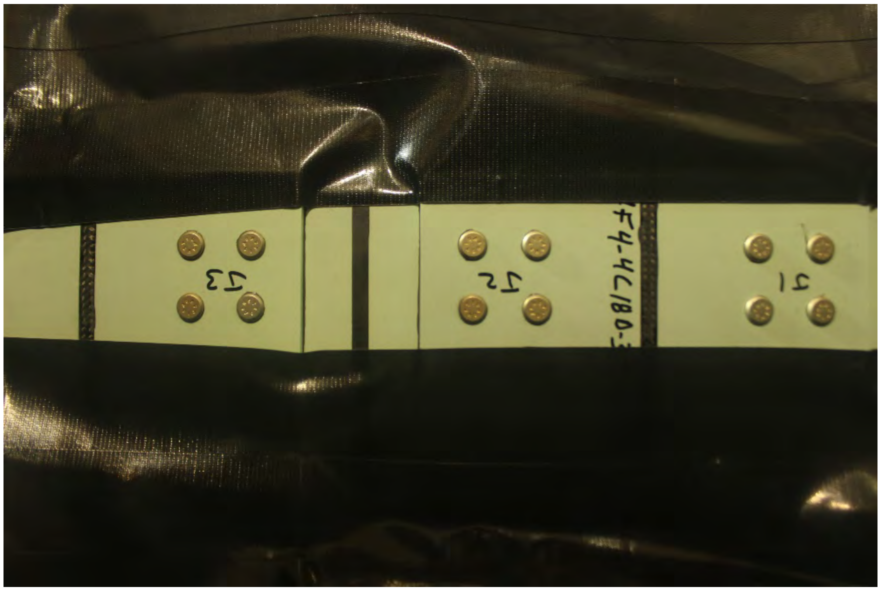


Figure 173: HF4-4C18D-3-Head Side-Open Box-Shot 1-20 kA

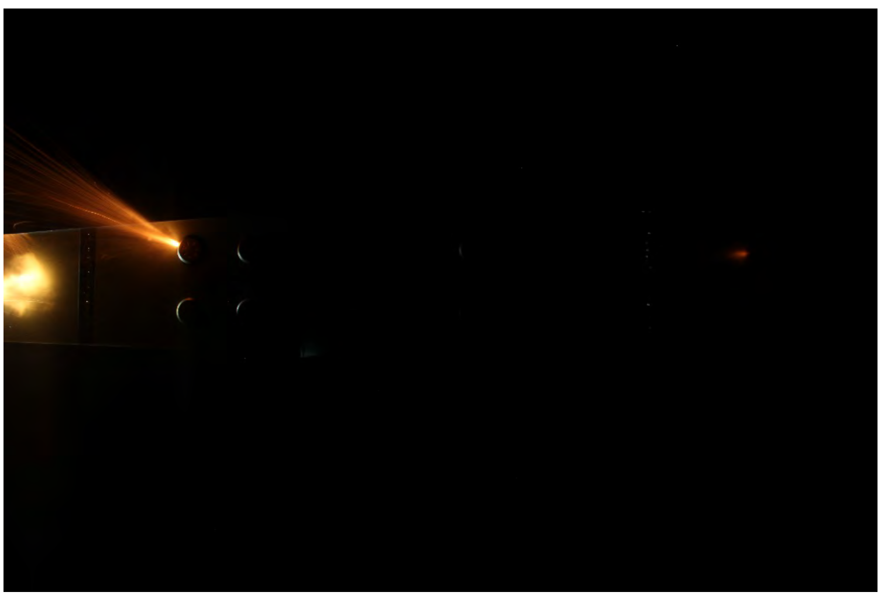


Figure 174: HF4-4C18D-3-Head Side-Test Photo-Shot 1-20 kA

Figure 175: HF4-4C18D-3-Tail Side-Open Box-Shot 1-20 kA

Figure 176: HF4-4C18D-3-Tail Side-Test Photo-Shot 1-20 kA

Figure 177: HF4-4C20C-1-Head Side-Open Box-Shot 1-10 kA


Figure 178: HF4-4C20C-1-Head Side-Test Photo-Shot 1-10 kA

Figure 179: HF4-4C20C-1-Tail Side-Open Box-Shot 1-10 kA

Figure 180: HF4-4C20C-1-Tail Side-Test Photo-Shot 1-10 kA

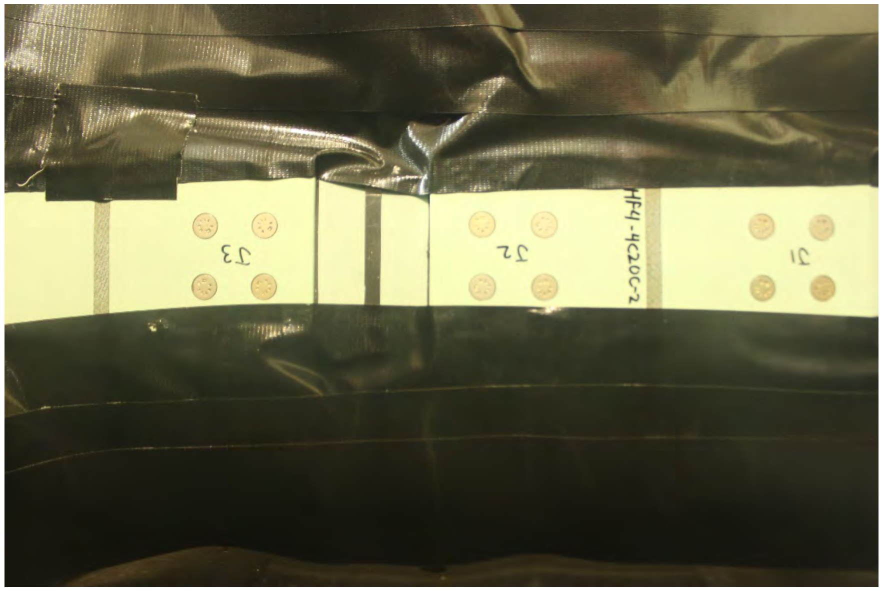


Figure 181: <u>HF4-4C20C-2-Head Side-Open Box-Shot 1-60 kA</u>

Figure 182: <u>HF4-4C20C-2-Head Side-Test Photo-Shot 1-60 kA</u>

Figure 183: HF4-4C20C-2-Tail Side-Open Box-Shot 1-60 kA

Figure 184: HF4-4C20C-2-Tail Side-Test Photo-Shot 1-60 kA

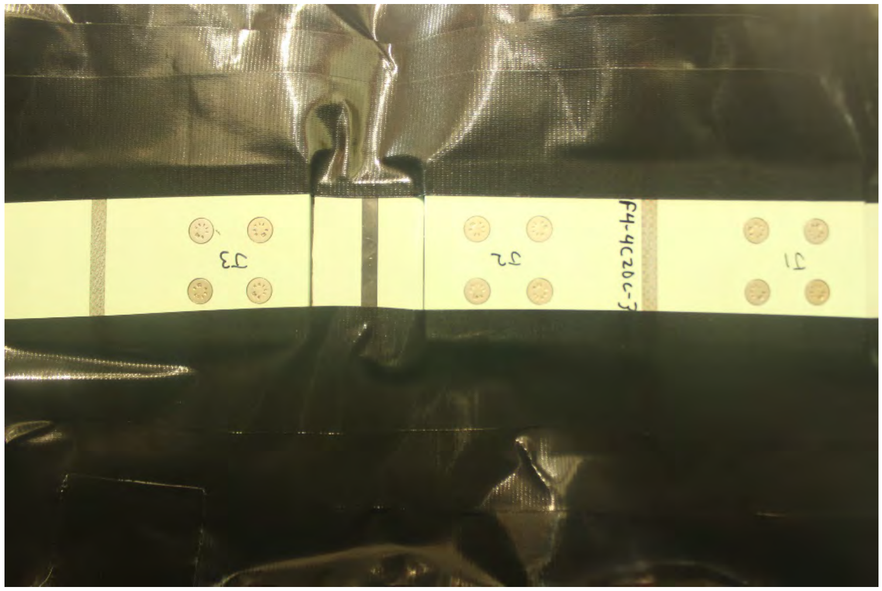


Figure 185: HF4-4C20C-3-Head Side-Open Box-Shot 1-30 kA

Figure 186: HF4-4C20C-3-Head Side-Test Photo-Shot 1-30 kA

Figure 187: HF4-4C20C-3-Tail Side-Open Box-Shot 1-30 kA

Figure 188: HF4-4C20C-3-Tail Side-Test Photo-Shot 1-30 kA

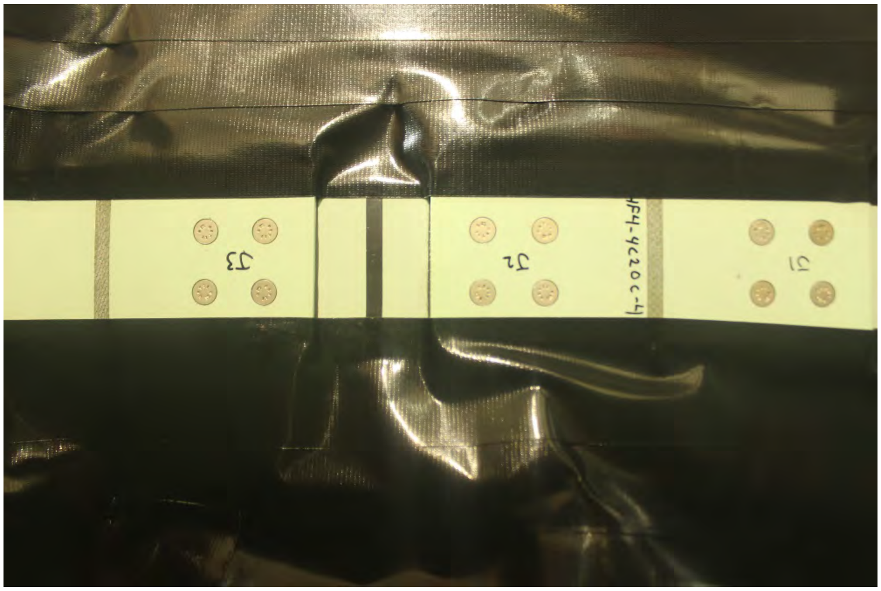


Figure 189: HF4-4C20C-4-Head Side-Open Box-Shot 1-20 kA

Figure 190: HF4-4C20C-4-Head Side-Test Photo-Shot 1-20 kA

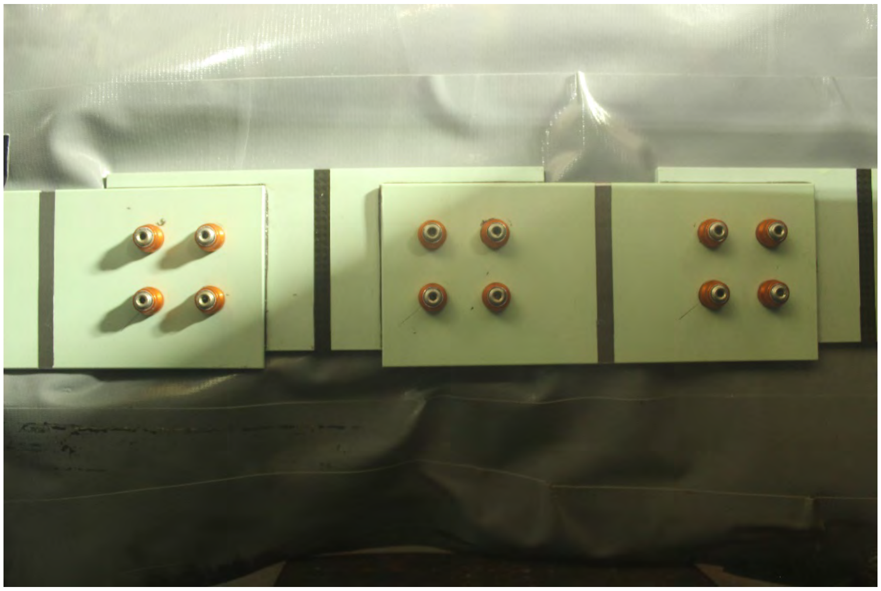


Figure 191: HF4-4C20C-4-Tail Side-Open Box-Shot 1-20 kA

Figure 192: HF4-4C20C-4-Tail Side-Test Photo-Shot 1-20 kA

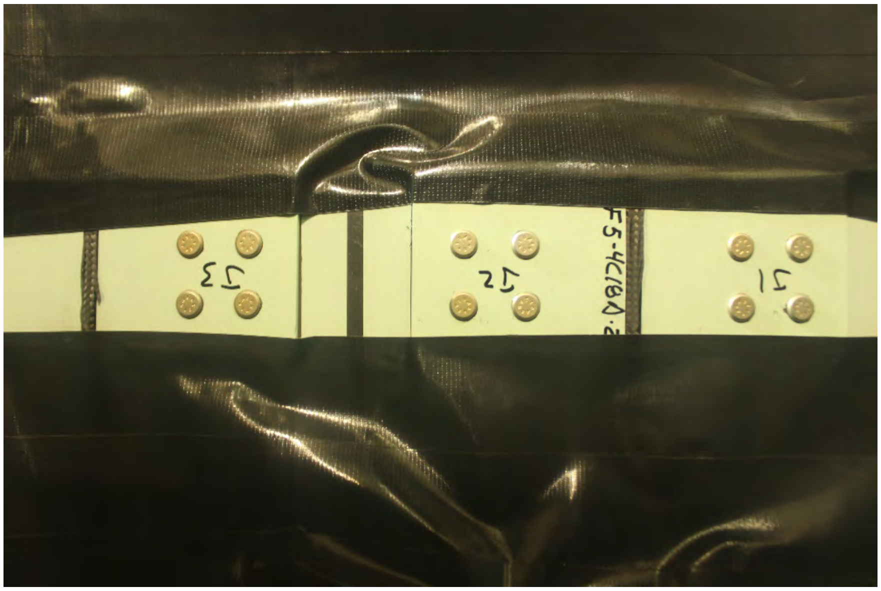


Figure 193: HF5-4C18D-2-Head Side-Open Box-Shot 1-30 kA

Figure 194: HF5-4C18D-2-Head Side-Test Photo-Shot 1-30 kA


Figure 195: HF5-4C18D-2-Tail Side-Open Box-Shot 1-30 kA


Figure 196: HF5-4C18D-2-Tail Side-Test Photo-Shot 1-30 kA

Figure 197: HF5-4C18D-3-Head Side-Open Box-Shot 1-20 kA

Figure 198: HF5-4C18D-3-Head Side-Test Photo-Shot 1-20 kA

Figure 199: HF5-4C18D-3-Tail Side-Open Box-Shot 1-20 kA

Figure 200: HF5-4C18D-3-Tail Side-Test Photo-Shot 1-20 kA

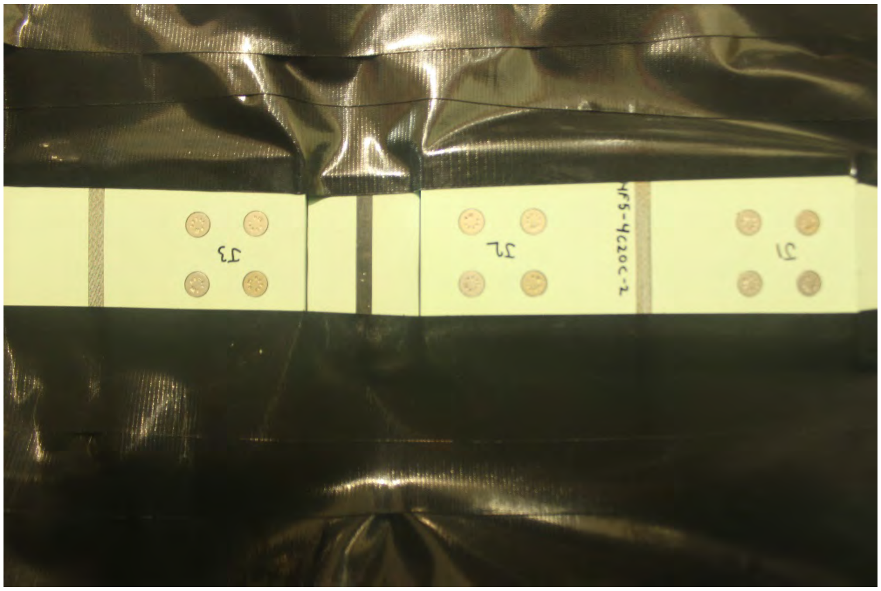


Figure 201: HF5-4C20C-2-Head Side-Open Box-Shot 1-60 kA

Figure 202: HF5-4C20C-2-Head Side-Test Photo-Shot 1-60 kA

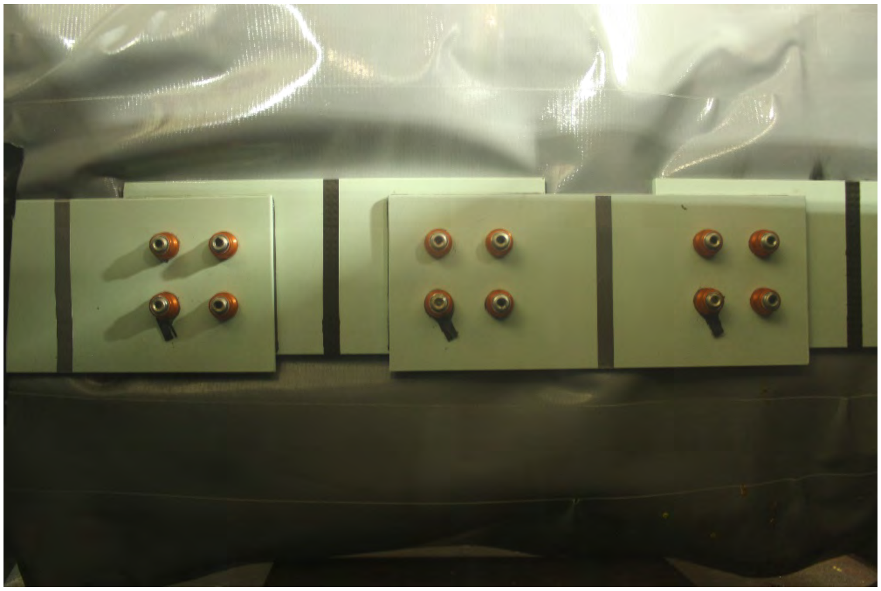


Figure 203: HF5-4C20C-2-Tail Side-Open Box-Shot 1-60 kA

Figure 204: HF5-4C20C-2-Tail Side-Test Photo-Shot 1-60 kA

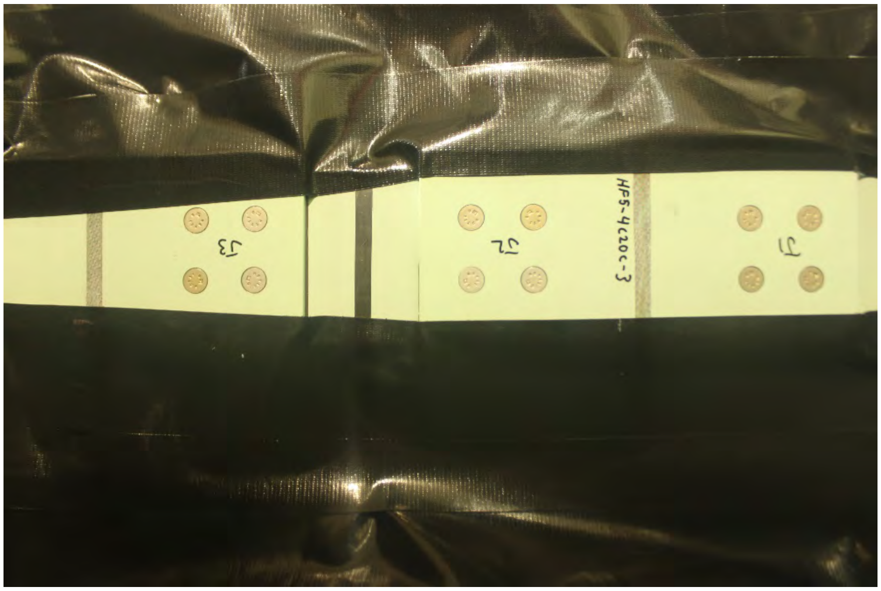


Figure 205: HF5-4C20C-3-Head Side-Open Box-Shot 1-30 kA

Figure 206: HF5-4C20C-3-Head Side-Test Photo-Shot 1-30 kA

Figure 207: HF5-4C20C-3-Tail Side-Open Box-Shot 1-30 kA

Figure 208: HF5-4C20C-3-Tail Side-Test Photo-Shot 1-30 kA

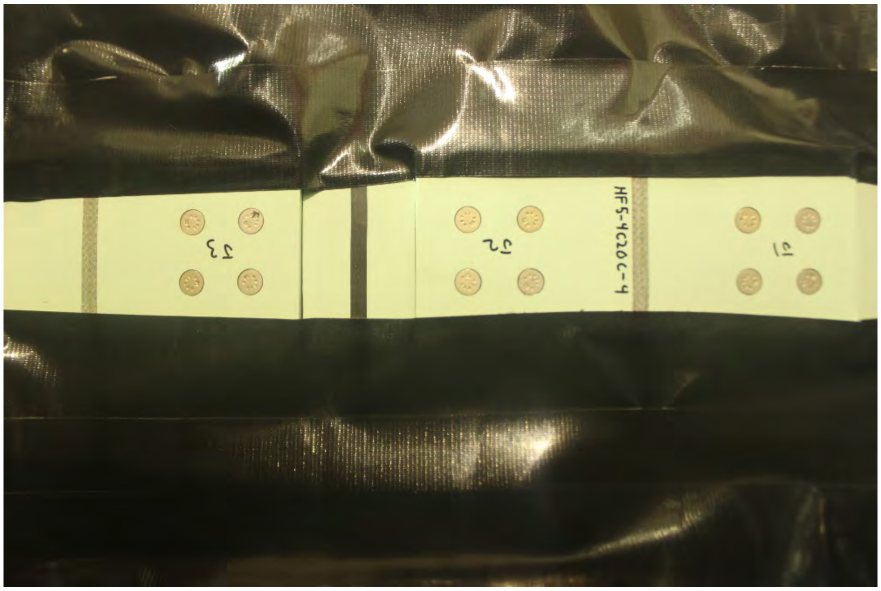


Figure 209: HF5-4C20C-4-Head Side-Open Box-Shot 1-20 kA

Figure 210: HF5-4C20C-4-Head Side-Test Photo-Shot 1-20 kA

Figure 211: HF5-4C20C-4-Tail Side-Open Box-Shot 1-20 kA

Figure 212: HF5-4C20C-4-Tail Side-Test Photo-Shot 1-20 kA

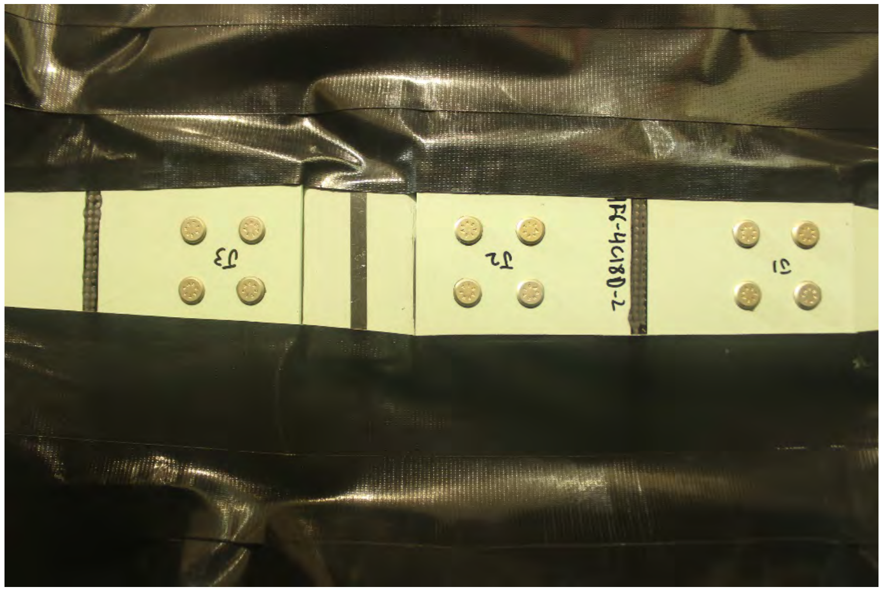


Figure 213: HF6-4C18D-2-Head Side-Open Box-Shot 1-60 kA

Figure 214: HF6-4C18D-2-Head Side-Test Photo-Shot 1-60 kA

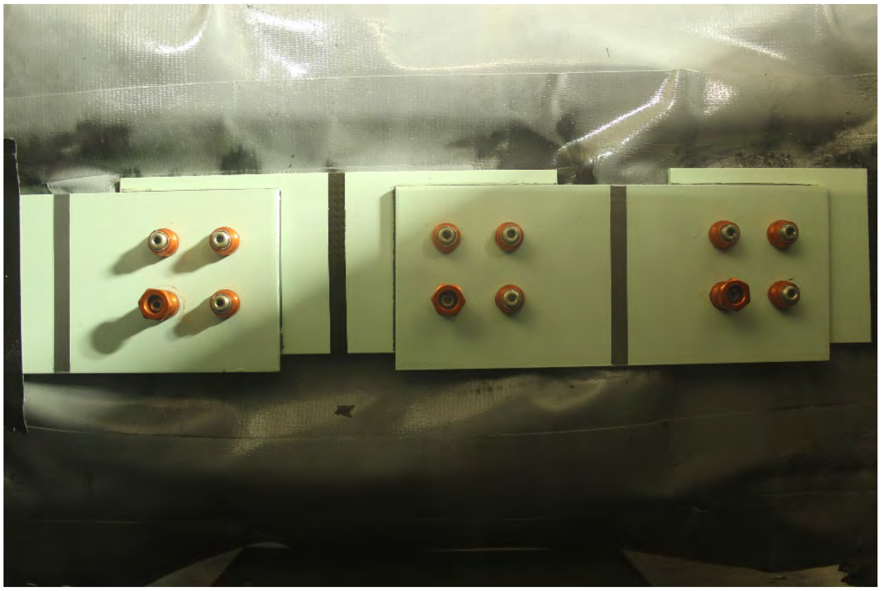


Figure 215: HF6-4C18D-2-Tail Side-Open Box-Shot 1-60 kA

Figure 216: HF6-4C18D-2-Tail Side-Test Photo-Shot 1-60 kA

Figure 217: HF6-4C18D-3-Head Side-Open Box-Shot 1-30 kA

Figure 218: HF6-4C18D-3-Head Side-Test Photo-Shot 1-30 kA

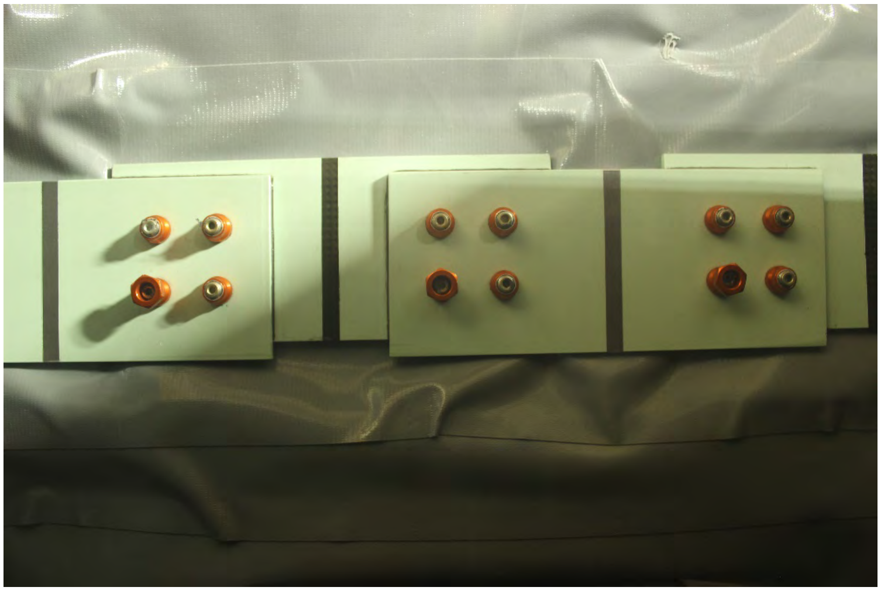


Figure 219: HF6-4C18D-3-Tail Side-Open Box-Shot 1-30 kA

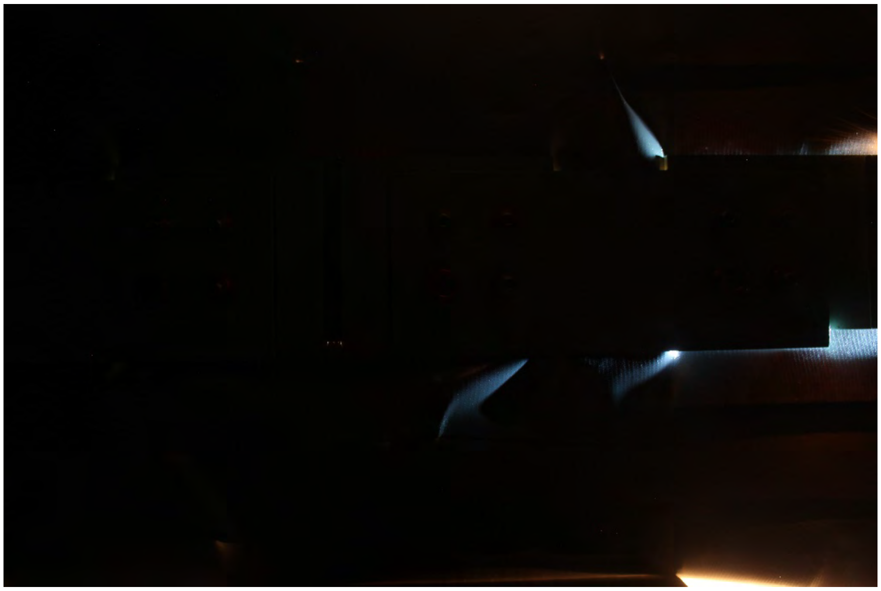


