IEEE/NFPA Arc Flash Phenomena Collaborative Research Project

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Steering Committee Chair

January 27, 2011

Introduction

- On average, approximately 5 to 10 arc flash incidents or events occur on the job every day in the United States.
- Though electrical incidents represent a relatively small percentage of all work-related incidents, they are disproportionately fatal and, in the case of burns, may result in extended hospitalization and rehabilitation.

Introduction

- IEEE 1584 and NFPA 70E have been developed to protect the safety of workers.
- Several areas of arc flash phenomena need further research and testing validation.
- IEEE and NFPA formed the Arc Flash Collaborative Research Project to support research and additional testing to increase the understanding of issues related to arc flash phenomena.

Introduction

- The identified areas include but are not limited to:
  - Heat and Thermal Effects
  - Blast Pressure
  - Sound
  - Luminance (Light) measurement
- This report highlights the activities of this collaborative research project.

Selection of the Testing Labs

- A total of four high power test/laboratory facilities have been “pre-qualified” through both written response and site visits. (Three labs are independent test laboratories and the one lab belongs to a corporate sponsor.)
- These test laboratories are third-party certified for quality assurance.
- All labs have qualified personnel, experience with arc flash testing, and adequate facilities.

Selection of the Testing Labs

- The initial phase of pre-qualification was concluded in August 2008. In February 2010, another independent test laboratory, S&C, was identified and pre-qualified through a similar process.
- These test laboratories were invited to submit technical and cost proposals for RFQs issued on behalf of the arc flash collaborative research project.

Phase I Testing

- The first round of “scouting” tests referred to as “Phase 1 Testing” was designed to check the following among test labs using identical test protocols and arrangement:
  - Instrumentation functionality and sensitivity
  - Overall measurement accuracy
  - Repeatability of experiments
  - Consistency of test results

Phase I Testing

- The test parameters are:
  - **System Voltage:** 480V, 3-phase and 1-phase, 60-Hz, Solidly Grounded and Ungrounded System.
  - **RMS Bolted Fault Current:** 5 and 20kA.
  - **Electrode:** 19mm (3/4”) cylindrical hard drawn Copper.
  - **Electrode Orientations:** Vertical and Horizontal.
  - **Electrode Gap Widths:** 10mm and 25mm (approx. 1 in)
  - **Arc Duration (60Hz Base):** 6 cycles (0.1 sec) and 12 cycles (0.2sec).
  - **Configurations:** Open Air, Cubic Box (3-Ph), Faraday cage (1-Ph), Electrodes Terminated in Barrier (1 lab).

Phase I Testing

- Test performed (Two tests per configuration)

3P-VCB-12-5-10-UB	3P-VCB-6-5-10-UB	3P-VOA-12-5-10
3P-VCB-12-5-10-B	3P-VCB-6-5-10-B	3P-VOA-12-5-25
3P-VCB-12-5-25-UB	3P-VCB-6-5-25-UB	3P-VOA-12-20-10
3P-VCB-12-5-25-B	3P-VCB-6-5-25-B	3P-VOA-12-20-25
3P-VCB-12-20-10-UB	3P-VCB-6-20-10-UB	
3P-VCB-12-20-10-B	3P-VCB-6-20-10-B	
3P-VCB-12-20-25-UB	3P-VCB-6-20-25-UB	
3P-VCB-12-20-25-B	3P-VCB-6-20-25-B	
3P-HCB-12-20-10-UB	3P-HOA-12-5-10	1P-VFC-12-5-10
3P-HCB-12-20-10-B	3P-HOA-12-5-25	1P-VFC-12-5-25
3P-HCB-12-20-25-UB	3P-HOA-12-20-10	1P-VFC-6-20-10
3P-HCB-12-20-25-B	3P-HOA-12-20-25	1P-VFC-12-20-25

480V Phase I Testing – 244 Tests

- Number of Tests by type (~50% each: 6,12 cycle)

Bolted Fault: Gap width:	~5kA 10mm	~5kA 25mm	~20kA 10mm	~20kA 25mm
HOA	7	3	8	5
HCB-B	4		5	8
HCB-UB	7		14	13
VOA	2		12	12
VCB-B	9	4	16	18
VCB-UB	12	5	20	18
VCB-Barrier	9	8	8	9
Faraday,1ph	2	2	2	2

Observations From Phase I Testing

- Important Factors for the Test
  - Bolted fault current level.
  - Duration of the arc.
  - Voltage level.
  - Electrode Orientation/Configuration (VCB, VCB-Barrier, HCB, VOA, HOA).
  - Gap width between electrodes.
  - Calorimeter arrangement and measurement locations.
  - Distance between electrode and back panel*.
  - Dimensions of the metal enclosure**.

Design of Phase II Testing

- Cover installations between (208V) 480V and 13.8kV.
- Compile/Analyze Phase I 480V testing results.
- Perform extensive tests on 600V, 2.4kV/4.16kV, and 13.8kV.
- Perform select tests on 208V and 7.2kV.

Design of Phase II Testing

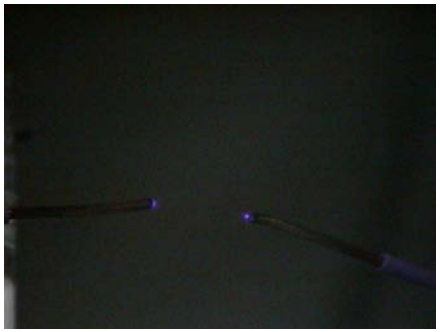
- Based upon engineering practice, select appropriate sized metal enclosure for Phase II testing. Other dimensions will be checked later (selective testing).
- Based upon engineering practice, select appropriate distance between electrode and back panel for Phase II testing. Other distances will be check later (selective testing).

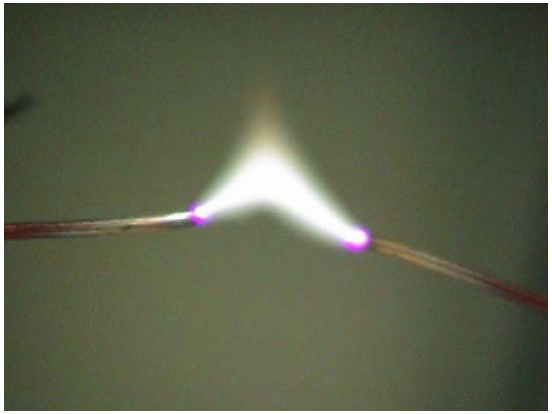
Design of Phase II Testing

- Measure IE at three different distances.
- Measure the sound levels at 3 meters and 5 meters for ANSI S1.4 peak.
- Measure pressure at three different distances (Same as IE measurement).
- Perform luminance (light) measurement at 3 meters and 5 meters.

Design of Phase II Testing

- Gaps between electrodes and over surface.
  - For medium voltage, the design is based upon the requirement of BIL (Basic Impulse Level).
  - The breakdown voltage in the dry air is around 30 kV/inch.
  - Laboratory testing shows that the breakdown voltage is around 15 kV/inch.





Design of Phase II Testing

- Gaps between electrodes and over surface.
  - Design parameters for gap between electrodes and electrodes to the back panel.

Voltage (kV)	BIL (kV)	Minimum Gap (inch)	Maximum Gap (inch)	Over Surface Phase-to-ground (inch)
0 – 0.125		0.5		0.75
0.126 – 0.250		0.75		1.0
0.251 – 0.600		1.0	2.0	4.0
2.4	60	1.5	4.5	4.0
4.16 (5)	60	1.5	4.5	4.0
7.2	75	2.5	4.5	4.0
13.8	95	3.0	6.0	7.0

Design of Phase II Testing

- Other Parameters.

Voltage (kV)	Maximum I_{bf} (kA)	Distance to the Back Panel (inch)	Box Size (inch)
0 – 0.125			
0.126 – 0.250			
0.251 – 0.600	100	4	20x20x20
2.4	63	4	26x26x26
4.16 (5)	63	4	26x26x26
7.2	63	4	26x26x26
13.8	63	7	36x36x36