Figure 220: HF6-4C18D-3-Tail Side-Test Photo-Shot 1-30 kA

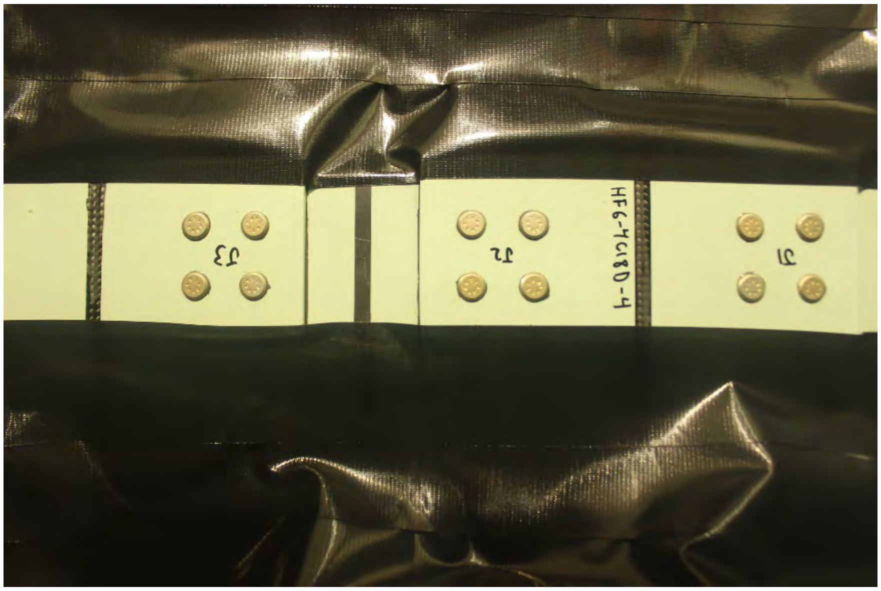


Figure 221: HF6-4C18D-4-Head Side-Open Box-Shot 1-20 kA

Figure 222: HF6-4C18D-4-Head Side-Test Photo-Shot 1-20 kA

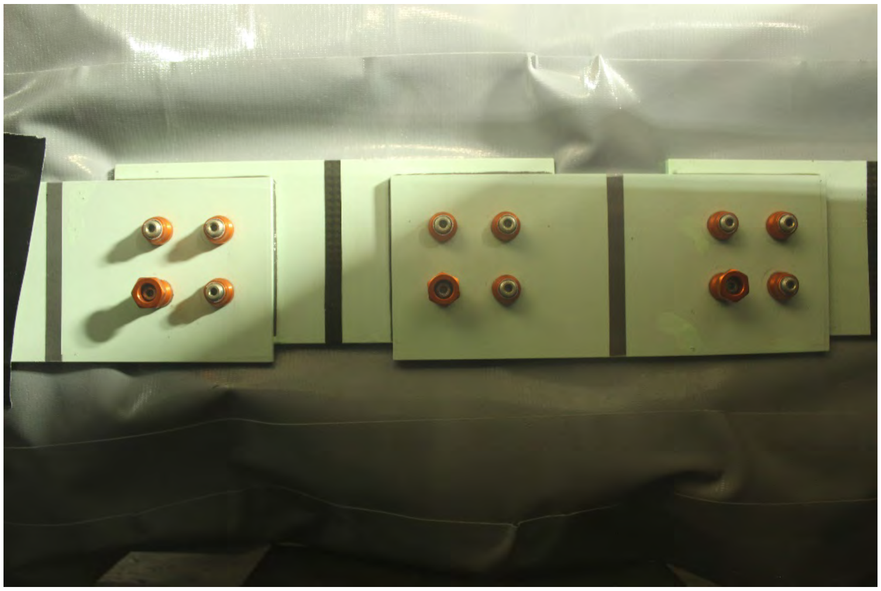


Figure 223: HF6-4C18D-4-Tail Side-Open Box-Shot 1-20 kA

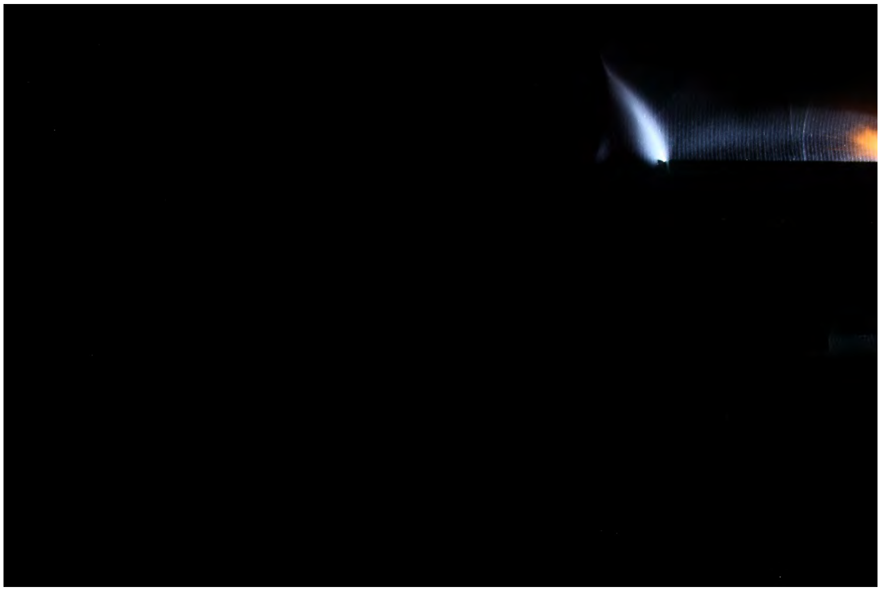


Figure 224: HF6-4C18D-4-Tail Side-Test Photo-Shot 1-20 kA

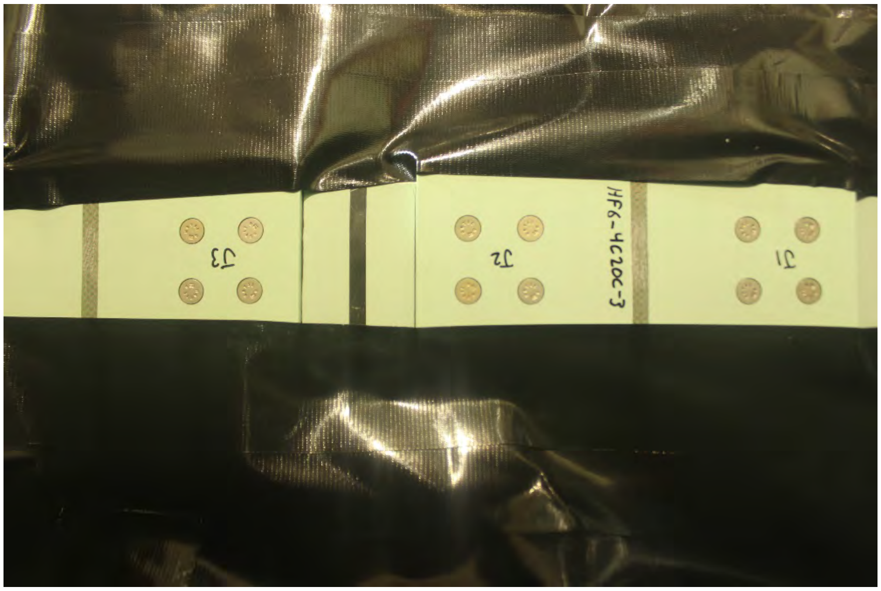


Figure 225: HF6-4C20C-3-Head Side-Open Box-Shot 1-60 kA

Figure 226: HF6-4C20C-3-Head Side-Test Photo-Shot 1-60 kA

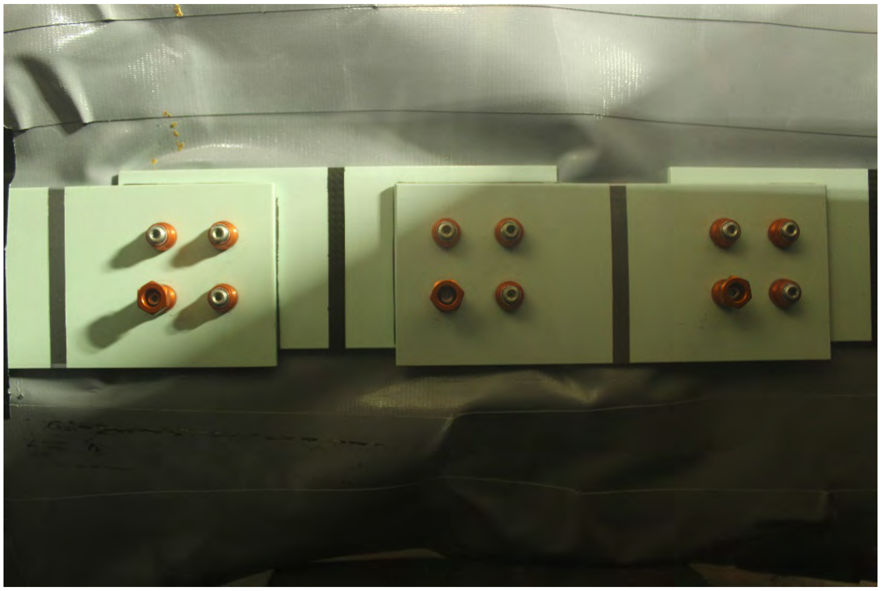


Figure 227: HF6-4C20C-3-Tail Side-Open Box-Shot 1-60 kA

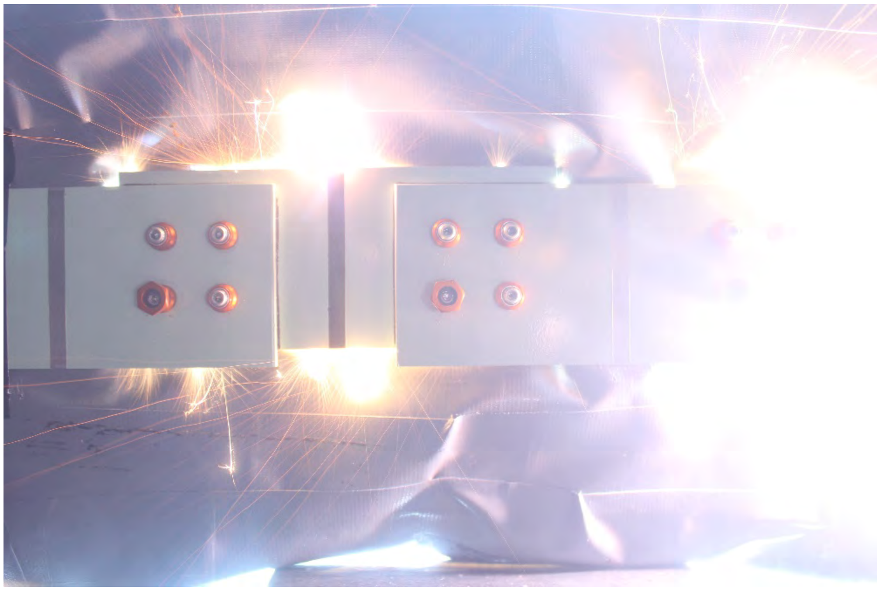


Figure 228: HF6-4C20C-3-Tail Side-Test Photo-Shot 1-60 kA

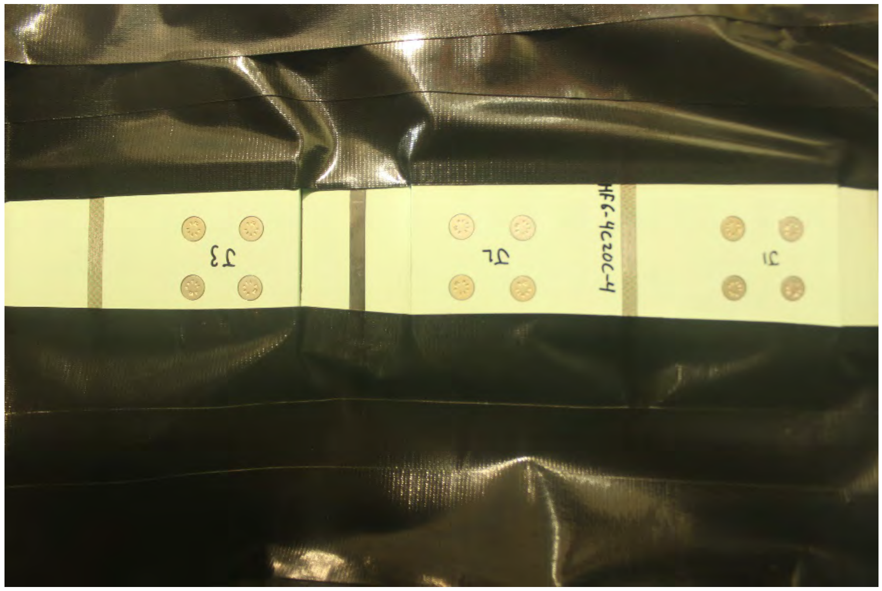


Figure 229: HF6-4C20C-4-Head Side-Open Box-Shot 1-30 kA

Figure 230: HF6-4C20C-4-Head Side-Test Photo-Shot 1-30 kA

Figure 231: HF6-4C20C-4-Tail Side-Open Box-Shot 1-30 kA

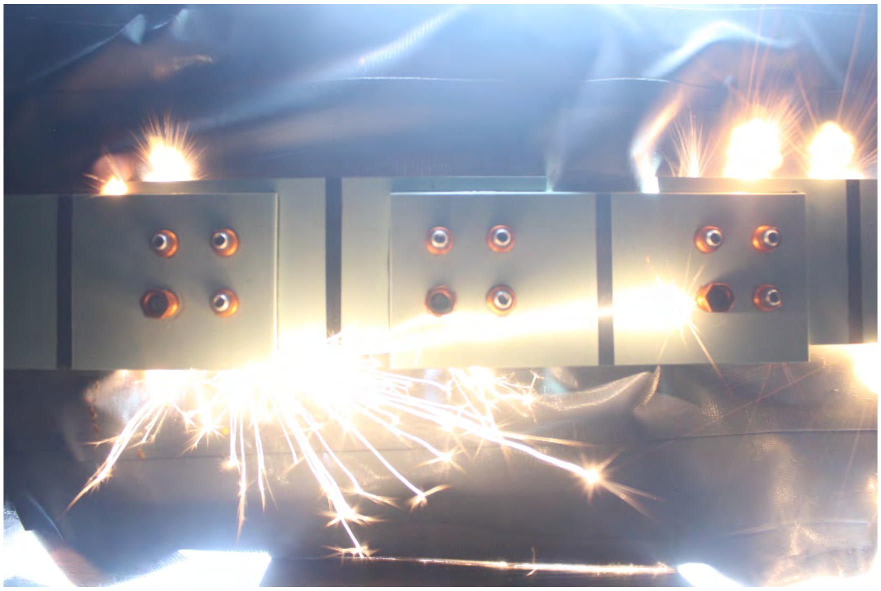


Figure 232: HF6-4C20C-4-Tail Side-Test Photo-Shot 1-30 kA

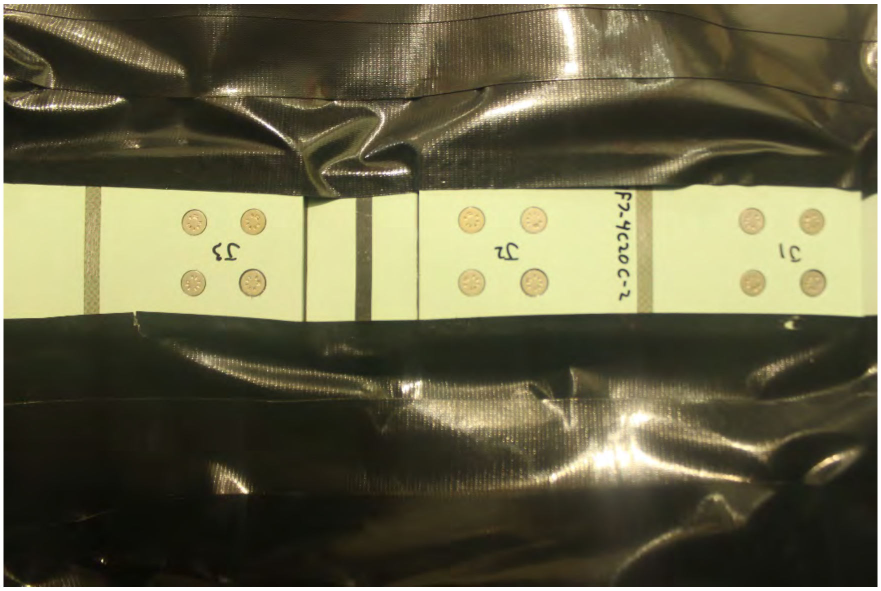


Figure 233: HF7-4C20C-2-Head Side-Open Box-Shot 1-60 kA

Figure 234: HF7-4C20C-2-Head Side-Test Photo-Shot 1-60 kA

Figure 235: HF7-4C20C-2-Tail Side-Open Box-Shot 1-60 kA

Figure 236: HF7-4C20C-2-Tail Side-Test Photo-Shot 1-60 kA

Figure 237: HF8-4C18D-2-Head Side-Open Box-Shot 1-30 kA

Figure 238: HF8-4C18D-2-Head Side-Test Photo-Shot 1-30 kA

Figure 239: HF8-4C18D-2-Tail Side-Open Box-Shot 1-30 kA

Figure 240: HF8-4C18D-2-Tail Side-Test Photo-Shot 1-30 kA

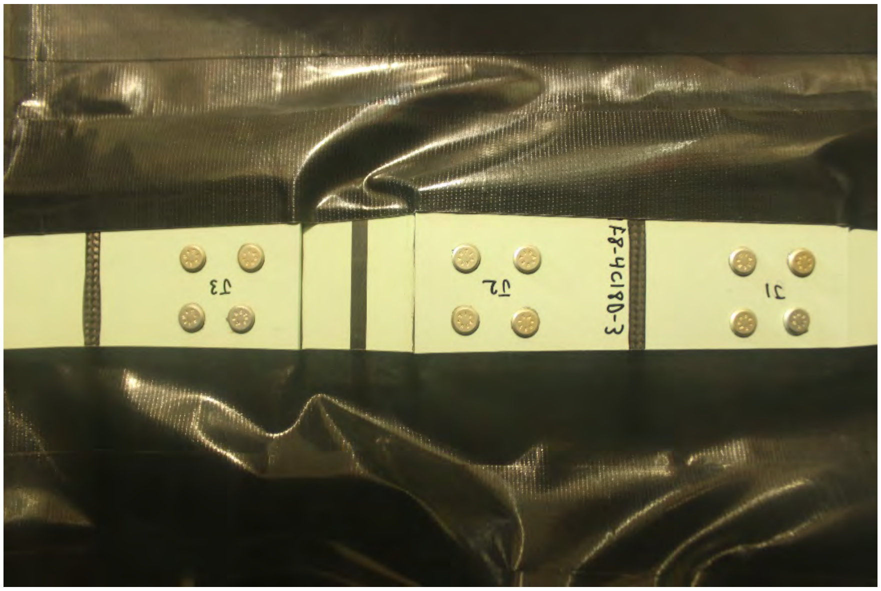


Figure 241: HF8-4C18D-3-Head Side-Open Box-Shot 1-20 kA

Figure 242: HF8-4C18D-3-Head Side-Test Photo-Shot 1-20 kA

Figure 243: HF8-4C18D-3-Tail Side-Open Box-Shot 1-20 kA

Figure 244: HF8-4C18D-3-Tail Side-Test Photo-Shot 1-20 kA

Figure 245: HF8-4C20C-2-Head Side-Open Box-Shot 1-60 kA

Figure 246: HF8-4C20C-2-Head Side-Test Photo-Shot 1-60 kA

Figure 247: HF8-4C20C-2-Tail Side-Open Box-Shot 1-60 kA

Figure 248: HF8-4C20C-2-Tail Side-Test Photo-Shot 1-60 kA

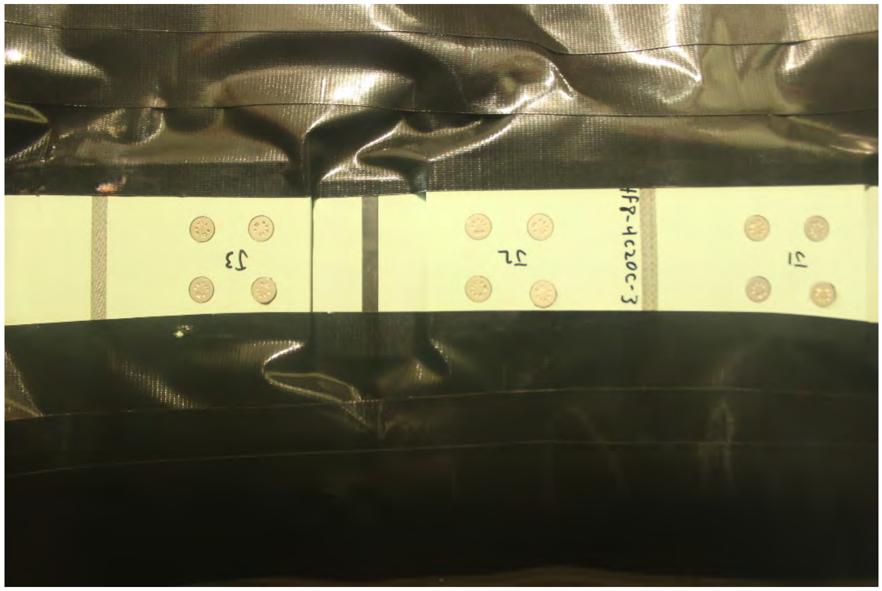


Figure 249: HF8-4C20C-3-Head Side-Open Box-Shot 1-40 kA

Figure 250: HF8-4C20C-3-Head Side-Test Photo-Shot 1-40 kA

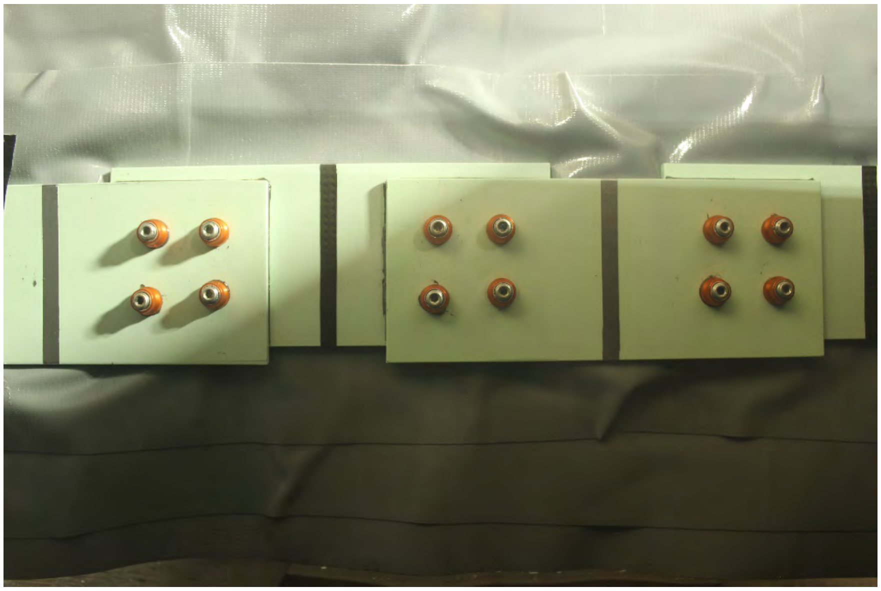


Figure 251: HF8-4C20C-3-Tail Side-Open Box-Shot 1-40 kA

Figure 252: HF8-4C20C-3-Tail Side-Test Photo-Shot 1-40 kA

Figure 253: HF8-4C20C-4-Head Side-Open Box-Shot 1-20 kA

Figure 254: HF8-4C20C-4-Head Side-Test Photo-Shot 1-20 kA

Figure 255: HF8-4C20C-4-Tail Side-Open Box-Shot 1-20 kA

Figure 256: HF8-4C20C-4-Tail Side-Test Photo-Shot 1-20 kA

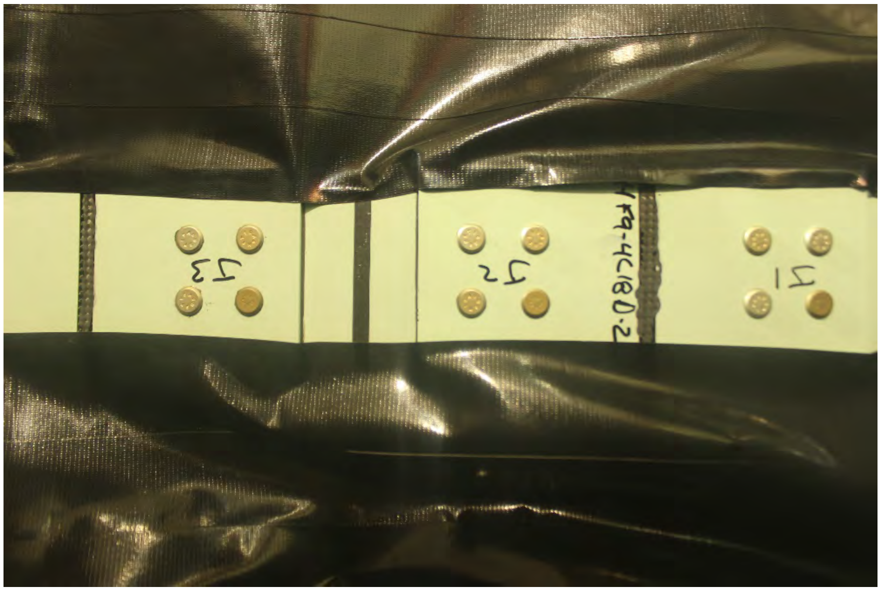


Figure 257: HF9-4C18D-2-Head Side-Open Box-Shot 1-60 kA

Figure 258: HF9-4C18D-2-Head Side-Test Photo-Shot 1-60 kA

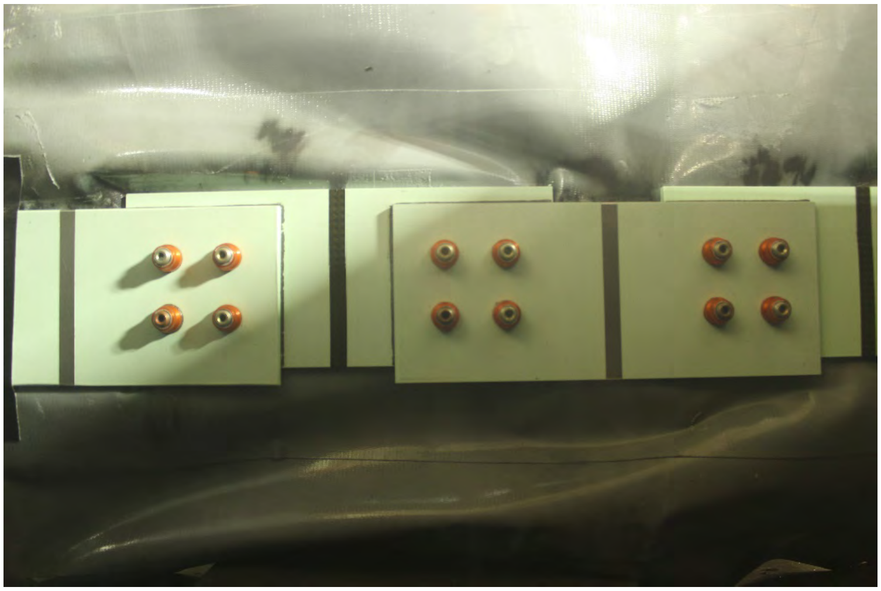


Figure 259: HF9-4C18D-2-Tail Side-Open Box-Shot 1-60 kA

Figure 260: HF9-4C18D-2-Tail Side-Test Photo-Shot 1-60 kA

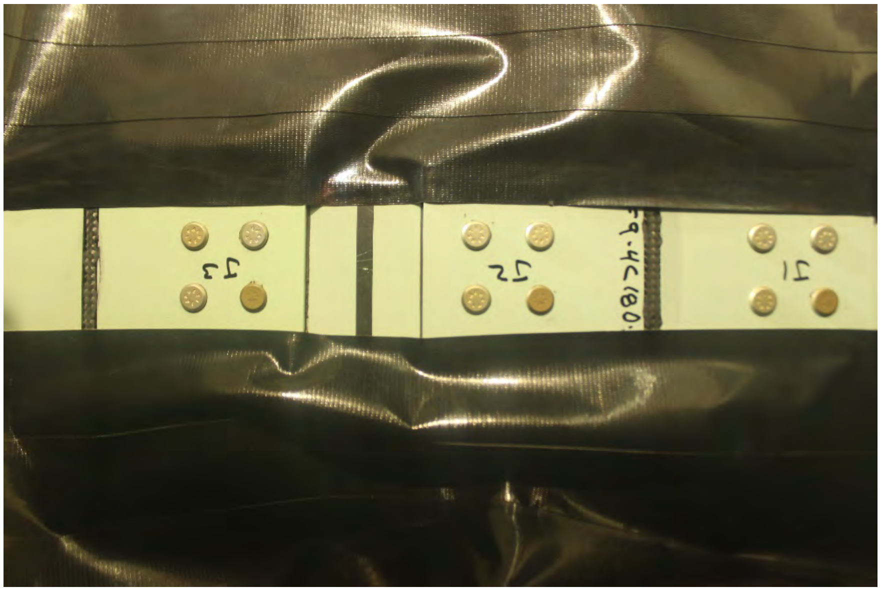


Figure 261: HF9-4C18D-3-Head Side-Open Box-Shot 1-30 kA

Figure 262: HF9-4C18D-3-Head Side-Test Photo-Shot 1-30 kA

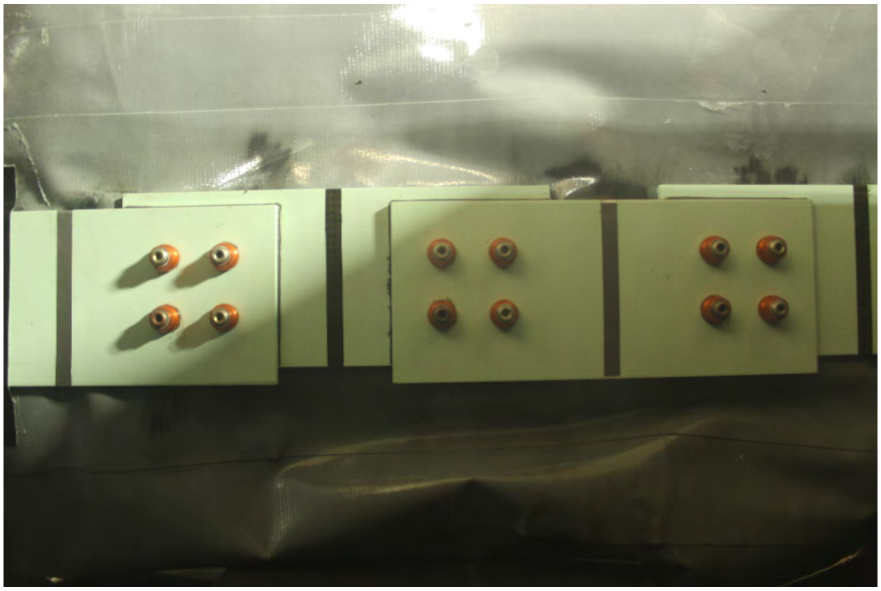


Figure 263: HF9-4C18D-3-Tail Side-Open Box-Shot 1-30 kA

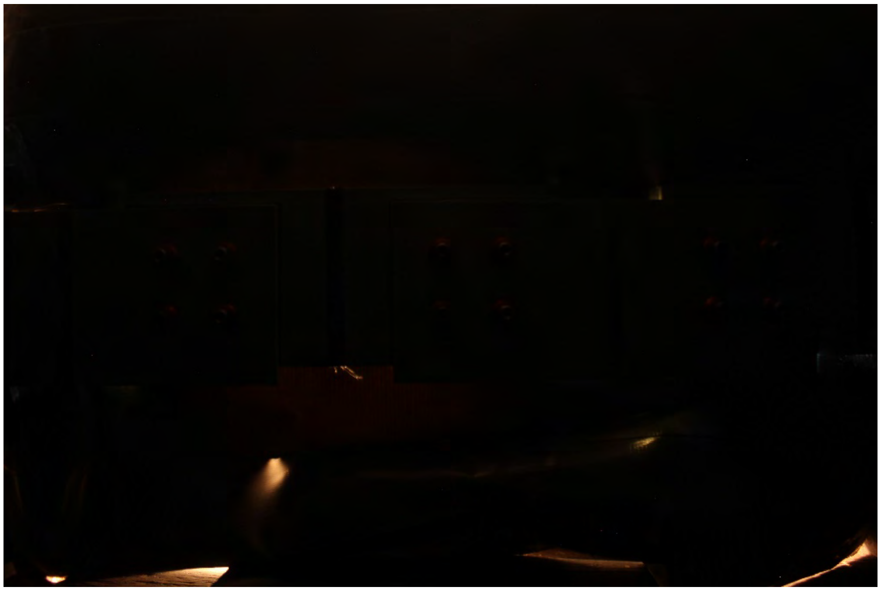


Figure 264: HF9-4C18D-3-Tail Side-Test Photo-Shot 1-30 kA

Figure 265: HF9-4C18D-4-Head Side-Open Box-Shot 1-20 kA

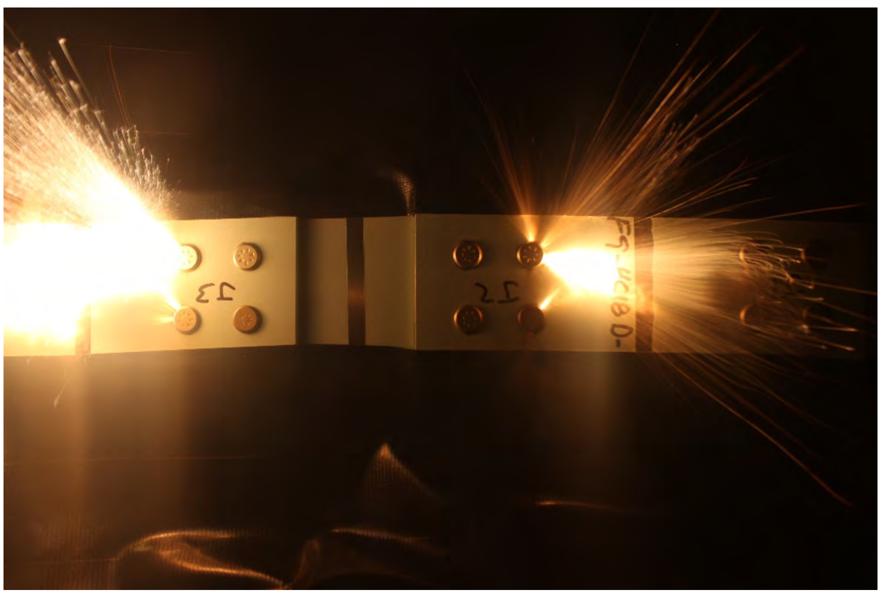