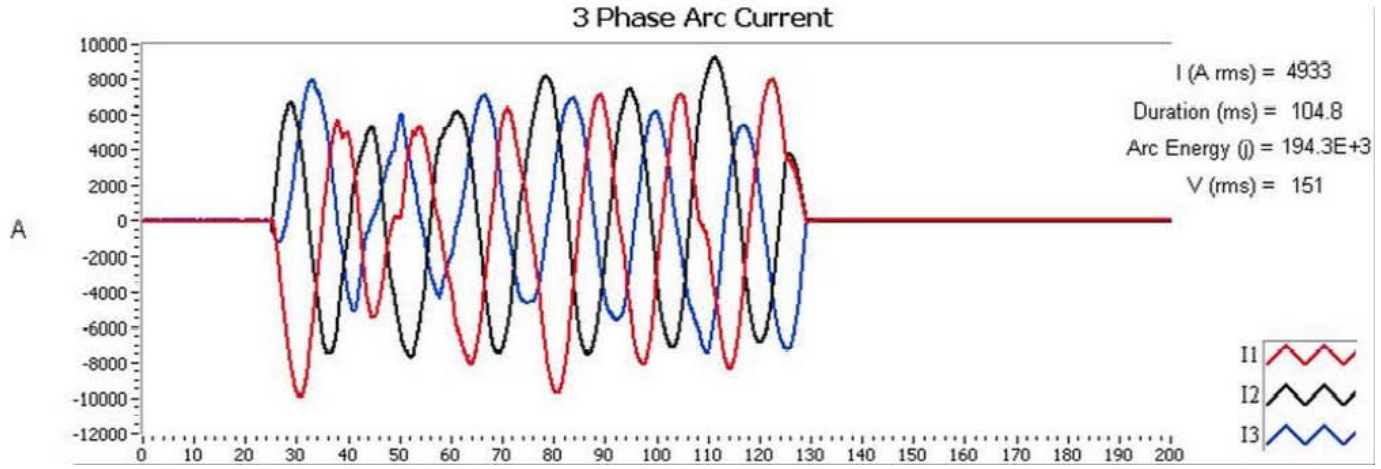
Design of Phase II Testing

- List of 4160V Testing (270 Tests).

Bolted Fault Current (KA)	Duration (cycles)	Gap (inch)	Distance to Back Panel (inch)	Measure Distance (inch)	VCB	VCB-Barr	HCB	Measure Distance (inch)	VOA	HOA
20/40/63	6	1.5/3.0/4.5	4	24	1	1	1	18	1	1
20/40/63	12	1.5/3.0/4.5	4	24	1	1	1	18	1	1
20/40/63	6	1.5/3.0/4.5	4	33	1	1	1	27	1	1
20/40/63	12	1.5/3.0/4.5	4	33	1	1	1	27	1	1
20/40/63	6	1.5/3.0/4.5	4	42	1	1	1	36	1	1
20/40/63	12	1.5/3.0/4.5	4	42	1	1	1	36	1	1