Figure 266: HF9-4C18D-4-Head Side-Test Photo-Shot 1-20 kA

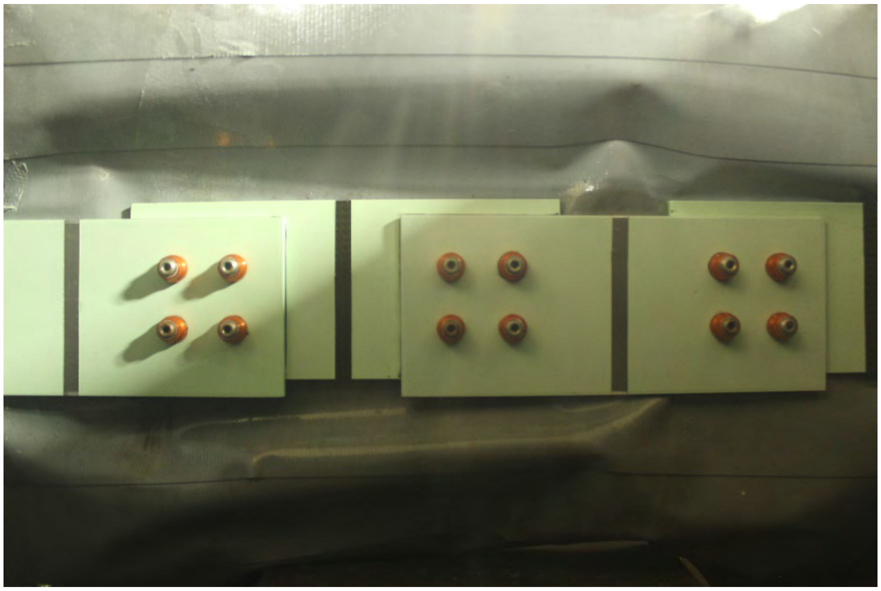


Figure 267: HF9-4C18D-4-Tail Side-Open Box-Shot 1-20 kA

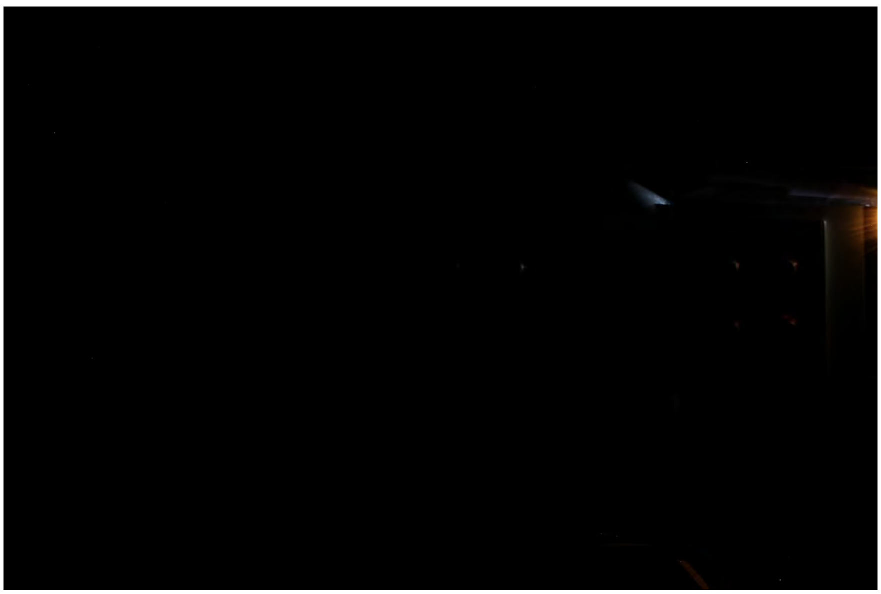


Figure 268: HF9-4C18D-4-Tail Side-Test Photo-Shot 1-20 kA

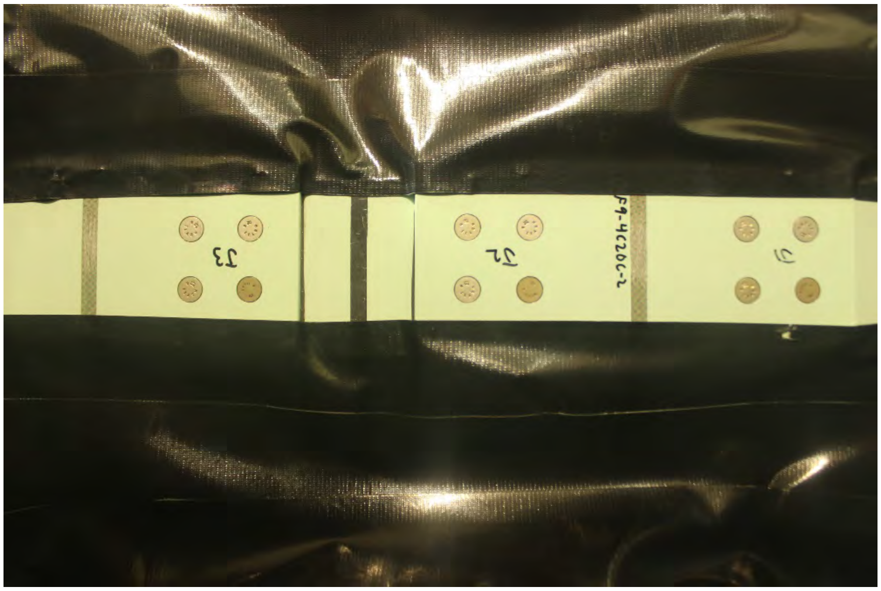


Figure 269: HF9-4C20C-2-Head Side-Open Box-Shot 1-60 kA

Figure 270: HF9-4C20C-2-Head Side-Test Photo-Shot 1-60 kA

Figure 271: HF9-4C20C-2-Tail Side-Open Box-Shot 1-60 kA

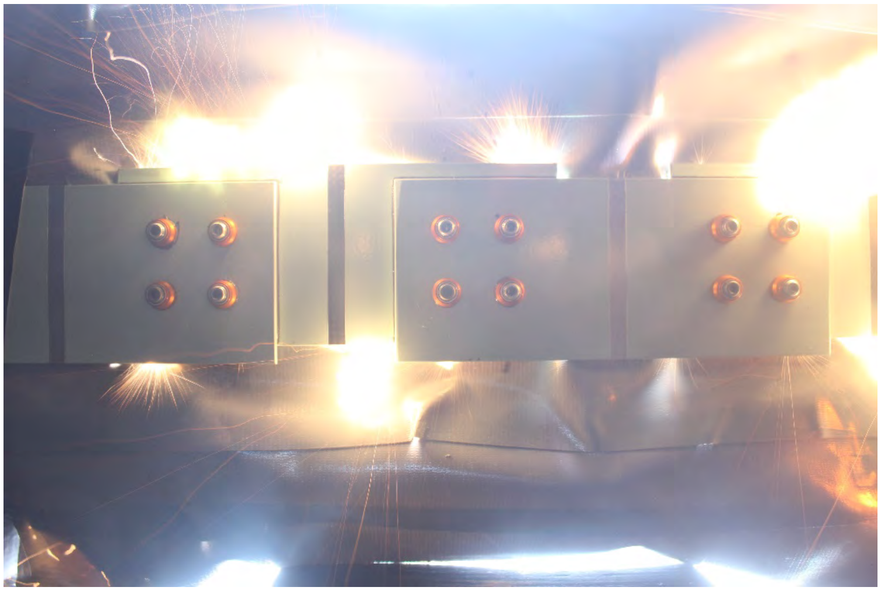


Figure 272: HF9-4C20C-2-Tail Side-Test Photo-Shot 1-60 kA

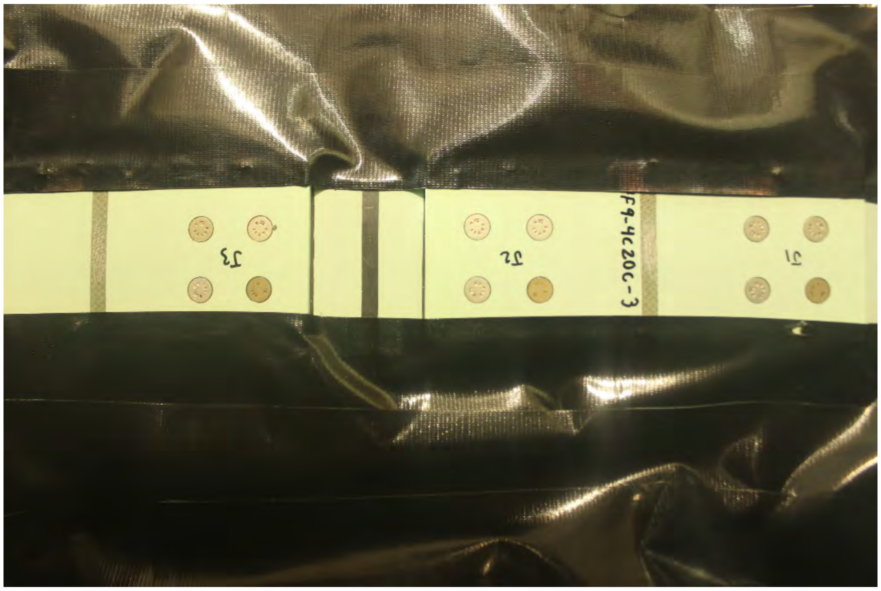


Figure 273: HF9-4C20C-3-Head Side-Open Box-Shot 1-30 kA

Figure 274: HF9-4C20C-3-Head Side-Test Photo-Shot 1-30 kA

Figure 275: HF9-4C20C-3-Tail Side-Open Box-Shot 1-30 kA

Figure 276: HF9-4C20C-3-Tail Side-Test Photo-Shot 1-30 kA

Figure 277: HN-4C18D-3-Head Side-Open Box-Shot 1-30 kA

Figure 278: HN-4C18D-3-Head Side-Test Photo-Shot 1-30 kA


Figure 279: HN-4C18D-3-Tail Side-Open Box-Shot 1-30 kA

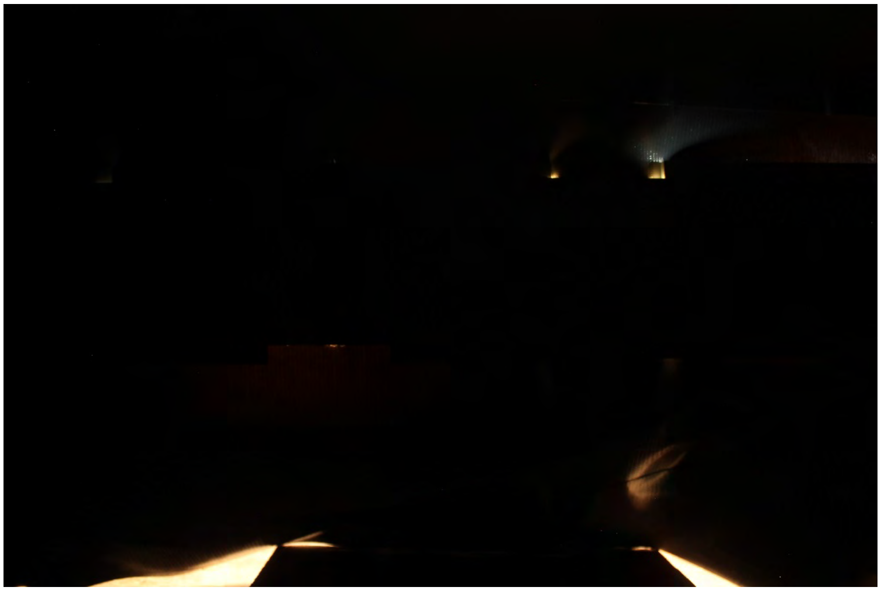


Figure 280: HN-4C18D-3-Tail Side-Test Photo-Shot 1-30 kA

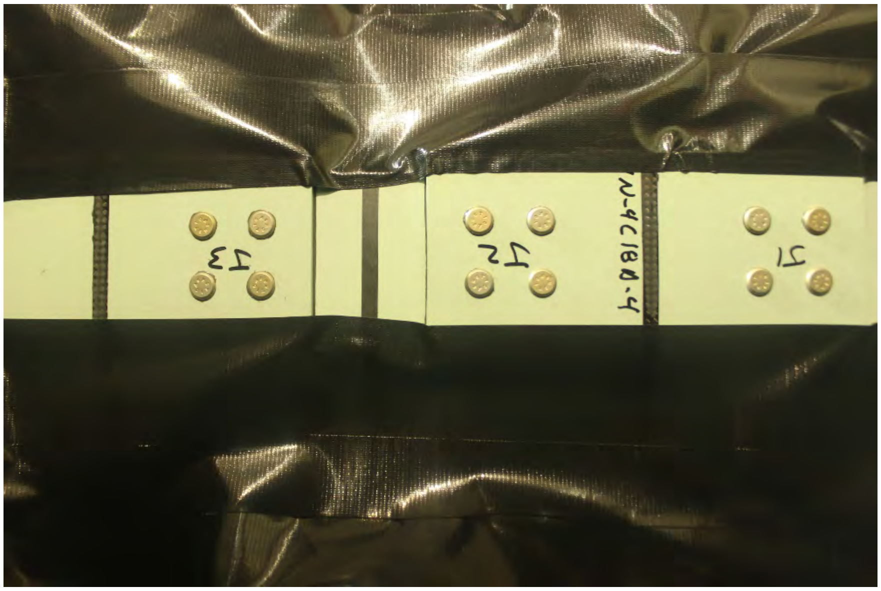


Figure 281: HN-4C18D-4-Head Side-Open Box-Shot 1-20 kA

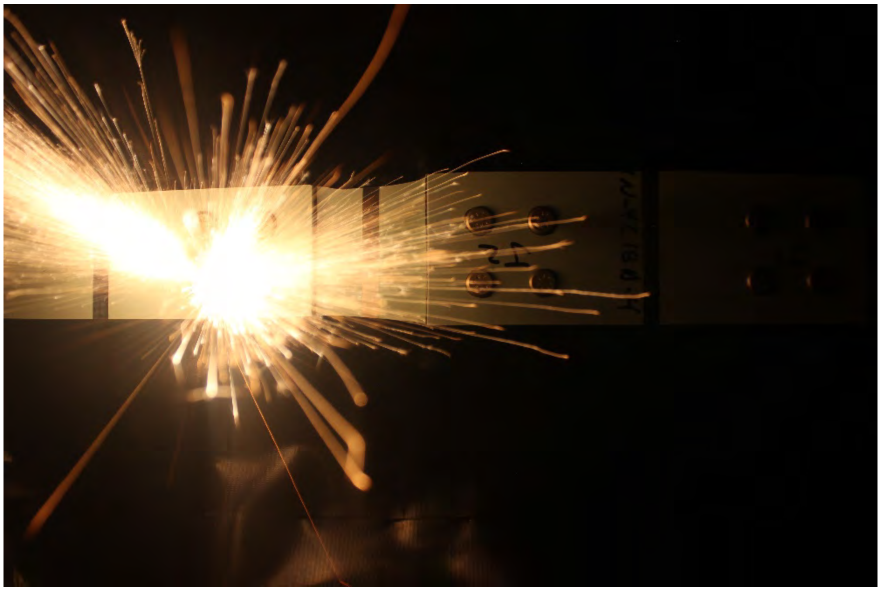


Figure 282: HN-4C18D-4-Head Side-Test Photo-Shot 1-20 kA

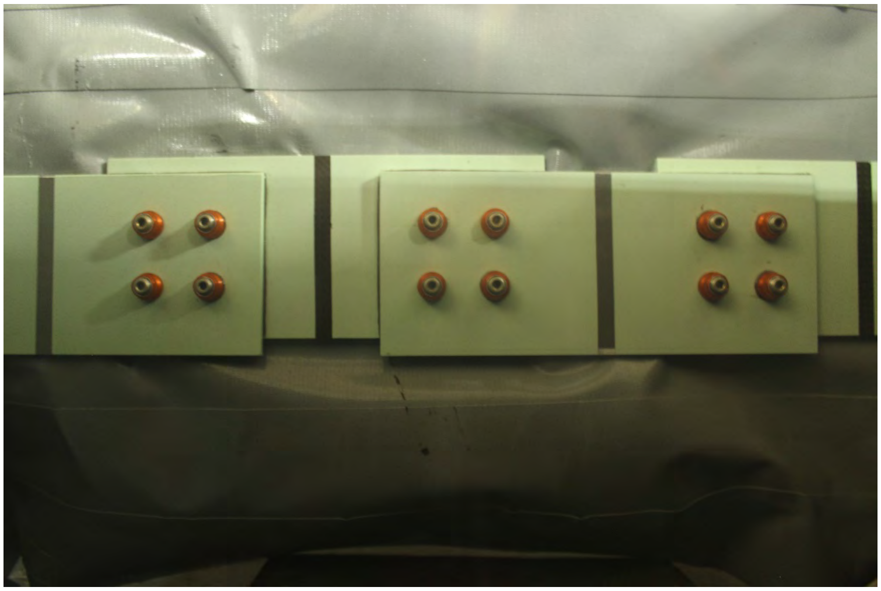


Figure 283: HN-4C18D-4-Tail Side-Open Box-Shot 1-20 kA

Figure 284: HN-4C18D-4-Tail Side-Test Photo-Shot 1-20 kA

Figure 285: HN-4C19D-1-Head Side-Open Box-Shot 1-5 kA

Figure 286: HN-4C19D-1-Head Side-Test Photo-Shot 1-5 kA

Figure 287: HN-4C19D-2-Head Side-Open Box-Shot 1-10 kA

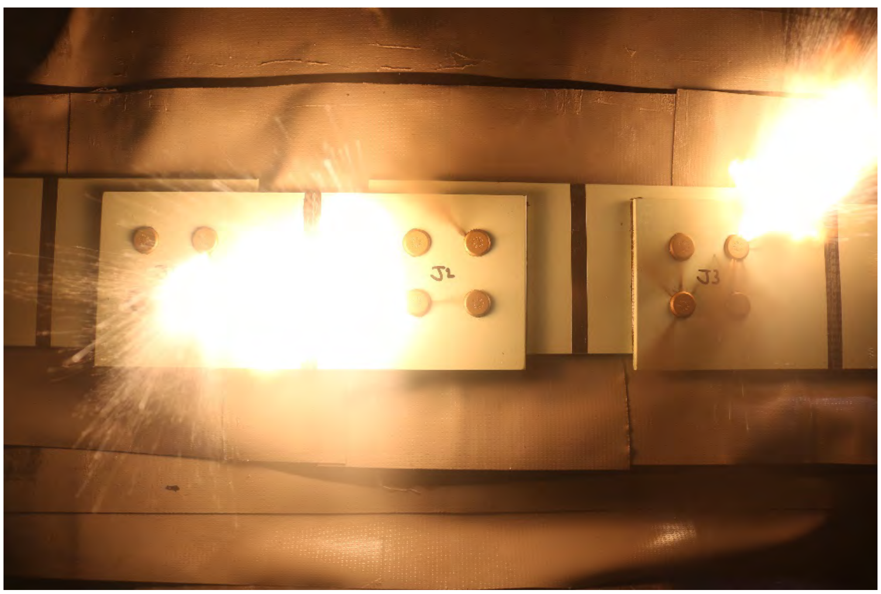


Figure 288: HN-4C19D-2-Head Side-Test Photo-Shot 1-10 kA

Figure 289: HN-4C19D-2-Tail Side-Open Box-Shot 1-10 kA

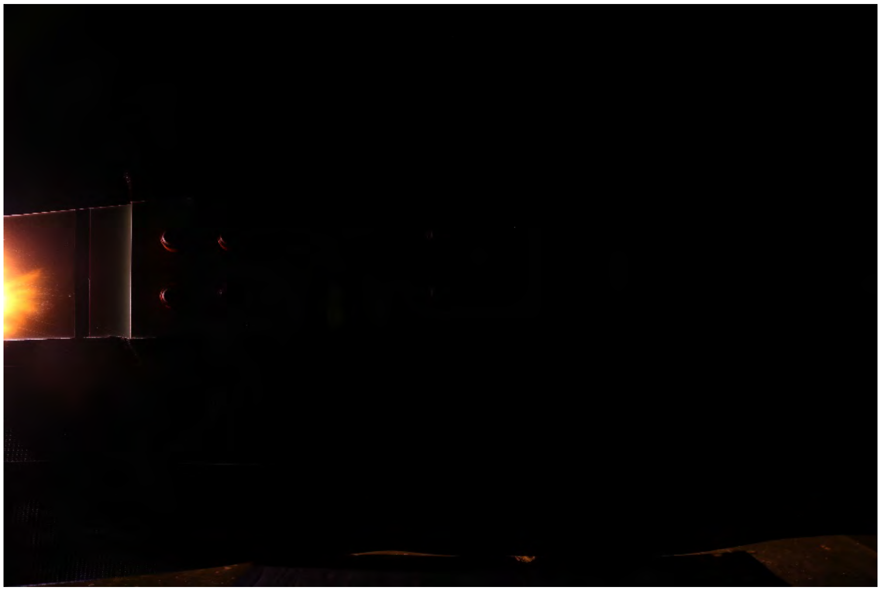


Figure 290: HN-4C19D-2-Tail Side-Test Photo-Shot 1-10 kA

Figure 291: HN-4C19D-3-Head Side-Open Box-Shot 1-7 kA

Figure 292: HN-4C19D-3-Head Side-Test Photo-Shot 1-7 kA

Figure 293: HN-4C19D-3-Tail Side-Open Box-Shot 1-7 kA

Figure 294: HN-4C19D-3-Tail Side-Test Photo-Shot 1-7 kA

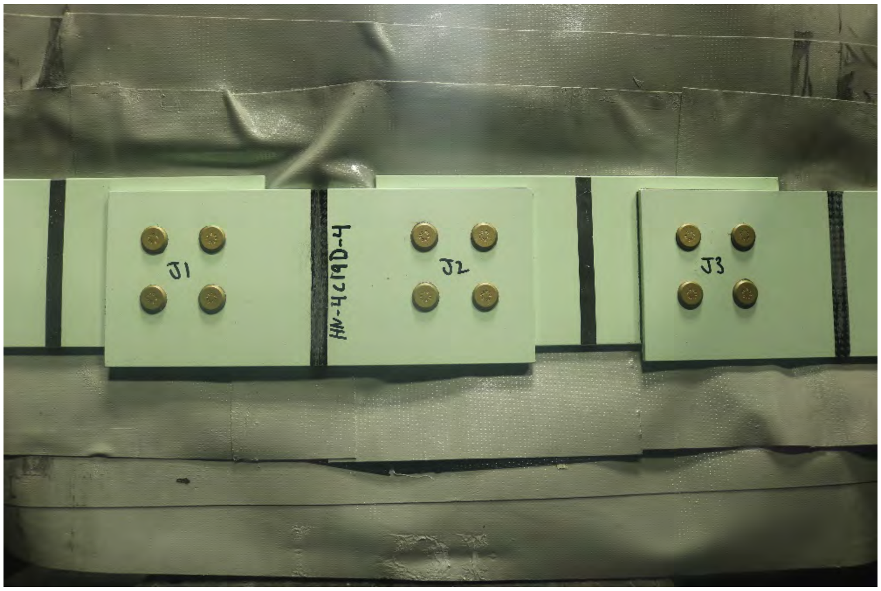


Figure 295: HN-4C19D-4-Head Side-Open Box-Shot 1-6 kA

Figure 296: HN-4C19D-4-Head Side-Test Photo-Shot 1-6 kA

Figure 297: HN-4C19D-4-Tail Side-Open Box-Shot 1-6 kA

Figure 298: HN-4C19D-4-Tail Side-Test Photo-Shot 1-6 kA

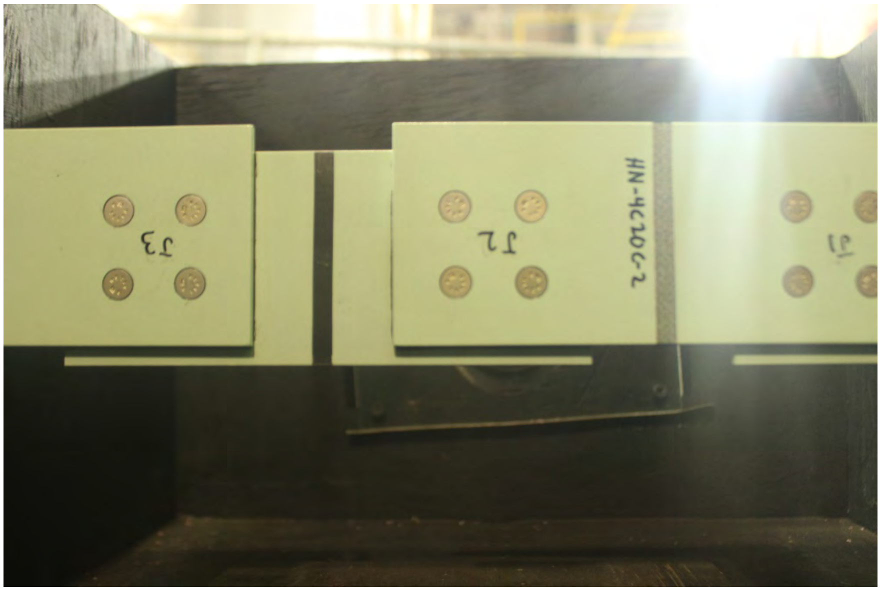


Figure 299: HN-4C20C-2-Head Side-Open Box-Shot 1-60 kA

Figure 300: HN-4C20C-2-Head Side-Test Photo-Shot 1-60 kA

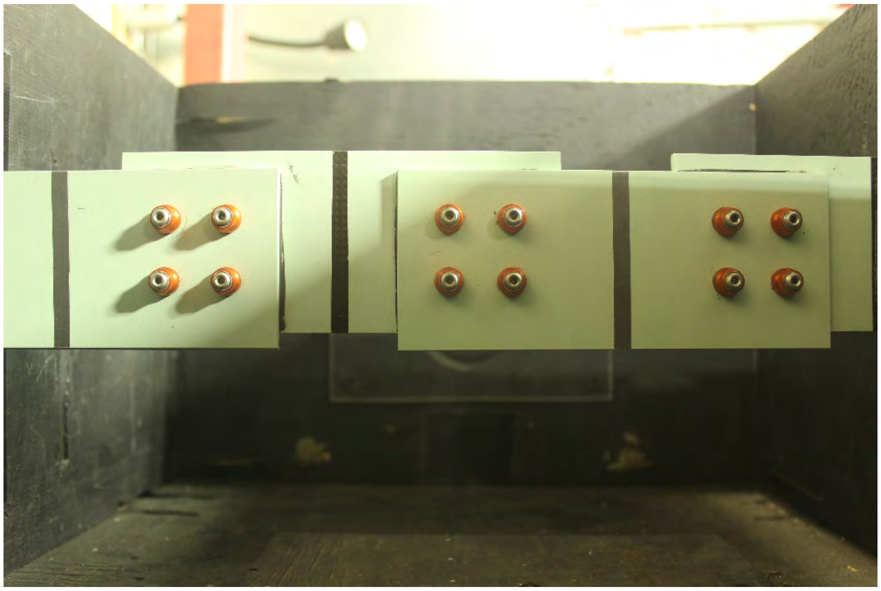


Figure 301: HN-4C20C-2-Tail Side-Open Box-Shot 1-60 kA

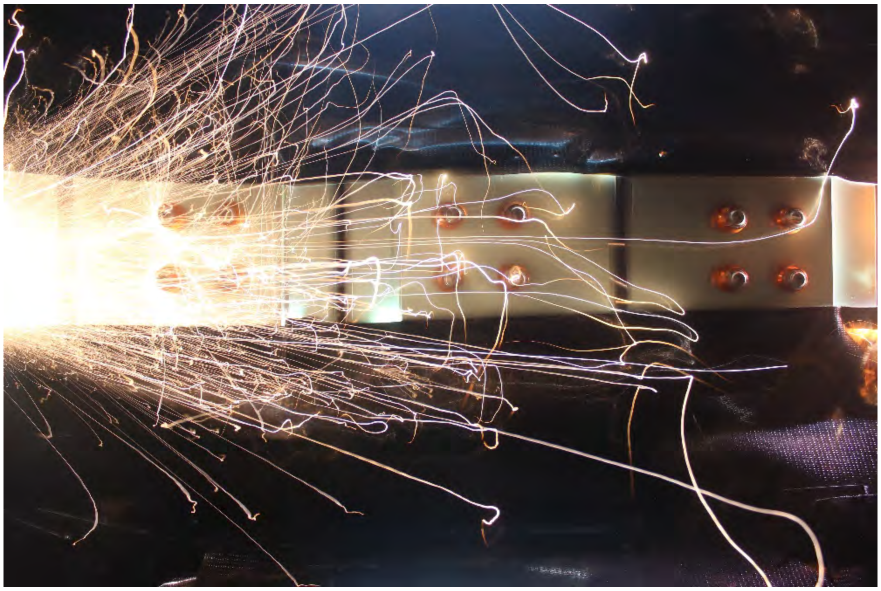


Figure 302: HN-4C20C-2-Tail Side-Test Photo-Shot 1-60 kA

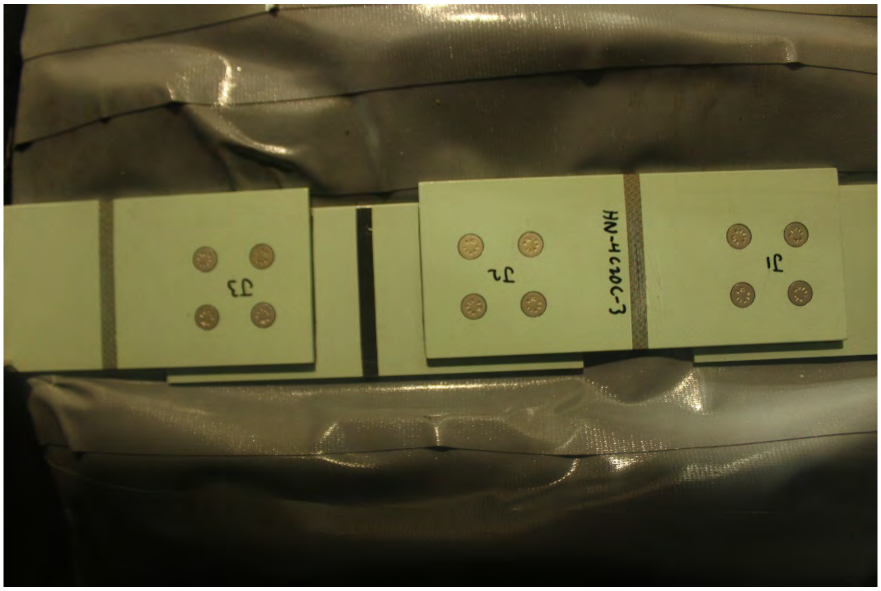


Figure 303: HN-4C20C-3-Head Side-Open Box-Shot 1-60 kA

Figure 304: HN-4C20C-3-Head Side-Test Photo-Shot 1-60 kA

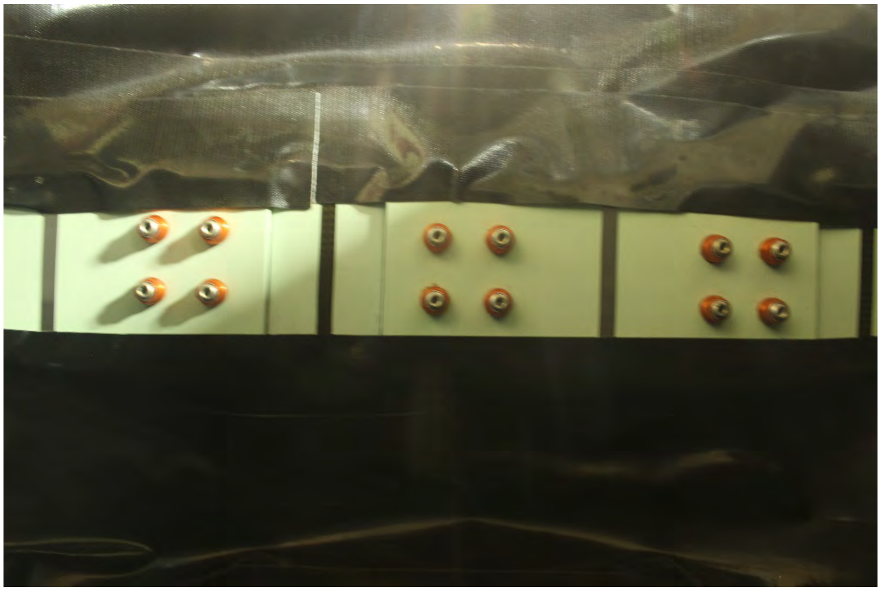


Figure 305: HN-4C20C-3-Tail Side-Open Box-Shot 1-60 kA

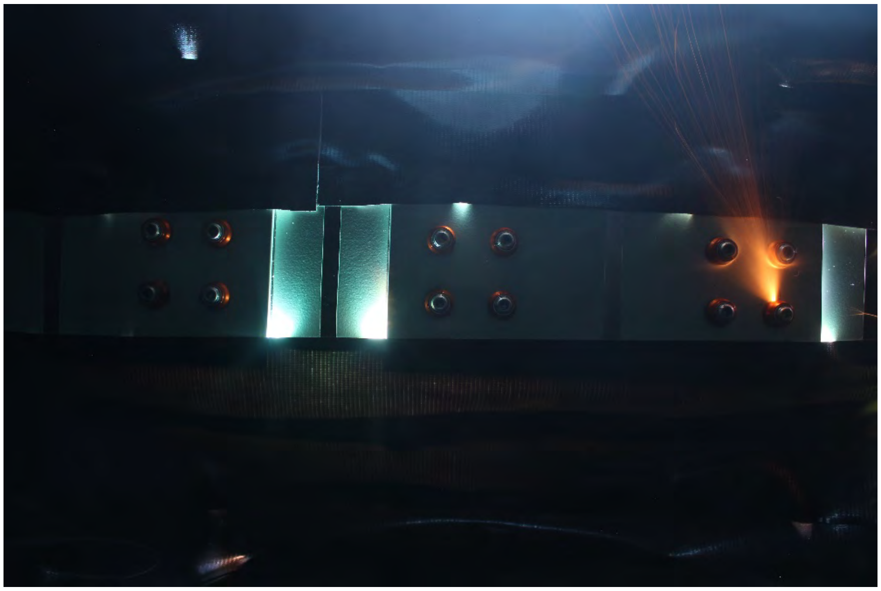


Figure 306: HN-4C20C-3-Tail Side-Test Photo-Shot 1-60 kA

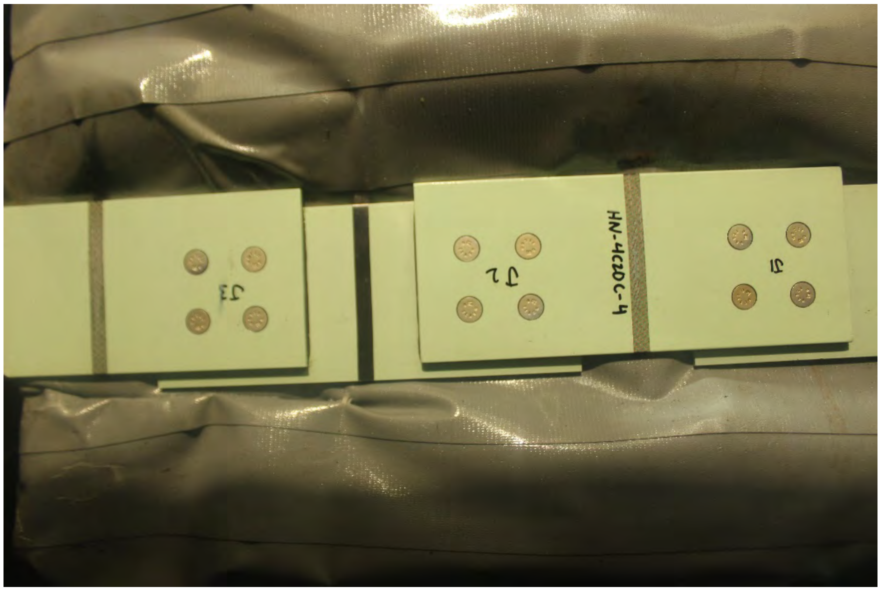


Figure 307: HN-4C20C-4-Head Side-Open Box-Shot 1-30 kA

Figure 308: HN-4C20C-4-Head Side-Test Photo-Shot 1-30 kA

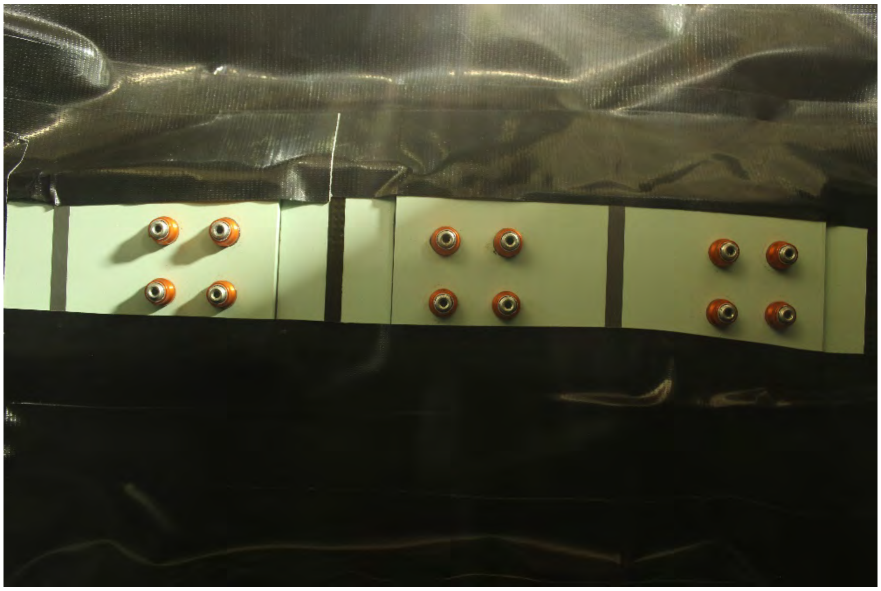


Figure 309: HN-4C20C-4-Tail Side-Open Box-Shot 1-30 kA

Figure 310: HN-4C20C-4-Tail Side-Test Photo-Shot 1-30 kA

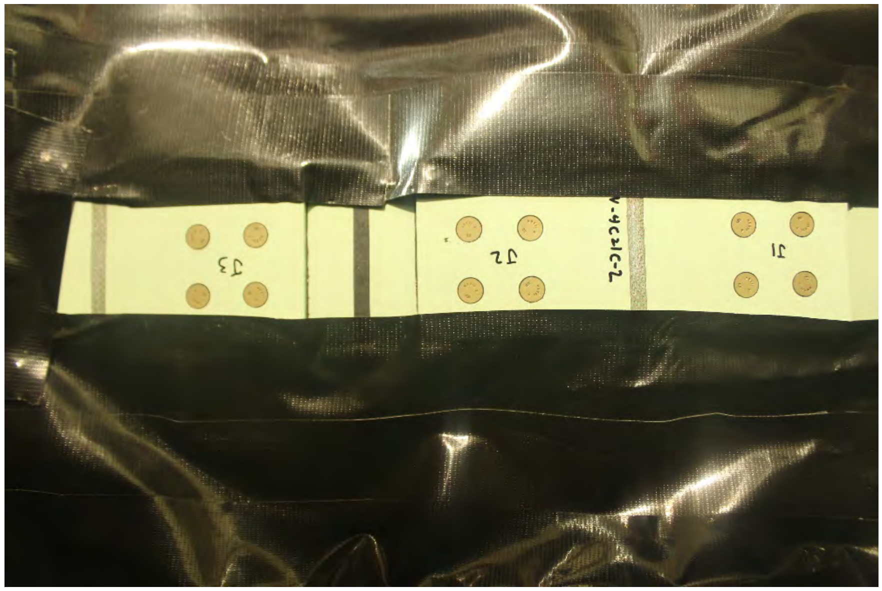


Figure 311: HN-4C21C-2-Head Side-Open Box-Shot 1-60 kA

Figure 312: HN-4C21C-2-Head Side-Test Photo-Shot 1-60 kA

Figure 313: HN-4C21C-2-Tail Side-Open Box-Shot 1-60 kA

Figure 314: HN-4C21C-2-Tail Side-Test Photo-Shot 1-60 kA

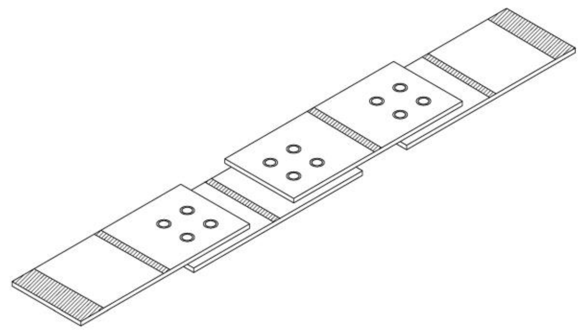
Figure 315: HN-4C21C-3-Head Side-Open Box-Shot 1-30 kA

Figure 316: HN-4C21C-3-Head Side-Test Photo-Shot 1-30 kA

Figure 317: HN-4C21C-3-Tail Side-Open Box-Shot 1-30 kA

Figure 318: HN-4C21C-3-Tail Side-Test Photo-Shot 1-30 kA

Appendix C – Test Article Drawings

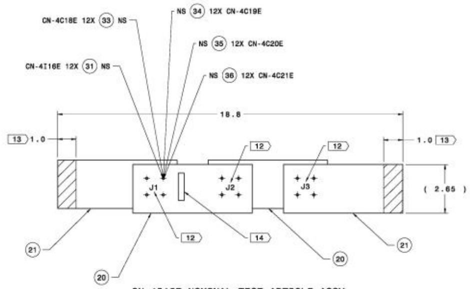


TYPICAL TEST ARTICLE ASSY

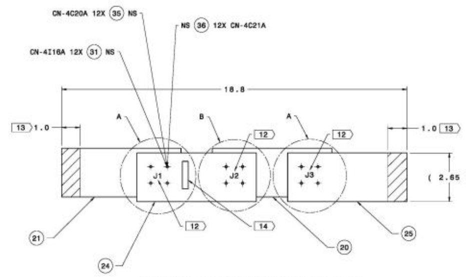
NOTES:

1. DIMENSIONS AND TOLERANCES PER ASME Y14.5-2009.
2. PREPARE HOLES FOR AND INSTALL HST10 AND HST11 FASTENERS PER HSTR_HLR-IS01 DOCUMENT.
3. PREPARE HOLES FOR TRI-LOCK FASTENERS PER HSTR_HLR-IS01 DOCUMENT.
4. USE SEALANT AMS-S-8802, TYPE 2, CLASS B FOR ALL FASTENERS.
5. WET INSTALL ALL FASTENERS PER PPG PR-1440 CLASS B FUEL TANK SEALANT TECHNICAL DATA SHEET. APPLY PR-1440 CLASS B FUEL TANK SEALANT TO THE SHANK AND UNDER THE HEAD OF THE FASTENER ENSURING FULL COVERAGE PRIOR TO INSTALLATION. THREADS MUST BE FREE OF SEALANT BEFORE AND AFTER INSTALLATION. IF TRACES ARE VISIBLE AFTER INSTALLATION, WIPE OFF WITH CLEAN DRY CLOTH. DO NOT USE SOLVENT. DURING INSTALLATION, A BEAD OF SEALANT MUST BE FORCED OUT FROM THE HEAD OF THE FASTENER. USE A DRY CLOTH TO WIPE OFF EXCESS SEALANT BEFORE CURE.
6. NS = FASTENER MANUFACTURED HEAD NEAR SIDE.
7. ASSEMBLE ALL CFRP COUPONS WITH ECF FACING NEAR SIDE (NS).
8. ASSEMBLE ALL CFRP COUPONS WITH GRP FACING FAR SIDE (FS).
9. CARBON FIBER COMPOSITE MATERIAL (CFRP) IS SOLVAY, CYCOM 5320-1 T650.
10. FIBERGLASS COMPOSITE MATERIAL (GRP) IS HEXCEL FIBERGLASS PREPREG M20/120.
11. EXPANDED COPPER FOIL (ECF) IS DEXMET 3CU7-125FA, 141.6 GSM
12. PERMANENTLY MARK, "J1", "J2", AND "J3" IN LOCATIONS SHOWN.
13. NO FUEL TANK COATING HERE. MASK OFF INDICATED AREAS ON BOTH SIDES OF PART BEFORE TANK COATING APPLICATION .
14. PART MARKING: PERMANENTLY MARK WITH COMPLETE PART NUMBER PER MIL-STD-130 IN LOCATION SHOWN
15. ABBREVIATIONS:
    - CFRP CARBON FIBER REINFORCED POLYMER
    - ECF EXPANDED COPPER FOIL
    - GRP GLASS FIBER REINFORCED POLYMER (FIBERGLASS)
    - LWD LONG WAY DIAMOND

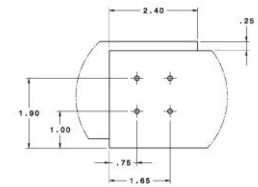
PROPRIETARY NOTICE THIS DRAWING IS PROPERTY OF WICHITA STATE UNIVERSITY AND SHALL NOT BE REPRODUCED, DISTRIBUTED, OR COMMUNICATED IN ANY FORM WITHOUT PRIOR WRITTEN CONSENT.	C.PARTEN	6/19/2020	NATIONAL INSTITUTE FOR AVIATION RESEARCH, ETL
	XXX	XX/XX/XXXX	TITLE 25.954 COMPOSITE NOMINAL TEST ARTICLE ASSY
	XXX	XX/XX/XXXX	SIZE E; DWG NO FST5700; REV
	UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES TOLERANCES ON DECIMALS .X = ±.1 .XX = ±.03 .XXX = ±.010	ANGLES ±30'	SCALE NONE; SHEET 1 OF 3



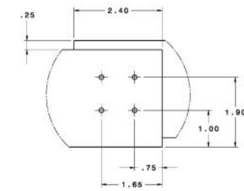
CN-4I16E NOMINAL TEST ARTICLE ASSY
CN-4C18E NOMINAL TEST ARTICLE ASSY
CN-4C19E NOMINAL TEST ARTICLE ASSY
CN-4C20E NOMINAL TEST ARTICLE ASSY
CN-4C21E NOMINAL TEST ARTICLE ASSY



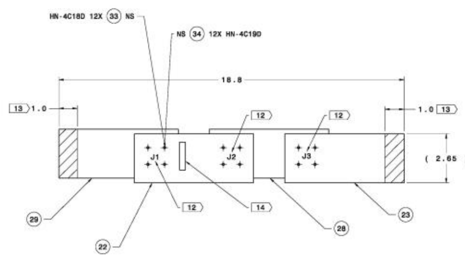
CN-4I16A NOMINAL TEST ARTICLE ASSY
CN-4C20A NOMINAL TEST ARTICLE ASSY
CN-4C21A NOMINAL TEST ARTICLE ASSY



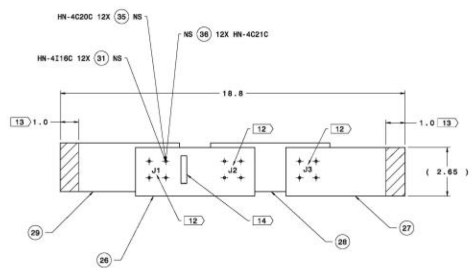
DETAIL A
DIMENSIONS FOR ALL TEST ARTICLES
SCALE: NONE



DETAIL B
DIMENSIONS FOR ALL TEST ARTICLES
SCALE: NONE



HN-4C18D NOMINAL TEST ARTICLE ASSY