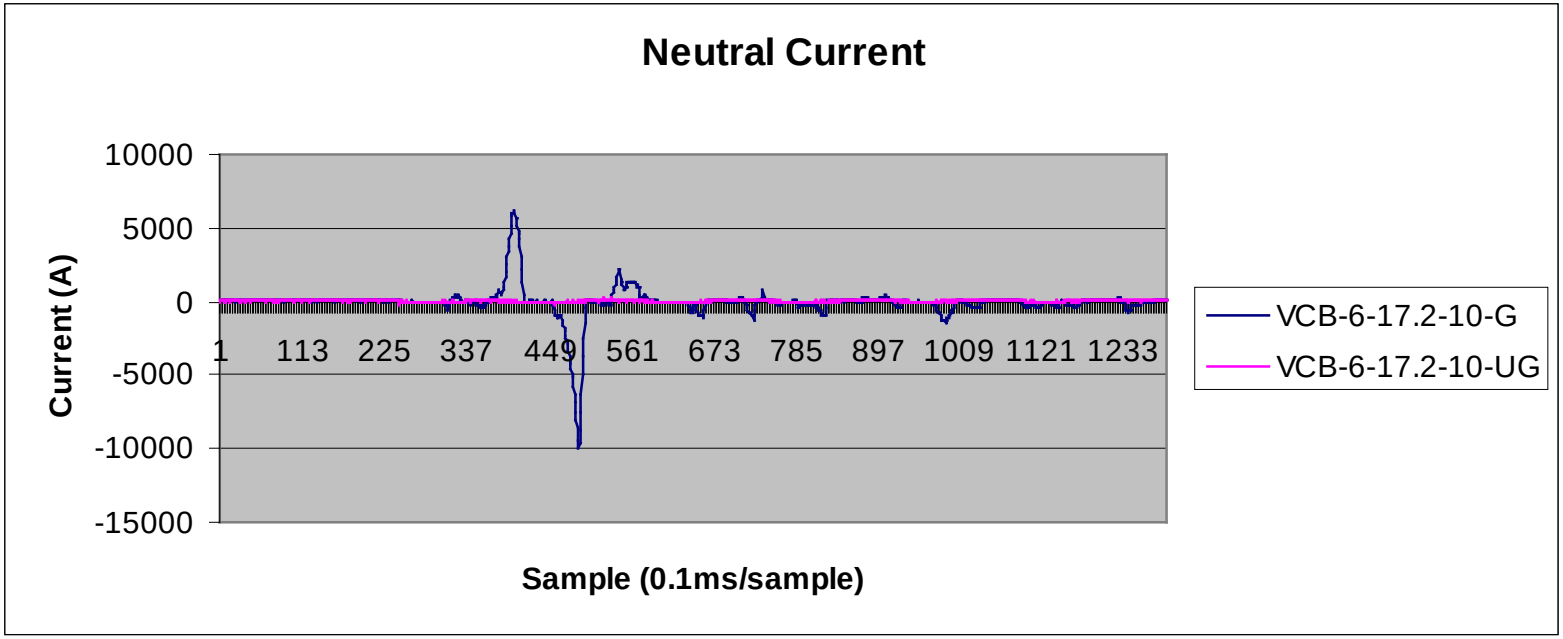
Data Measurement and Analysis

- Voltage and Current
  - Voltage and current are measured near the electrodes.
  - The sampling rate is between 10K and 20K samples per second.
  - Arc power and energy are calculated from V·I samples.



Data Measurement and Analysis

- Voltage and Current
  - Bonded or Un-bonded.



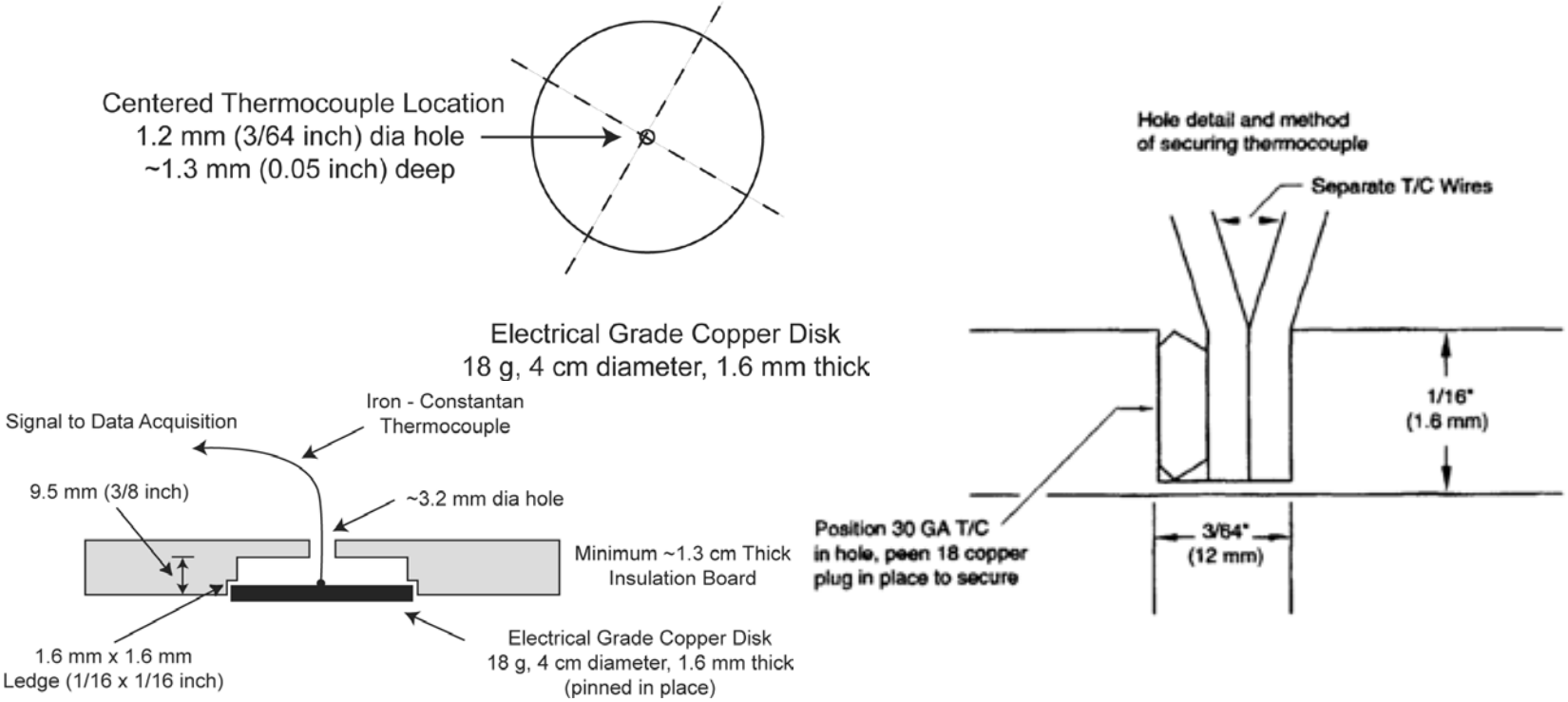
Data Measurement and Analysis

- Voltage and Current
  - Arc Power, MW (480V Testing)