HN-4C19D NOMINAL TEST ARTICLE ASSY

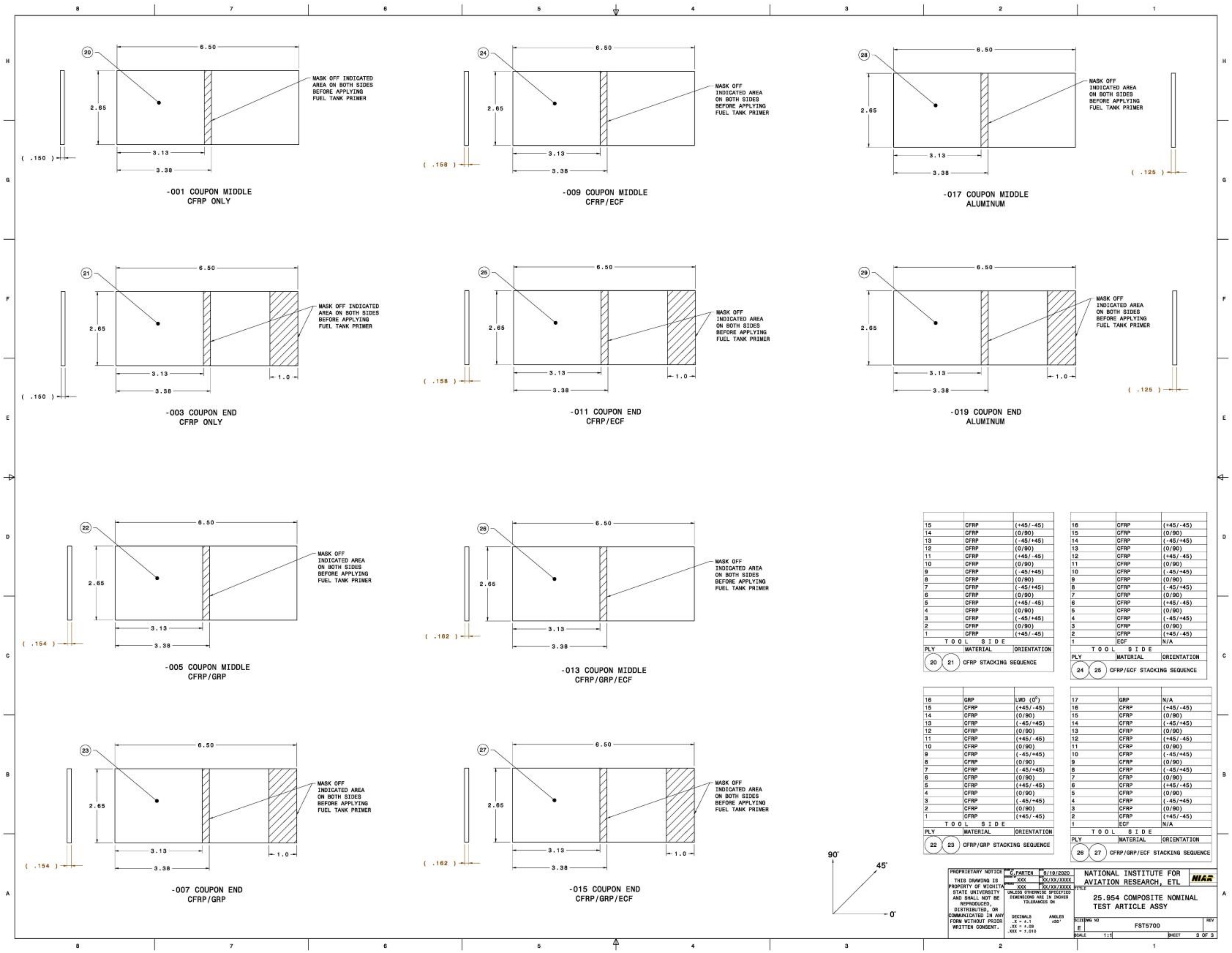


HN-4I16C NOMINAL TEST ARTICLE ASSY
HN-4C20C NOMINAL TEST ARTICLE ASSY
HN-4C21C NOMINAL TEST ARTICLE ASSY

CN-4C21E	CN-4C20E	CN-4C19E	CN-4C18E	CN-4I16E	HN-4C19D	HN-4C18D	HN-4C21C	HN-4C20C	HN-4I16C	CN-4C21A	CN-4C20A	CN-4I16A	ITEM	PART OR IDENTIFYING NUMBER	DESCRIPTION	MATERIAL/SUPPLIER	SIZE	HOLE DIMENSIONS	FIT TYPE	NOTES
12							12			12			36	HST11AG8-5/HST79CY8	FASTENER/COLLAR					TOTAL QTY = 144
	12							12			12		35	HST11BJ8-5/HST79CY8	FASTENER/COLLAR					TOTAL QTY = 144
		12			12								34	HST10AG8-5/HST79CY8	FASTENER/COLLAR					TOTAL QTY = 96
			12			12							33	HST10BJ8-5/HST79CY8	FASTENER/COLLAR					TOTAL QTY = 96
													32							
				12					12			12	31	PF AA7CC-08-05	FASTENER					TOTAL QTY = 144
													30							
					1	1	1	1	1				29	FST5700-019	COUPON END	AL CLAD 2024-T3 (AMS-QQ-A-250/5)	0.125 THK			TOTAL QTY = 20
					1	1	1	1	1				28	FST5700-017	COUPON MIDDLE	AL CLAD 2024-T3 (AMS-QQ-A-250/5)	0.125 THK			TOTAL QTY = 20
							1	1	1				27	FST5700-015	COUPON END	CFRP / ECF / GRP	0.162 THK			TOTAL QTY = 12
							1	1	1				26	FST5700-013	COUPON MIDDLE	CFRP / ECF / GRP	0.162 THK			TOTAL QTY = 12
										1	1	1	25	FST5700-011	COUPON END	CFRP / ECF	0.158 THK			TOTAL QTY = 12
										1	1	1	24	FST5700-009	COUPON MIDDLE	CFRP / ECF	0.158 THK			TOTAL QTY = 12
					1	1							23	FST5700-007	COUPON END	CFRP / GRP	0.154 THK			TOTAL QTY = 8
					1	1							22	FST5700-005	COUPON MIDDLE	CFRP / GRP	0.154 THK			TOTAL QTY = 8
2	2	2	2	2						1	1	1	21	FST5700-003	COUPON END	CFRP	0.150 THK			TOTAL QTY = 52
2	2	2	2	2						1	1	1	20	FST5700-001	COUPON MIDDLE	CFRP	0.150 THK			TOTAL QTY = 52
													19							
													18							
													17							
													16							
													15							
													14							
													13	CN-4C21E	TEST ARTICLE ASSY			Ø.2495-.2505	CLEARANCE	ASSY QTY = 4
													12	CN-4C20E	TEST ARTICLE ASSY			Ø.2495-.2505	CLEARANCE	ASSY QTY = 4
													11	CN-4C19E	TEST ARTICLE ASSY			Ø.2495-.2505	CLEARANCE	ASSY QTY = 4
													10	CN-4C18E	TEST ARTICLE ASSY			Ø.2495-.2505	CLEARANCE	ASSY QTY = 4
													9	CN-4I16E	TEST ARTICLE ASSY			Ø.2495-.2505	CLEARANCE	ASSY QTY = 4
													8	HN-4C19D	TEST ARTICLE ASSY			Ø.2495-.2505	CLEARANCE	ASSY QTY = 4
													7	HN-4C18D	TEST ARTICLE ASSY			Ø.2495-.2505	CLEARANCE	ASSY QTY = 4
													6	HN-4C21C	TEST ARTICLE ASSY			Ø.2495-.2505	CLEARANCE	ASSY QTY = 4
													5	HN-4C20C	TEST ARTICLE ASSY			Ø.2495-.2505	CLEARANCE	ASSY QTY = 4
													4	HN-4I16C	TEST ARTICLE ASSY			Ø.2495-.2505	CLEARANCE	ASSY QTY = 4
													3	CN-4C21A	TEST ARTICLE ASSY			Ø.2495-.2505	CLEARANCE	ASSY QTY = 4
													2	CN-4C20A	TEST ARTICLE ASSY			Ø.2495-.2505	CLEARANCE	ASSY QTY = 4
													1	CN-4I16A	TEST ARTICLE ASSY			Ø.2495-.2505	CLEARANCE	ASSY QTY = 4

PARTS LIST INFORMATION

PROPRIETARY NOTICE THIS DRAWING IS PROPERTY OF WICHITA STATE UNIVERSITY AND SHALL NOT BE REPRODUCED, DISTRIBUTED, OR COMMUNICATED IN ANY FORM WITHOUT PRIOR WRITTEN CONSENT.	C.PARTEN 6/19/2020 XXX XX/XX/XXXX XXX XX/XX/XXXX UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES TOLERANCES ON DECIMALS .X = ±.1 .XX = ±.03 .XXX = ±.010 ANGLES ±30'	NATIONAL INSTITUTE FOR AVIATION RESEARCH, ETL TITLE 25.954 COMPOSITE NOMINAL TEST ARTICLE ASSY	NIAR
		SIZE E DWG NO FST5700 REV	
		SCALE NONE SHEET 2 OF 3	



(20) (21) CFRP STACKING SEQUENCE

PLY	MATERIAL	ORIENTATION
15	CFRP	(+45/-45)
14	CFRP	(0/90)
13	CFRP	(-45/+45)
12	CFRP	(0/90)
11	CFRP	(+45/-45)
10	CFRP	(0/90)
9	CFRP	(-45/+45)
8	CFRP	(0/90)
7	CFRP	(-45/+45)
6	CFRP	(0/90)
5	CFRP	(+45/-45)
4	CFRP	(0/90)
3	CFRP	(-45/+45)
2	CFRP	(0/90)
1	CFRP	(+45/-45)
TOOL SIDE		

(24) (25) CFRP/ECF STACKING SEQUENCE

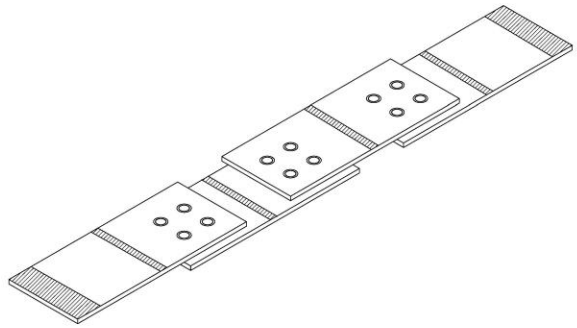
PLY	MATERIAL	ORIENTATION
16	CFRP	(+45/-45)
15	CFRP	(0/90)
14	CFRP	(-45/+45)
13	CFRP	(0/90)
12	CFRP	(+45/-45)
11	CFRP	(0/90)
10	CFRP	(-45/+45)
9	CFRP	(0/90)
8	CFRP	(-45/+45)
7	CFRP	(0/90)
6	CFRP	(+45/-45)
5	CFRP	(0/90)
4	CFRP	(-45/+45)
3	CFRP	(0/90)
2	CFRP	(+45/-45)
1	ECF	N/A
TOOL SIDE		

(22) (23) CFRP/GRP STACKING SEQUENCE

PLY	MATERIAL	ORIENTATION
16	GRP	LWD (0^0)
15	CFRP	(+45/-45)
14	CFRP	(0/90)
13	CFRP	(-45/+45)
12	CFRP	(0/90)
11	CFRP	(+45/-45)
10	CFRP	(0/90)
9	CFRP	(-45/+45)
8	CFRP	(0/90)
7	CFRP	(-45/+45)
6	CFRP	(0/90)
5	CFRP	(+45/-45)
4	CFRP	(0/90)
3	CFRP	(-45/+45)
2	CFRP	(0/90)
1	CFRP	(+45/-45)
TOOL SIDE		

(26) (27) CFRP/GRP/ECF STACKING SEQUENCE

PLY	MATERIAL	ORIENTATION
17	GRP	N/A
16	CFRP	(+45/-45)
15	CFRP	(0/90)
14	CFRP	(-45/+45)
13	CFRP	(0/90)
12	CFRP	(+45/-45)
11	CFRP	(0/90)
10	CFRP	(-45/+45)
9	CFRP	(0/90)
8	CFRP	(-45/+45)
7	CFRP	(0/90)
6	CFRP	(+45/-45)
5	CFRP	(0/90)
4	CFRP	(-45/+45)
3	CFRP	(0/90)
2	CFRP	(+45/-45)
1	ECF	N/A
TOOL SIDE		

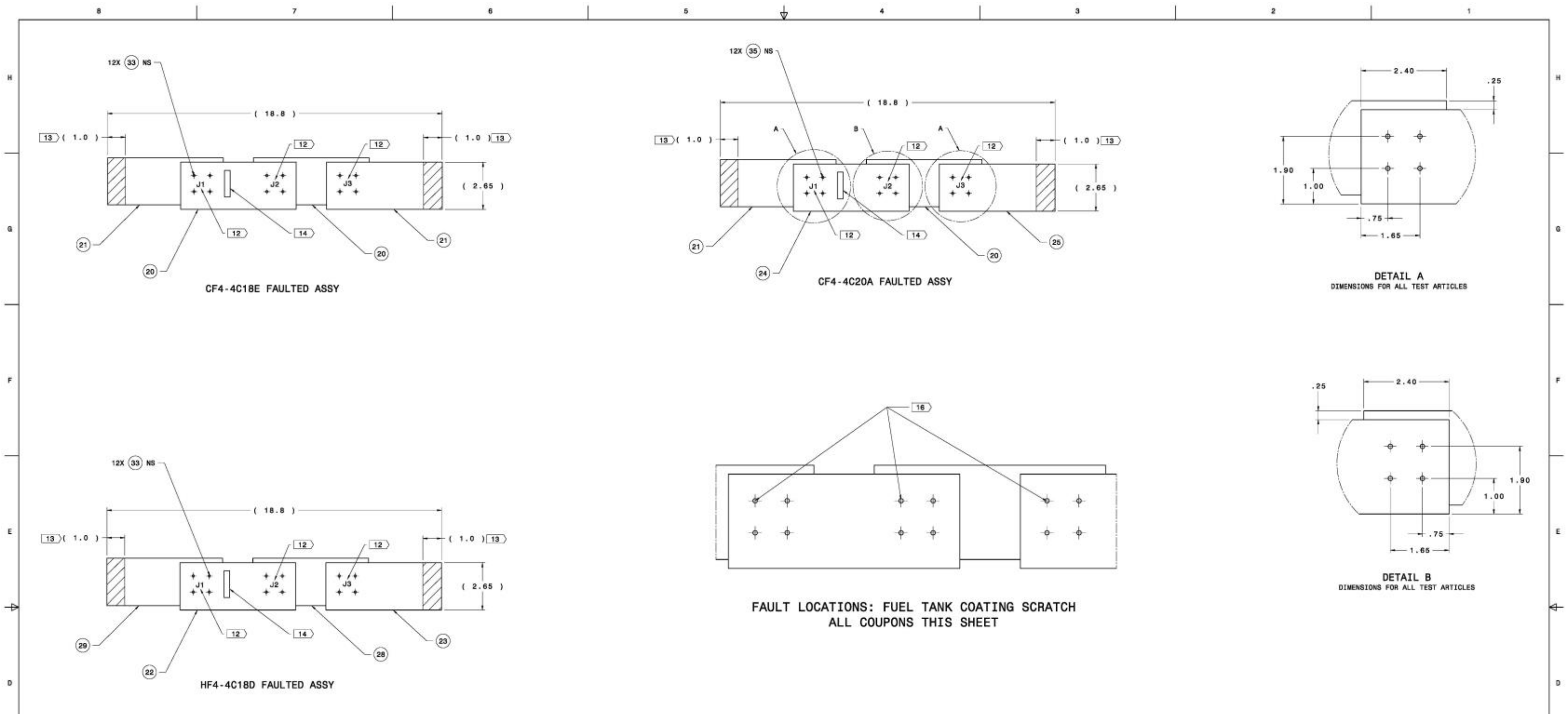


TYPICAL TEST ARTICLE ASSY

NOTES:

1. DIMENSIONS AND TOLERANCES PER ASME Y14.5-2009.
2. PREPARE HOLES FOR AND INSTALL HST10 AND HST11 FASTENERS PER HSTR_HLR-IS01 DOCUMENT.
3. PREPARE HOLES FOR TRI-LOCK FASTENERS PER HSTR_HLR-IS01 DOCUMENT.
4. USE SEALANT AMS-S-8802, TYPE 2, CLASS B FOR ALL FASTENERS.
5. WET INSTALL ALL FASTENERS PER PPG PR-1440 CLASS B FUEL TANK SEALANT TECHNICAL DATA SHEET. APPLY PR-1440 CLASS B FUEL TANK SEALANT TO THE SHANK AND UNDER THE HEAD OF THE FASTENER ENSURING FULL COVERAGE PRIOR TO INSTALLATION. THREADS MUST BE FREE OF SEALANT BEFORE AND AFTER INSTALLATION. IF TRACES ARE VISIBLE AFTER INSTALLATION, WIPE OFF WITH CLEAN DRY CLOTH. DO NOT USE SOLVENT. DURING INSTALLATION, A BEAD OF SEALANT MUST BE FORCED OUT FROM THE HEAD OF THE FASTENER. USE A DRY CLOTH TO WIPE OFF EXCESS SEALANT BEFORE CURE.
6. NS = FASTENER MANUFACTURED HEAD NEAR SIDE.
7. ASSEMBLE ALL CFRP COUPONS WITH ECF FACING NEAR SIDE (NS).
8. ASSEMBLE ALL CFRP COUPONS WITH GRP FACING FAR SIDE (FS).
9. CARBON FIBER COMPOSITE MATERIAL (CFRP) IS SOLVAY, CYCOM 5320-1 T650.
10. FIBERGLASS COMPOSITE MATERIAL (GRP) IS HEXCEL FIBERGLASS PREPREG M20/120.
11. EXPANDED COPPER FOIL (ECF) IS DEXMET 3CU7-125FA, 141.6 GSM
12. PERMANENTLY MARK, "J1", "J2", AND "J3" IN LOCATIONS SHOWN.
13. NO FUEL TANK COATING HERE. MASK OFF INDICATED AREAS ON BOTH SIDES OF PART BEFORE TANK COATING APPLICATION .
14. PART MARKING: PERMANENTLY MARK WITH COMPLETE PART NUMBER PER MIL-STD-130 IN LOCATION SHOWN.
15. FASTENER HOLES SHALL BE DRILLED PERDENDICULAR WITHIN 2 DEGREES UNLESS OTHERWISE SPECIFIED.
16. AT INDICATED FASTENER LOCATIONS, CREATE A SCRATCH IN THE COLLAR-SIDE PLATE PRIOR TO FASTENER INSTALLATION. SCRATCH SHALL BE 0.5 IN. LONG, 0.005 IN. DEEP AND SHALL START AT THE EDGE OF THE FASTENER HOLE. IT IS RECOMMENDED TO USE ELCOMETER 1538 DIN SCRATCHING TOOL OR SIMILAR TO CREATE THIS SCRATCH.
17. WHILE INSTALLING THE INDICATED FASTENERS, CREATE OR SIMULATE A BURR BETWEEN THE COLLAR OF THE FASTENER AND THE PLATE. SPECIFY SIZE OF BURR AND INSPECTION METHOD.
18. AT INDICATED FASTENER LOCATIONS, TORQUE INDICATED FASTENERS TO 42-56 IN-LBS. IT IS PERMISSIBLE FOR THE WRENCHING FEATURE ON THE COLLAR TO NOT TORQUE OFF.
19. AT INDICATED FASTENER LOCATIONS, DRILL HOLE NOMINAL DIAMETER-A TO 0.4145 TO ACHEIVE COUNTERSUNK HEAD TOO DEEP FAULT.
20. DRILL FASTENER HOLES AT INDICATED LOCATIONS 4 DEGREES ±0.5 DEGREES FROM PERPENDICULAR TO FACE OF COUPON.
21. ABBREVIATIONS:
    - CFRP CARBON FIBER REINFORCED POLYMER
    - ECF EXPANDED COPPER FOIL
    - GRP GLASS FIBER REINFORCED POLYMER (FIBERGLASS)
    - LWD LONG WAY DIAMOND

PROPRIETARY NOTICE THIS DRAWING IS PROPERTY OF WICHITA STATE UNIVERSITY AND SHALL NOT BE REPRODUCED, DISTRIBUTED, OR COMMUNICATED IN ANY FORM WITHOUT PRIOR WRITTEN CONSENT.	C.PARTEN	11/19/2020	NATIONAL INSTITUTE FOR AVIATION RESEARCH, ETL
	XXX	XX/XX/XXXX	
	XXX	XX/XX/XXXX	TITLE: 25.954 COMPOSITE FAULTED TEST ARTICLE ASSY
	UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES TOLERANCES ON DECIMALS .X = ±.1 .XX = ±.03 .XXX = ±.010 ANGLES ±30'		SIZE E; DWG NO FST5701; REV
			SCALE NONE; SHEET 1 OF 8



CF4-4C18E	HF4-4C18D	HF4-4C20C	CF4-4C20A	ITEM	PART OR IDENTIFYING NUMBER	DESCRIPTION	MATERIAL/SUPPLIER	SIZE	HOLE DIMENSIONS	FIT TYPE	NOTES
				36	HST11AG8-5/HST79CY8	FASTENER/COLLAR					
		12	12	35	HST11BJ8-5/HST79CY8	FASTENER/COLLAR					TOTAL QTY = 96
				34	HST10AG8-5/HST79CY8	FASTENER/COLLAR					
12	12			33	HST10BJ8-5/HST79CY8	FASTENER/COLLAR					TOTAL QTY = 96
				32							
				31							
				30							
	1	1		29	FST5700-019	COUPON END	AL CLAD 2024-T3 (AMS-QQ-A-250/5)	0.125 THK			TOTAL QTY = 8
	1	1		28	FST5700-017	COUPON MIDDLE	AL CLAD 2024-T3 (AMS-QQ-A-250/5)	0.125 THK			TOTAL QTY = 8
		1		27	FST5700-015	COUPON END	CFRP / ECF / GRP	0.162 THK			TOTAL QTY = 4
		1		26	FST5700-013	COUPON MIDDLE	CFRP / ECF / GRP	0.162 THK			TOTAL QTY = 4
			1	25	FST5700-011	COUPON END	CFRP / ECF	0.158 THK			TOTAL QTY = 4
			1	24	FST5700-009	COUPON MIDDLE	CFRP / ECF	0.158 THK			TOTAL QTY = 4
	1			23	FST5700-007	COUPON END	CFRP / GRP	0.154 THK			TOTAL QTY = 4
	1			22	FST5700-005	COUPON MIDDLE	CFRP / GRP	0.154 THK			TOTAL QTY = 4
2			1	21	FST5700-003	COUPON END	CFRP	0.150 THK			TOTAL QTY = 12
2			1	20	FST5700-001	COUPON MIDDLE	CFRP	0.150 THK			TOTAL QTY = 12
				19							
				18							
				17							
				16							
				15							
				14							
				13							
				12							
				11							
				10							
				9							
				8							
				7							
				6							
				5							
				4	CF4-4C18E	FAULTED ASSY			Ø.2495-.2505	CLEARANCE	ASSY QTY = 4
				3	HF4-4C18D	FAULTED ASSY			Ø.2495-.2505	CLEARANCE	ASSY QTY = 4
				2	HF4-4C20C	FAULTED ASSY			Ø.2495-.2505	CLEARANCE	ASSY QTY = 4
				1	CF4-4C20A	FAULTED ASSY			Ø.2495-.2505	CLEARANCE	ASSY QTY = 4

PROPRIETARY NOTICE
THIS DRAWING IS PROPERTY OF WICHITA STATE UNIVERSITY AND SHALL NOT BE REPRODUCED, DISTRIBUTED, OR COMMUNICATED IN ANY FORM WITHOUT PRIOR WRITTEN CONSENT.

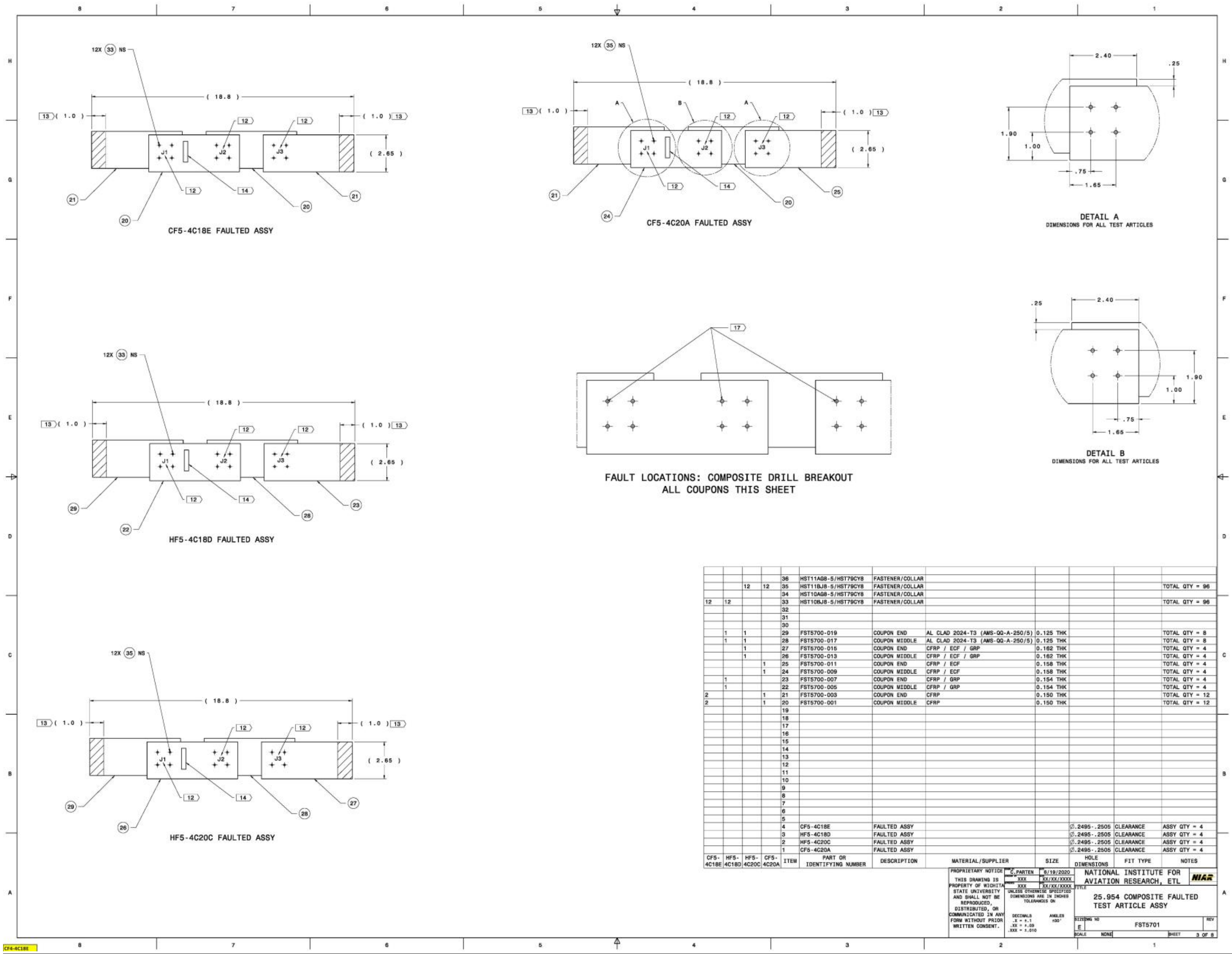
C.PARTEN 6/19/2020
XXX XX/XX/XXXX
XXX XX/XX/XXXX

UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES TOLERANCES ON
DECIMALS .X = ±.1 .XX = ±.03 .XXX = ±.010
ANGLES ±30'

NATIONAL INSTITUTE FOR AVIATION RESEARCH, ETL

TITLE 25.954 COMPOSITE FAULTED TEST ARTICLE ASSY

SIZE E DWG NO FST5701 REV
SCALE NONE SHEET 2 OF 8



CF5-4C18E	HF5-4C18D	HF5-4C20C	CF5-4C20A	ITEM	PART OR IDENTIFYING NUMBER	DESCRIPTION	MATERIAL/SUPPLIER	SIZE	HOLE DIMENSIONS	FIT TYPE	NOTES
				36	HST11AG8-5/HST79CY8	FASTENER/COLLAR					
		12	12	35	HST11BJ8-5/HST79CY8	FASTENER/COLLAR					TOTAL QTY = 96
				34	HST10AG8-5/HST79CY8	FASTENER/COLLAR					
12	12			33	HST10BJ8-5/HST79CY8	FASTENER/COLLAR					TOTAL QTY = 96
				32							
				31							
				30							
	1	1		29	FST5700-019	COUPON END	AL CLAD 2024-T3 (AMS-QQ-A-250/5)	0.125 THK			TOTAL QTY = 8
	1	1		28	FST5700-017	COUPON MIDDLE	AL CLAD 2024-T3 (AMS-QQ-A-250/5)	0.125 THK			TOTAL QTY = 8
		1		27	FST5700-015	COUPON END	CFRP / ECF / GRP	0.162 THK			TOTAL QTY = 4
		1		26	FST5700-013	COUPON MIDDLE	CFRP / ECF / GRP	0.162 THK			TOTAL QTY = 4
			1	25	FST5700-011	COUPON END	CFRP / ECF	0.158 THK			TOTAL QTY = 4
			1	24	FST5700-009	COUPON MIDDLE	CFRP / ECF	0.158 THK			TOTAL QTY = 4
	1			23	FST5700-007	COUPON END	CFRP / GRP	0.154 THK			TOTAL QTY = 4
	1			22	FST5700-005	COUPON MIDDLE	CFRP / GRP	0.154 THK			TOTAL QTY = 4
2			1	21	FST5700-003	COUPON END	CFRP	0.150 THK			TOTAL QTY = 12
2			1	20	FST5700-001	COUPON MIDDLE	CFRP	0.150 THK			TOTAL QTY = 12
				19							
				18							
				17							
				16							
				15							
				14							
				13							
				12							
				11							
				10							
				9							
				8							
				7							
				6							
				5							
				4	CF5-4C18E	FAULTED ASSY			Ø.2495-.2505	CLEARANCE	ASSY QTY = 4
				3	HF5-4C18D	FAULTED ASSY			Ø.2495-.2505	CLEARANCE	ASSY QTY = 4
				2	HF5-4C20C	FAULTED ASSY			Ø.2495-.2505	CLEARANCE	ASSY QTY = 4
				1	CF5-4C20A	FAULTED ASSY			Ø.2495-.2505	CLEARANCE	ASSY QTY = 4

PROPRIETARY NOTICE
THIS DRAWING IS PROPERTY OF WICHITA STATE UNIVERSITY AND SHALL NOT BE REPRODUCED, DISTRIBUTED, OR COMMUNICATED IN ANY FORM WITHOUT PRIOR WRITTEN CONSENT.

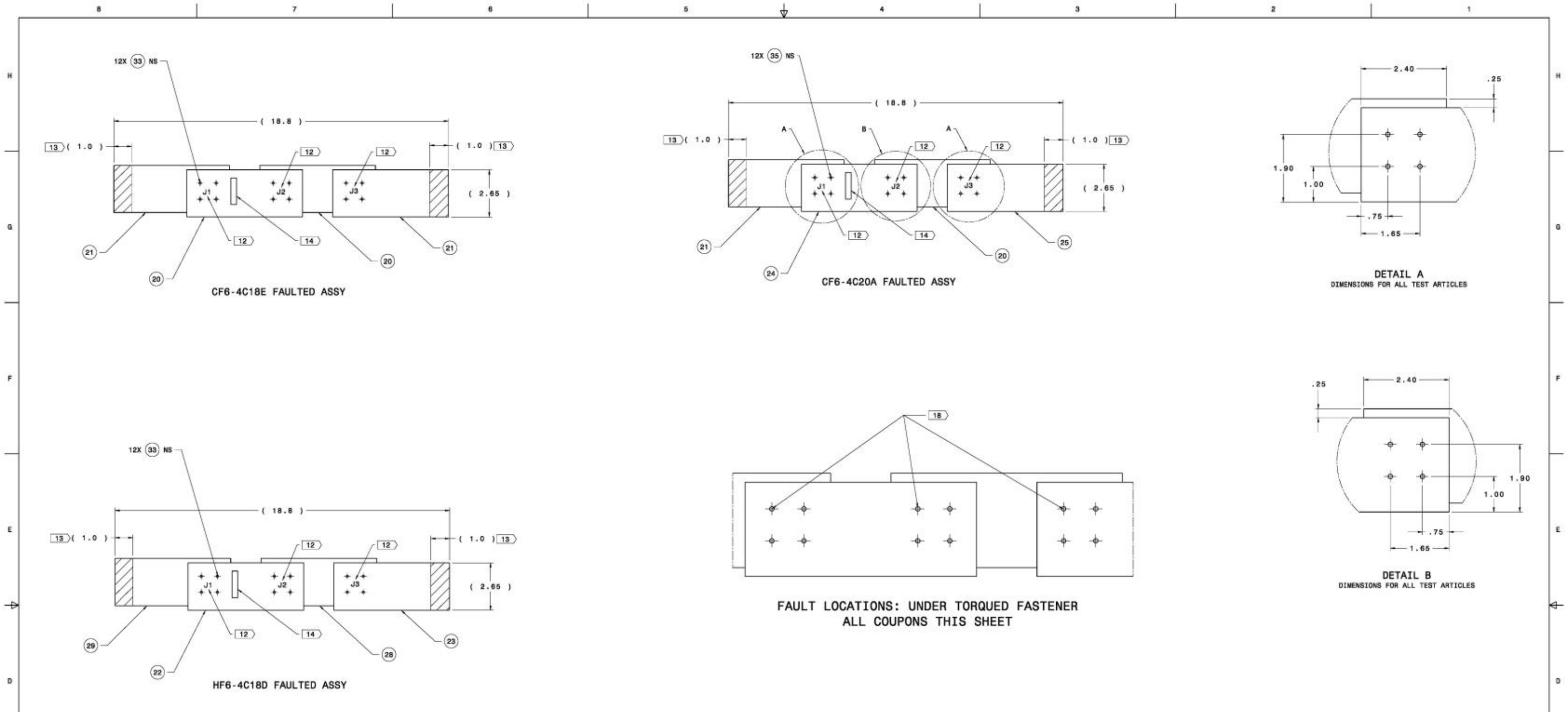
C.PARTEN 6/19/2020
XXX XX/XX/XXXX
XXX XX/XX/XXXX

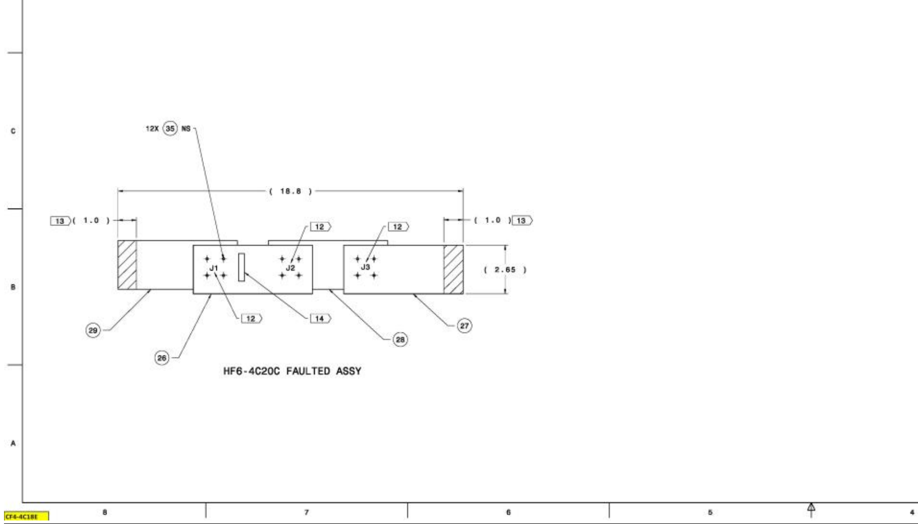
UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES TOLERANCES ON
DECIMALS .X = ±.1 .XX = ±.03 .XXX = ±.010
ANGLES ±30'

NATIONAL INSTITUTE FOR AVIATION RESEARCH, ETL

TITLE 25.954 COMPOSITE FAULTED TEST ARTICLE ASSY

SIZE E DWG NO FST5701 REV
SCALE NONE SHEET 3 OF 8

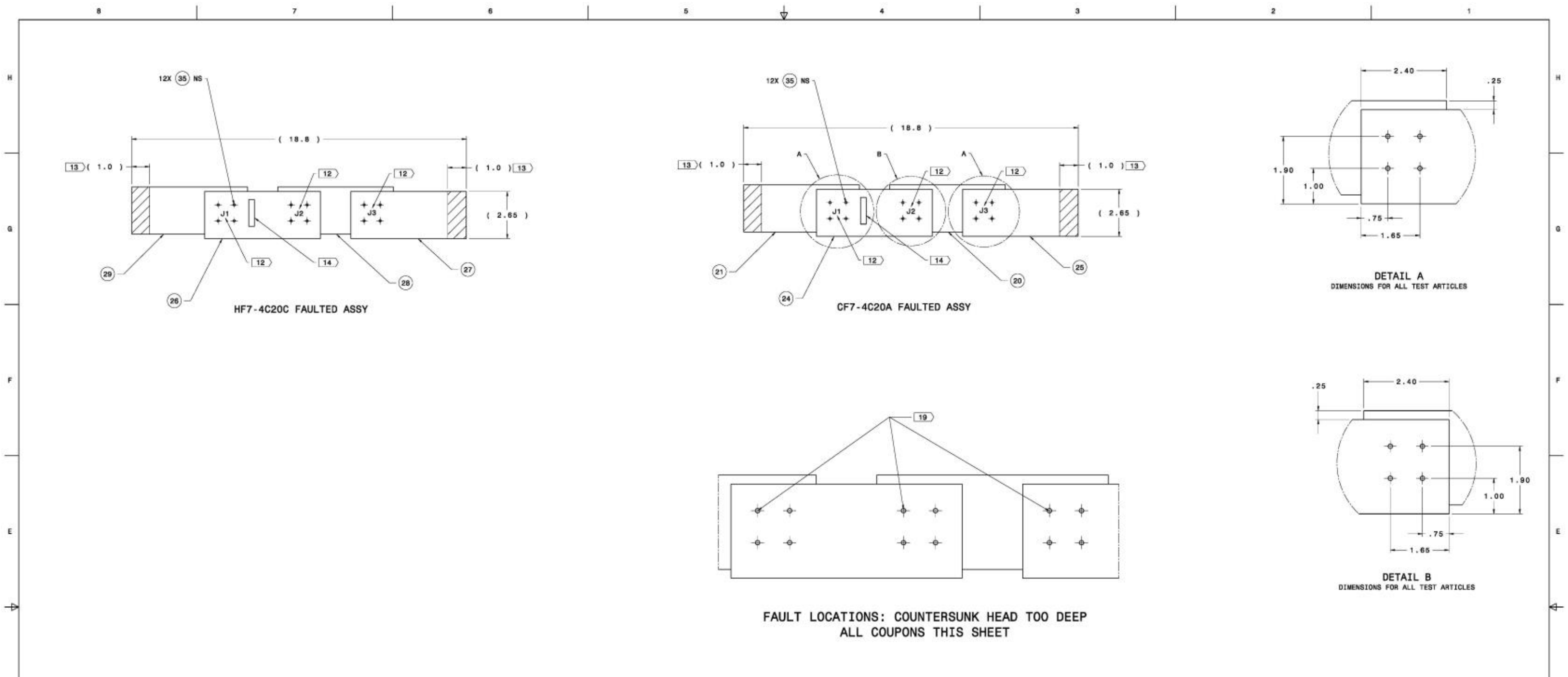




CF6-4C18E	HF6-4C18D	HF6-4C20C	CF6-4C20A	ITEM	PART OR IDENTIFYING NUMBER	DESCRIPTION	MATERIAL/SUPPLIER	SIZE	HOLE DIMENSIONS	FIT TYPE	NOTES
				36	HST11AG8-5/HST79CY8	FASTENER/COLLAR					
		12	12	35	HST11BJ8-5/HST79CY8	FASTENER/COLLAR					TOTAL QTY = 96
				34	HST10AG8-5/HST79CY8	FASTENER/COLLAR					
12	12			33	HST10BJ8-5/HST79CY8	FASTENER/COLLAR					TOTAL QTY = 96
				32							
				31							
				30							
	1	1		29	FST5700-019	COUPON END	AL CLAD 2024-T3 (AMS-QQ-A-250/5)	0.125 THK			TOTAL QTY = 8
	1	1		28	FST5700-017	COUPON MIDDLE	AL CLAD 2024-T3 (AMS-QQ-A-250/5)	0.125 THK			TOTAL QTY = 8
		1		27	FST5700-015	COUPON END	CFRP / ECF / GRP	0.162 THK			TOTAL QTY = 4
		1		26	FST5700-013	COUPON MIDDLE	CFRP / ECF / GRP	0.162 THK			TOTAL QTY = 4
			1	25	FST5700-011	COUPON END	CFRP / ECF	0.158 THK			TOTAL QTY = 4
			1	24	FST5700-009	COUPON MIDDLE	CFRP / ECF	0.158 THK			TOTAL QTY = 4
	1			23	FST5700-007	COUPON END	CFRP / GRP	0.154 THK			TOTAL QTY = 4
	1			22	FST5700-005	COUPON MIDDLE	CFRP / GRP	0.154 THK			TOTAL QTY = 4
2			1	21	FST5700-003	COUPON END	CFRP	0.150 THK			TOTAL QTY = 12
2			1	20	FST5700-001	COUPON MIDDLE	CFRP	0.150 THK			TOTAL QTY = 12
				19							
				18							
				17							
				16							
				15							
				14							
				13							
				12							
				11							
				10							
				9							
				8							
				7							
				6							
				5							
				4	CF6-4C18E	FAULTED ASSY			Ø.2495-.2505	CLEARANCE	ASSY QTY = 4
				3	HF6-4C18D	FAULTED ASSY			Ø.2495-.2505	CLEARANCE	ASSY QTY = 4
				2	HF6-4C20C	FAULTED ASSY			Ø.2495-.2505	CLEARANCE	ASSY QTY = 4
				1	CF6-4C20A	FAULTED ASSY			Ø.2495-.2505	CLEARANCE	ASSY QTY = 4

PROPRIETARY NOTICE THIS DRAWING IS PROPERTY OF WICHITA STATE UNIVERSITY AND SHALL NOT BE REPRODUCED, DISTRIBUTED, OR COMMUNICATED IN ANY FORM WITHOUT PRIOR WRITTEN CONSENT.	C.PARTEN 8/19/2020 XXX XX/XX/XXXX XXX XX/XX/XXXX UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES TOLERANCES ON DECIMALS .X = ±.1 .XX = ±.03 .XXX = ±.010 ANGLES ±30'	NATIONAL INSTITUTE FOR AVIATION RESEARCH, ETL TITLE 25.954 COMPOSITE FAULTED TEST ARTICLE ASSY	
		SIZE E · DWG NO FST5701 · REV	
		SCALE NONE · SHEET 4 OF 8	

CF6-4C18E



HF7-4C20C	CF7-4C20A	ITEM	PART OR IDENTIFYING NUMBER	DESCRIPTION	MATERIAL/SUPPLIER	SIZE	HOLE DIMENSIONS	FIT TYPE	NOTES
		36	HST11AG8-5/HST79CY8	FASTENER/COLLAR					
12	12	35	HST11BJ8-5/HST79CY8	FASTENER/COLLAR					TOTAL QTY = 96
		34	HST10AG8-5/HST79CY8	FASTENER/COLLAR					
		33	HST10BJ8-5/HST79CY8	FASTENER/COLLAR					
		32							
		31							
		30							
1		29	FST5700-019	COUPON END	AL CLAD 2024-T3 (AMS-QQ-A-250/5)	0.125 THK			TOTAL QTY = 4
1		28	FST5700-017	COUPON MIDDLE	AL CLAD 2024-T3 (AMS-QQ-A-250/5)	0.125 THK			TOTAL QTY = 4
1		27	FST5700-015	COUPON END	CFRP / ECF / GRP	0.162 THK			TOTAL QTY = 4
1		26	FST5700-013	COUPON MIDDLE	CFRP / ECF / GRP	0.162 THK			TOTAL QTY = 4
	1	25	FST5700-011	COUPON END	CFRP / ECF	0.158 THK			TOTAL QTY = 4
	1	24	FST5700-009	COUPON MIDDLE	CFRP / ECF	0.158 THK			TOTAL QTY = 4
		23	FST5700-007	COUPON END	CFRP / GRP	0.154 THK			
		22	FST5700-005	COUPON MIDDLE	CFRP / GRP	0.154 THK			
	1	21	FST5700-003	COUPON END	CFRP	0.150 THK			TOTAL QTY = 4
	1	20	FST5700-001	COUPON MIDDLE	CFRP	0.150 THK			TOTAL QTY = 4
		19							
		18							
		17							
		16							
		15							
		14							
		13							
		12							
		11							
		10							
		9							
		8							
		7							
		6							
		5							
		4							
		3							
		2	HF7-4C20C	FAULTED ASSY			Ø.2495-.2505	CLEARANCE	ASSY QTY = 4
		1	CF7-4C20A	FAULTED ASSY			Ø.2495-.2505	CLEARANCE	ASSY QTY = 4

PROPRIETARY NOTICE
THIS DRAWING IS PROPERTY OF WICHITA STATE UNIVERSITY AND SHALL NOT BE REPRODUCED, DISTRIBUTED, OR COMMUNICATED IN ANY FORM WITHOUT PRIOR WRITTEN CONSENT.

C.PARTEN 6/19/2020
XXX XX/XX/XXXX
XXX XX/XX/XXXX

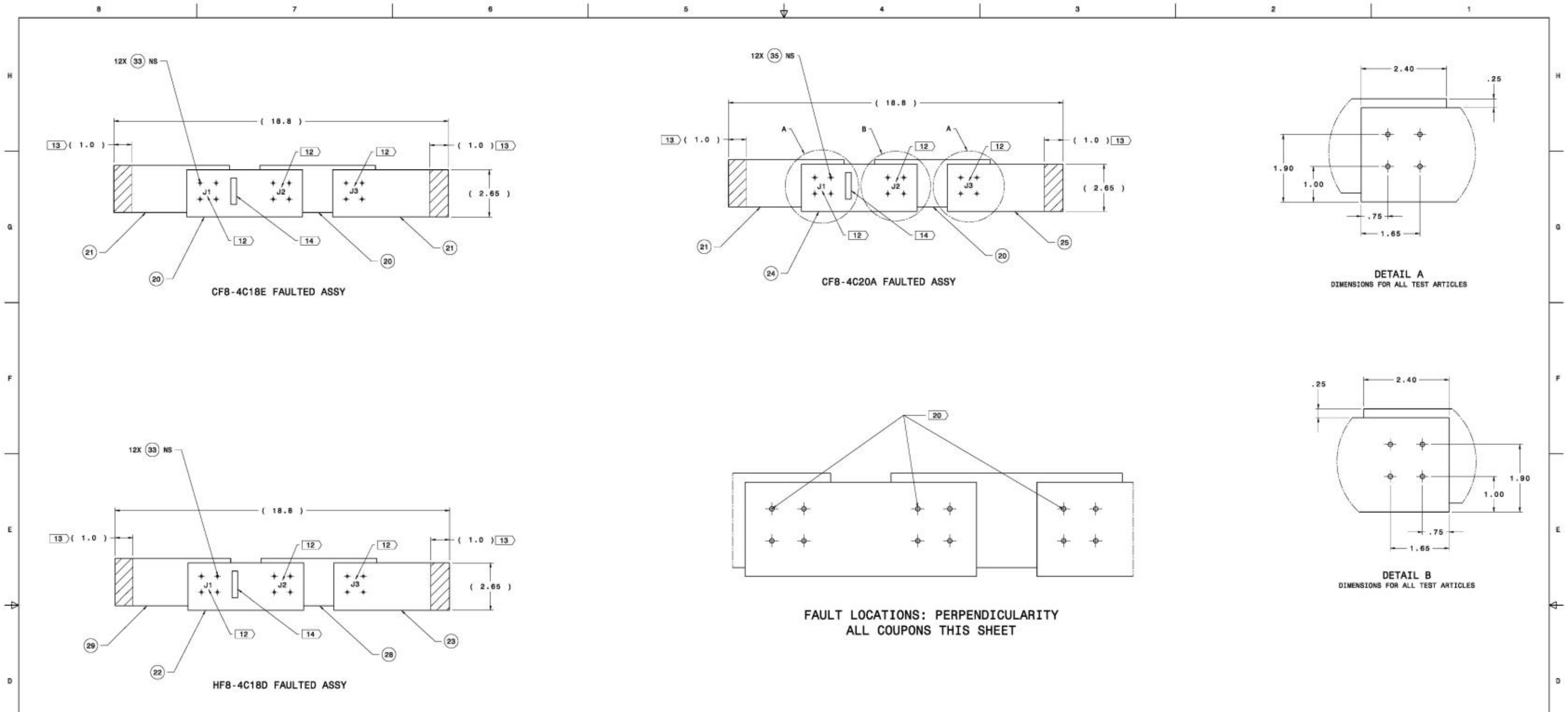
UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES TOLERANCES ON
DECIMALS .X = ±.1 .XX = ±.03 .XXX = ±.010
ANGLES ±30'

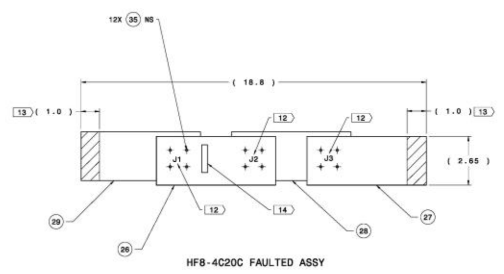
NATIONAL INSTITUTE FOR AVIATION RESEARCH, ETL

TITLE 25.954 COMPOSITE FAULTED TEST ARTICLE ASSY

SIZE E DWG NO FST5701 REV

SCALE NONE SHEET 5 OF 8





CF8-4C18E	HF8-4C18D	HF8-4C20C	CF8-4C20A	ITEM	PART OR IDENTIFYING NUMBER	DESCRIPTION	MATERIAL/SUPPLIER	SIZE	HOLE DIMENSIONS	FIT TYPE	NOTES
				36	HST11AG8-5/HST79CY8	FASTENER/COLLAR					
		12	12	35	HST11BJ8-5/HST79CY8	FASTENER/COLLAR					TOTAL QTY = 96
				34	HST10AG8-5/HST79CY8	FASTENER/COLLAR					
12	12			33	HST10BJ8-5/HST79CY8	FASTENER/COLLAR					TOTAL QTY = 96
				32							
				31							
				30							
	1	1		29	FST5700-019	COUPON END	AL CLAD 2024-T3 (AMS-QQ-A-250/5)	0.125 THK			TOTAL QTY = 8
	1	1		28	FST5700-017	COUPON MIDDLE	AL CLAD 2024-T3 (AMS-QQ-A-250/5)	0.125 THK			TOTAL QTY = 8
		1		27	FST5700-015	COUPON END	CFRP / ECF / GRP	0.162 THK			TOTAL QTY = 4
		1		26	FST5700-013	COUPON MIDDLE	CFRP / ECF / GRP	0.162 THK			TOTAL QTY = 4
			1	25	FST5700-011	COUPON END	CFRP / ECF	0.158 THK			TOTAL QTY = 4
			1	24	FST5700-009	COUPON MIDDLE	CFRP / ECF	0.158 THK			TOTAL QTY = 4
	1			23	FST5700-007	COUPON END	CFRP / GRP	0.154 THK			TOTAL QTY = 4
	1			22	FST5700-005	COUPON MIDDLE	CFRP / GRP	0.154 THK			TOTAL QTY = 4
2			1	21	FST5700-003	COUPON END	CFRP	0.150 THK			TOTAL QTY = 12
2			1	20	FST5700-001	COUPON MIDDLE	CFRP	0.150 THK			TOTAL QTY = 12
				19							
				18							
				17							
				16							
				15							
				14							
				13							
				12							
				11							
				10							
				9							
				8							
				7							
				6							
				5							
				4	CF8-4C18E	FAULTED ASSY			Ø.2495-.2505	CLEARANCE	ASSY QTY = 4
				3	HF8-4C18D	FAULTED ASSY			Ø.2495-.2505	CLEARANCE	ASSY QTY = 4
				2	HF8-4C20C	FAULTED ASSY			Ø.2495-.2505	CLEARANCE	ASSY QTY = 4
				1	CF8-4C20A	FAULTED ASSY			Ø.2495-.2505	CLEARANCE	ASSY QTY = 4

PROPRIETARY NOTICE
THIS DRAWING IS PROPERTY OF WICHITA STATE UNIVERSITY AND SHALL NOT BE REPRODUCED, DISTRIBUTED, OR COMMUNICATED IN ANY FORM WITHOUT PRIOR WRITTEN CONSENT.

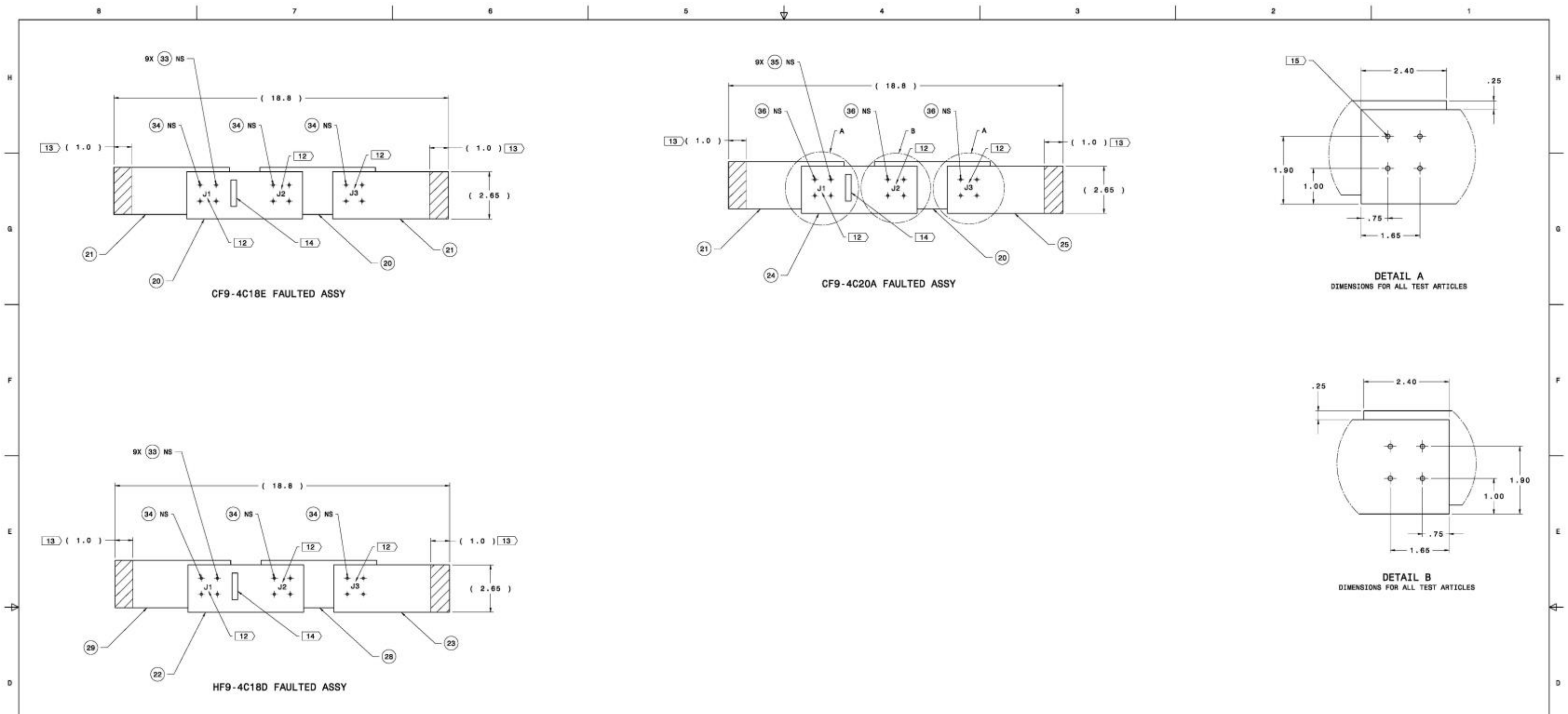
C.PARTEN 6/19/2020
XXX XX/XX/XXXX
XXX XX/XX/XXXX

UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES TOLERANCES ON
DECIMALS .X = ±.1 .XX = ±.03 .XXX = ±.010
ANGLES ±30'

NATIONAL INSTITUTE FOR AVIATION RESEARCH, ETL

TITLE 25.954 COMPOSITE FAULTED TEST ARTICLE ASSY

SIZE E DWG NO FST5701 REV
SCALE NONE SHEET 6 OF 8



CF9-4C18E	HF9-4C18D	HF9-4C20C	CF9-4C20A	ITEM	PART OR IDENTIFYING NUMBER	DESCRIPTION	MATERIAL/SUPPLIER	SIZE	HOLE DIMENSIONS	FIT TYPE	NOTES
		3	3	36	HST11AG8-5/HST79CY8	FASTENER/COLLAR					TOTAL QTY = 24
		9	9	35	HST11BJ8-5/HST79CY8	FASTENER/COLLAR					TOTAL QTY = 72
3	3			34	HST10AG8-5/HST79CY8	FASTENER/COLLAR					TOTAL QTY = 24
9	9			33	HST10BJ8-5/HST79CY8	FASTENER/COLLAR					TOTAL QTY = 72
				32							
				31							
				30							
	1	1		29	FST5700-019	COUPON END	AL CLAD 2024-T3 (AMS-QQ-A-250/5)	0.125 THK			TOTAL QTY = 8
	1	1		28	FST5700-017	COUPON MIDDLE	AL CLAD 2024-T3 (AMS-QQ-A-250/5)	0.125 THK			TOTAL QTY = 8
		1		27	FST5700-015	COUPON END	CFRP / ECF / GRP	0.162 THK			TOTAL QTY = 4
		1		26	FST5700-013	COUPON MIDDLE	CFRP / ECF / GRP	0.162 THK			TOTAL QTY = 4
			1	25	FST5700-011	COUPON END	CFRP / ECF	0.158 THK			TOTAL QTY = 4
			1	24	FST5700-009	COUPON MIDDLE	CFRP / ECF	0.158 THK			TOTAL QTY = 4
	1			23	FST5700-007	COUPON END	CFRP / GRP	0.154 THK			TOTAL QTY = 4
	1			22	FST5700-005	COUPON MIDDLE	CFRP / GRP	0.154 THK			TOTAL QTY = 4
2			1	21	FST5700-003	COUPON END	CFRP	0.150 THK			TOTAL QTY = 12
2			1	20	FST5700-001	COUPON MIDDLE	CFRP	0.150 THK			TOTAL QTY = 12
				19							
				18							
				17							
				16							
				15							
				14							
				13							
				12							
				11							
				10							
				9							
				8							
				7							
				6							
				5							
				4	CF9-4C18E	FAULTED ASSY			Ø.2495-.2505	CLEARANCE	ASSY QTY = 4
				3	HF9-4C18D	FAULTED ASSY			Ø.2495-.2505	CLEARANCE	ASSY QTY = 4
				2	HF9-4C20C	FAULTED ASSY			Ø.2495-.2505	CLEARANCE	ASSY QTY = 4
				1	CF9-4C20A	FAULTED ASSY			Ø.2495-.2505	CLEARANCE	ASSY QTY = 4

C.PARTEN 6/19/2020
XXX XX/XX/XXXX
XXX XX/XX/XXXX

UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES TOLERANCES ON
DECIMALS .X = ±.1 .XX = ±.03 .XXX = ±.010
ANGLES ±30'

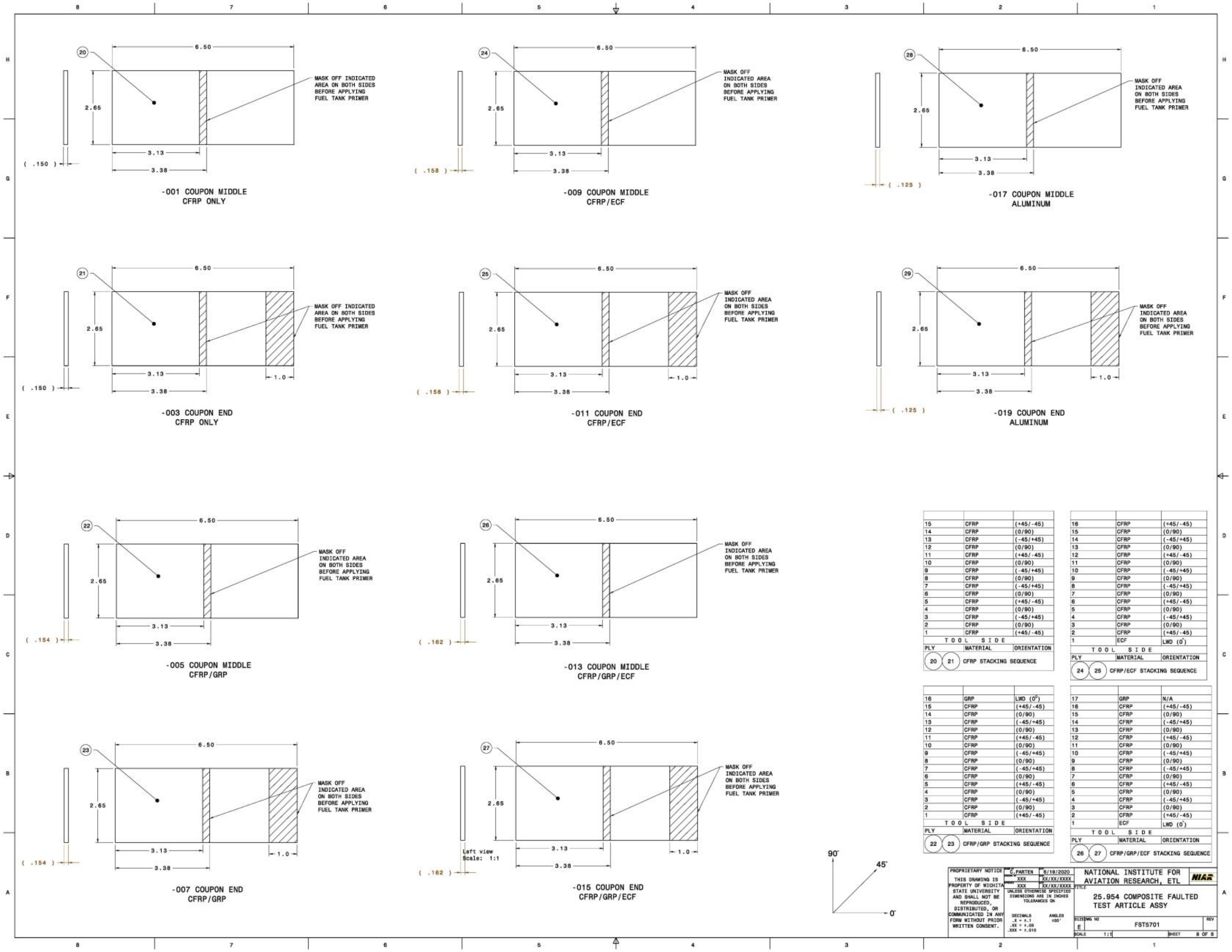
NATIONAL INSTITUTE FOR AVIATION RESEARCH, ETL

TITLE 25.954 COMPOSITE FAULTED TEST ARTICLE ASSY

SIZE E DWG NO FST5701 REV

SCALE NONE SHEET 7 OF 8

CF9-4C18E



(20) (21) CFRP STACKING SEQUENCE

PLY	MATERIAL	ORIENTATION
15	CFRP	(+45/-45)
14	CFRP	(0/90)
13	CFRP	(-45/+45)
12	CFRP	(0/90)
11	CFRP	(+45/-45)
10	CFRP	(0/90)
9	CFRP	(-45/+45)
8	CFRP	(0/90)
7	CFRP	(-45/+45)
6	CFRP	(0/90)
5	CFRP	(+45/-45)
4	CFRP	(0/90)
3	CFRP	(-45/+45)
2	CFRP	(0/90)
1	CFRP	(+45/-45)
TOOL SIDE		

(24) (25) CFRP/ECF STACKING SEQUENCE

PLY	MATERIAL	ORIENTATION
16	CFRP	(+45/-45)
15	CFRP	(0/90)
14	CFRP	(-45/+45)
13	CFRP	(0/90)
12	CFRP	(+45/-45)
11	CFRP	(0/90)
10	CFRP	(-45/+45)
9	CFRP	(0/90)
8	CFRP	(-45/+45)
7	CFRP	(0/90)
6	CFRP	(+45/-45)
5	CFRP	(0/90)
4	CFRP	(-45/+45)
3	CFRP	(0/90)
2	CFRP	(+45/-45)
1	ECF	LWD (0°)
TOOL SIDE		

(22) (23) CFRP/GRP STACKING SEQUENCE

PLY	MATERIAL	ORIENTATION
16	GRP	LWD (0°)
15	CFRP	(+45/-45)
14	CFRP	(0/90)
13	CFRP	(-45/+45)
12	CFRP	(0/90)
11	CFRP	(+45/-45)
10	CFRP	(0/90)
9	CFRP	(-45/+45)
8	CFRP	(0/90)
7	CFRP	(-45/+45)
6	CFRP	(0/90)
5	CFRP	(+45/-45)
4	CFRP	(0/90)
3	CFRP	(-45/+45)
2	CFRP	(0/90)
1	CFRP	(+45/-45)
TOOL SIDE		

(26) (27) CFRP/GRP/ECF STACKING SEQUENCE

PLY	MATERIAL	ORIENTATION
17	GRP	N/A
16	CFRP	(+45/-45)
15	CFRP	(0/90)
14	CFRP	(-45/+45)
13	CFRP	(0/90)
12	CFRP	(+45/-45)
11	CFRP	(0/90)
10	CFRP	(-45/+45)
9	CFRP	(0/90)
8	CFRP	(-45/+45)
7	CFRP	(0/90)
6	CFRP	(+45/-45)
5	CFRP	(0/90)
4	CFRP	(-45/+45)
3	CFRP	(0/90)
2	CFRP	(+45/-45)
1	ECF	LWD (0°)
TOOL SIDE		

Appendix D – 200 µJ Camera Calibration

National Institute for Aviation Research
Wichita State University
1845 N. Fairmount
Wichita, Kansas 67260-0093

NIAR Camera Verification Procedure

April-May 2021

TABLE OF CONTENTS

List of Abbreviations, Acronyms, and Symbols

A, Amp	Amperes
ARP	Aerospace Recommended Practice
C	Coulomb
°F	Degrees Fahrenheit
DC, dc	Direct Current
DEL	Direct Effects of Lightning
ETL	Environmental Test Laboratory
EUT	Equipment Under Test
Hz	Hertz (measure of Frequency)
KART	Kansas Aviation Research and Technology
kA	Kilo amperes
kA^2s	Kilo amperes squared seconds (measure of action integral)
kHz	Kilohertz
MHz	Megahertz
µJ	micro joules
µΩ	Micro ohms
µs	Microseconds
mΩ	Milliohms
ms	Milliseconds
NIAR	National Institute for Aviation Research
Ω	Ohms
RH	Relative humidity
SAE	Society of Automotive Engineers
TP	Test point

1.0 Scope

The purpose of this document is to serve as the procedure for the verification of cameras for use with the photographic method of ignition source detection. The resulting peak pixel value thresholds in Appendix A serve as the verification data for each cameras, valid for one year after the verification procedure is performed.

1.1 Introduction

SAE ARP 5416A section 7.7.1.1 allows cameras to be used to detect ignition sources of electrical sparks or thermal sparks. The guidance states that digital cameras can be used, but that they must be capable of detecting a 200 µJ +0/-10% electrical spark. There is much variation on how bright a picture of a 200 µJ spark in a dark box appears from different cameras, even when the cameras are both of the same make and model. To use digital cameras to detect an ignition source, a quantitative method must be used to determine if the possible ignition source detected during testing is above the 200 µJ threshold. The allowable false pass rate for 200 µJ photos is set at 10%, in correlation with the flammable gas mixture test method, which in section 7.7.2.3 step 1 requires the verification of the mixture calibration in nine out of ten successive tests using 200 µJ sparks. The pass/fail threshold is derived from the peak pixel values present in multiple images of the 200 µJ spark. The threshold is then verified by proving that all of the photos taken of 300 µJ sparks fall above the threshold. Peak pixel value is obtained during post-test image analysis using an open source image processing software, ImageJ, or equivalent. During analysis, peak pixel values are obtained when the image is scaled to 8 bits, resulting in a brightness scale ranging from 0-255.

2.0 Test Setup

2.1 Cameras

The quantitative output of the camera verification is the peak pixel value obtained from the image using image analysis software. The camera, lens, and camera settings should be treated as a set of calibrated equipment, which should be calibrated every 12 months. The changing of lenses or camera settings falls outside the verification and will require reverification of the cameras.

2.2 Voltage Spark Circuit

The spark circuit should be operated in relatively dry air. 1.6 mm tungsten electrodes with a 0.8 mm radius hemispherical tip are recommended, with a gap of 1.5 ± 0.1 mm between them. A calibrated capacitance bridge should be used to verify the capacitance of the circuit. The spark circuit should be charged with a high voltage power supply, and the breakdown voltage between the electrodes should be recorded with a calibrated meter. The energy (Joules) in the spark can be found by the following formula for energy in a capacitor: $J = \frac{1}{2} C*V^2$.

3.0 Equipment List

Description	Manufacturer	Model	Serial Number	Cal Due
Electrostatic Volt Meter	Trek	341B-L-CE	073	08/04/2021
Oscilloscope	Rigol	DS1104	DS1ZA181305414	9/30/2021
LCR Meter	Hewlett Packard	4263A	3145J02971	9/30/2021
200 µJ Spark circuit	NIAR	SS001	001	N/A

4.0 Applicable Documents

Document Number	Description
SAE Aerospace ARP 5416A Revised 2013	Aircraft Lightning Test Methods

5.0 Procedure for Verification

1. Condition the spark electrode with approximately 10,000 discharges to achieve a consistent level of oxidation on the electrodes. Tungsten electrodes are recommended.
2. Record camera manufacturer, model number or name, and serial number. If the camera uses removable parts such as lenses, camera backs, etc., record the manufacturer, model number or name, and serial number for each of these items. The verification only applies to the recorded camera system.
3. Determine breakdown voltage and set the capacitance of the spark circuit accordingly to ensure spark energies are 200 µJ +0/-10%. Verify capacitance with calibrated meter.
4. Set up the voltage spark source in black-out-box in order to eliminate any extraneous light sources.

5. Place both cameras (front and rear) at the same distance from the spark gap. Camera centerline of sight should be perpendicular to the electrode gap. The distance from camera to electrodes should be the same or slightly farther than the distance between the camera and the test articles that will be tested with the calibrated cameras.
6. Record the distance from camera to electrodes, environmental conditions, and any mirrors used.
7. Take open box photo of the spark source electrodes with the camera's "auto" mode to verify the location of the spark gap, that the electrodes are in focus, and that the spark gap is at least 5 pixels across.
8. Set up camera and record camera and lens settings. The camera and lens settings should be manual and all internal image processing and filters should be disabled. The aperture setting (f-number) should be based on the required depth of field so that the distance range for expected test articles is in focus.
9. Close the box and take a pre-test dark box photo to verify that there are no light leaks. This dark box photo will later be used for background subtraction with the spark photos.
10. In the black out box, take several photos of 200 µJ +0/-10% sparks. Analyze the photos and determine the peak pixel value of the spark. Adjust and record the ISO and camera aperture settings so that the measured peak pixel value is well above the random noise in the photo, and falls near the middle of the camera's dynamic range.

11. Capture 100 photos of 200 μJ +0/-10% spark events. Verify that all recorded sparks fall within the required energy range. Save an unedited copy of the original photo data file.
12. Analyze images using ImageJ 1.48v software or equivalent as follows.
    a. Perform a background subtraction of each spark photo minus the pre-test dark box photo to remove noise/hot pixels.
    b. Measure peak pixel values for the 100 background subtracted photos, save the results from each image in a spreadsheet.
    c. Set the threshold level T_W of the analysis method so that 10% of the photos have peak pixel values of the spark that fall below the threshold and the remaining 90% of the photos have peak pixel values of the spark above the threshold.
    d. Multiply T_W by 0.8 to get $T_{P/F}$. $T_{P/F}$ is the threshold that test photos will be compared against. Record pass/fail threshold $T_{P/F}$.
13. Adjust capacitance of the spark circuit to produce 300 uJ +0/-10% sparks. Verify capacitance with calibrated meter.
14. Take an open box photo of sparker to verify the location of the spark gap, that the spark gap is in focus, and that the spark gap is at least 5 pixels across.
15. Close the box and take a pre-test dark box photo to verify that there are no light leaks. This dark box photo will be used for background subtraction with the spark photos.
16. Capture 100 photos of 300 uJ +0/-10% spark events
17. Analyze images using ImageJ 1.48v software or equivalent as follows.

a. Perform a background subtraction of each spark photo minus the pre-test dark box photo to remove noise/hot pixels.
b. Measure peak pixel values for the 100 photos, save the results for each image in a spreadsheet.
c. Ensure that all of the max pixel values for the 300 uJ sparks fall above the threshold T_W.

5.1 Procedure for Testing:

1. Set up cameras and test article so that the distance between them is no farther than the calibrated distance. There should be a clear, unobstructed, in focus view of the entire test article.
2. Perform test and capture test images.
3. Analyze the images and determine the peak pixel value of the image in the region of interest. The same software used for the verification must be used for the test itself.
   a. Perform a background subtraction of the test photo minus the dark box photo to remove noise/hot pixels.
   b. Cropping around the test article to remove false light artifacts is permitted as long as the region of interest for analysis includes the entire test article area that is being evaluated for potential ignition sources.
4. Measure the peak pixel value of the test image and evaluate it against the pass/fail threshold $T_{P/F}$ and identify any potential ignition sources.

5. Verify that the identified potential ignition sources can be correlated to the test article and eliminate possible camera defects or test artifacts. The use of two or three calibrated digital cameras will help eliminate possible camera defects that may otherwise be confused as ignition sources.
6. If the peak pixel value falls above the pass/fail threshold $T_{P/F}$ the test should be considered a failure. If all peak pixel values in regions of potential ignition sources fall below the pass/fail threshold $T_{P/F}$ the test should be considered a pass.

Appendix A

Results of Verification

Data charts display the resulting peak pixel values from 100 images of 200 µJ +0/-10% spark events, the pass/fail threshold $T_{P/F}$, and the resulting peak pixel values from 100 images of 300 µJ +0/-10% spark events. The pass/fail threshold $T_{P/F}$ is the threshold value that test photos will be compared against.

Material of electrodes: Tungsten

Electrode gap: 1.4 - 1.6 mm

Distance from camera to electrode: 10"

	Camera 3 and 8	Camera 6 and 7
F Stop	f/4.0	f/4.0
ISO	400	100
Exposure Time (s)	5	5
Exposure Bias	0	0
Focal Length (mm)	18mm	18mm
File Type	Fine Quality JPEG	Fine Quality JPEG

Description	Manufacturer	Model	Serial Number	Last Cal	Cal Due
Camera 3	Canon	EOS Rebel T3i DS126311	Body: 402077002849 Lens: 1446092416	05/07/2021	05/07/2022
Camera 8	Canon	EOS Rebel T3i DS126311	Body: 402077002846 Lens: 1446092413	05/07/2021	05/07/2022
Camera 6	Canon	EOS Rebel T6i DS126571	Body: 352072015432 Lens: 610204005366	04/14/2021	04/14/2022
Camera 7	Canon	EOS Rebel T6i DS126571	Body: 352072015496 Lens: 610204005502	04/14/2021	04/14/2022

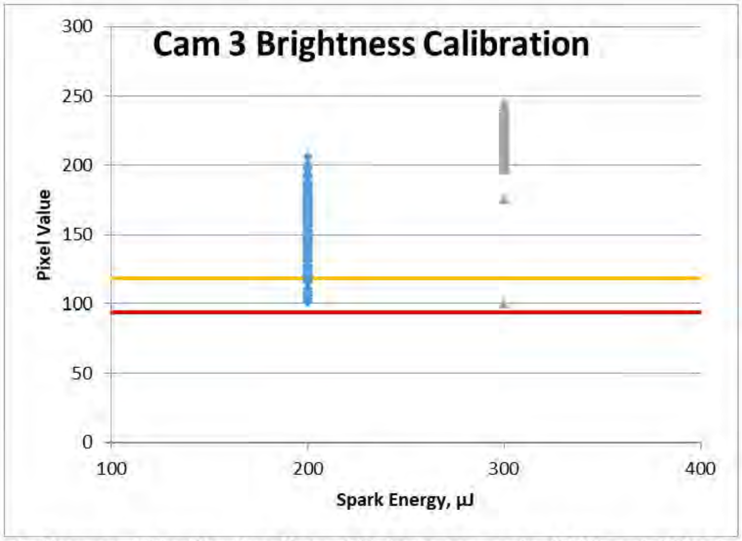


Figure 1: Camera 3 Verification Data, 100 instances each of 200 and 300 µJ sparks. Threshold, $T_{P/F}$ = 94.4

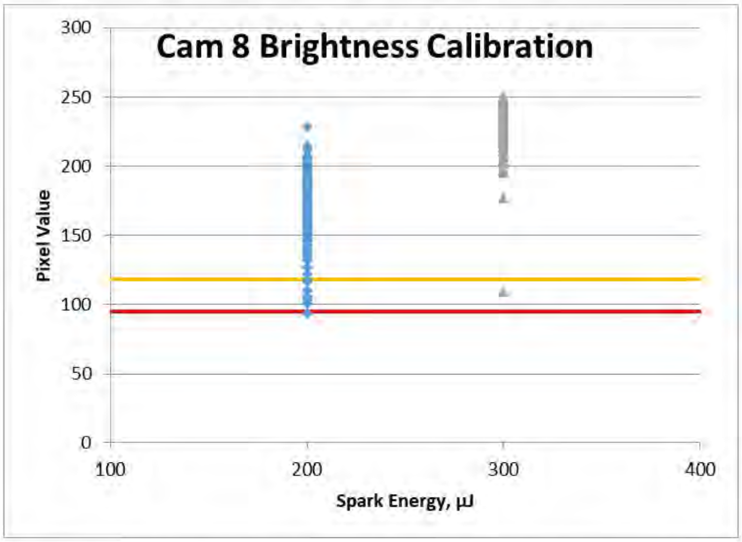


Figure 2: Camera 8 Verification Data, 100 instances each of 200 and 300 µJ sparks. Threshold, $T_{P/F}$ = 94.4

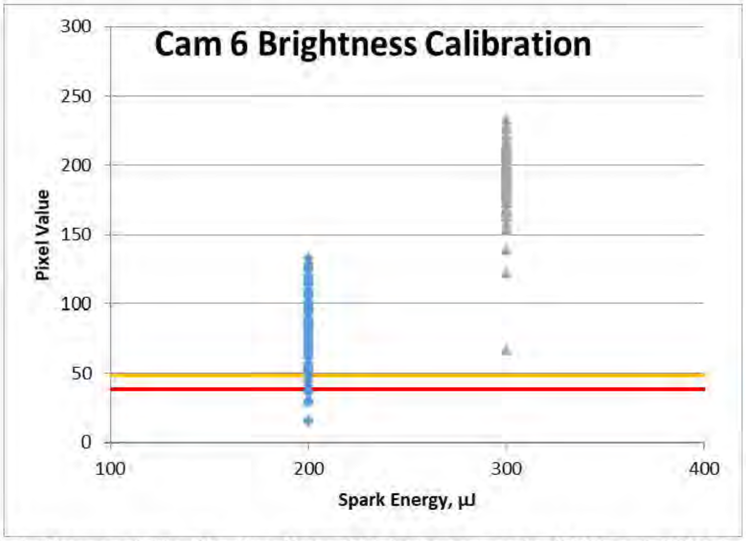


Figure 3: Camera 6 Verification Data, 100 instances each of 200 and 300 µJ sparks. Threshold, $T_{P/F}$ = 38.4

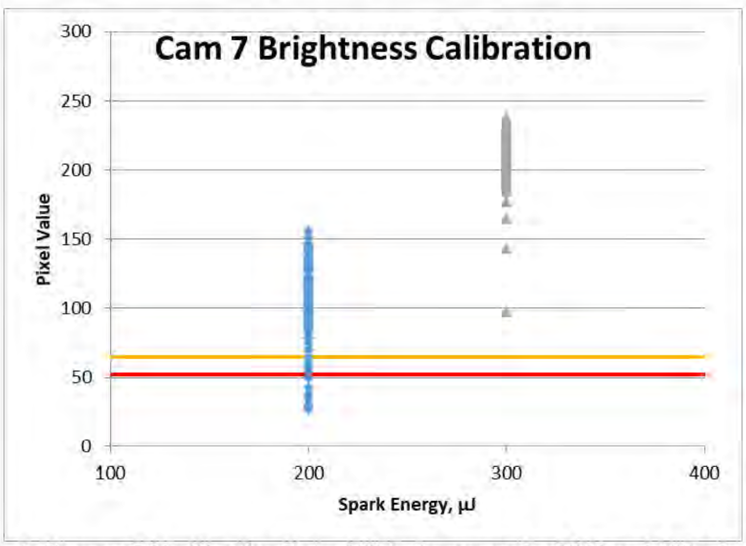


Figure 4: Camera 7 Verification Data, 100 instances each of 200 and 300 µJ sparks. Threshold, $T_{P/F}$ = 52