	Ibf kA	3Ph, VCB	3Ph, HCB, HOA	3Ph, VOA	1Ph, VFC	3Ph ~Psc
Lower Bolted-Fault Currents						
Kinectrics	5.9 – 6.3	1.7 – 2.0			0.4 – 0.6	4.9
Ferraz	5.2	1.3 – 1.5	1.8 – 1.9			4.3
KEMA	5.0 – 5.1	2.0	1.8 – 1.9		0.4 – 0.5	4.2
Higher Bolted-Fault Currents						
Kinectrics	17.2 – 17.6	4.0 – 4.8	4.4 – 5.4	5.1 – 5.6	1.8	14.3
Ferraz	19.8 – 20.1	5.2 – 6.4	6.9			16.6
KEMA	20.6 – 21.7	3.6 – 6.9	4.8 – 7.3	4.9 – 6.7	2.6	17.1

Data Measurement and Analysis

- Incident Energy
  - ASTM 1959 Slug Calorimeters.

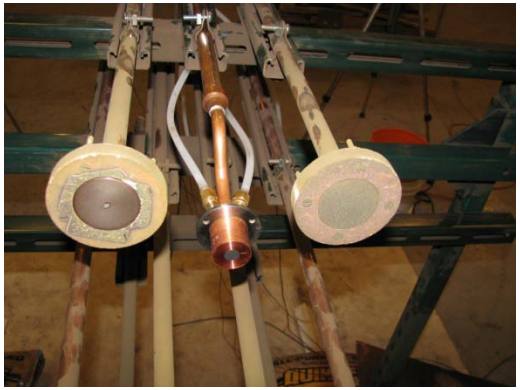


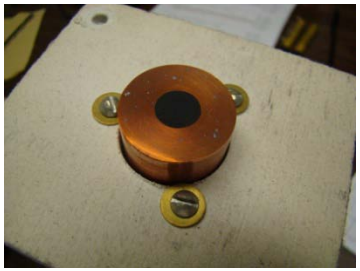
Data Measurement and Analysis

- Incident Energy
  - ASTM 1959 Slug Calorimeters.

Data Measurement and Analysis

- Incident Energy
  - Gardon Gauge Calorimeters.



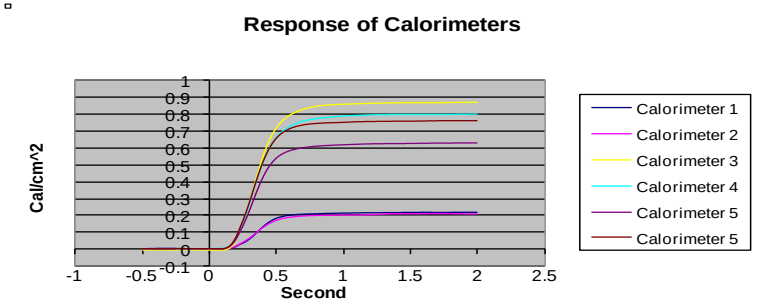


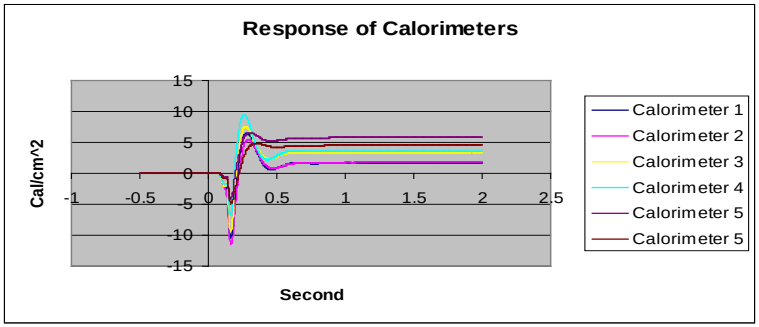
Data Measurement and Analysis

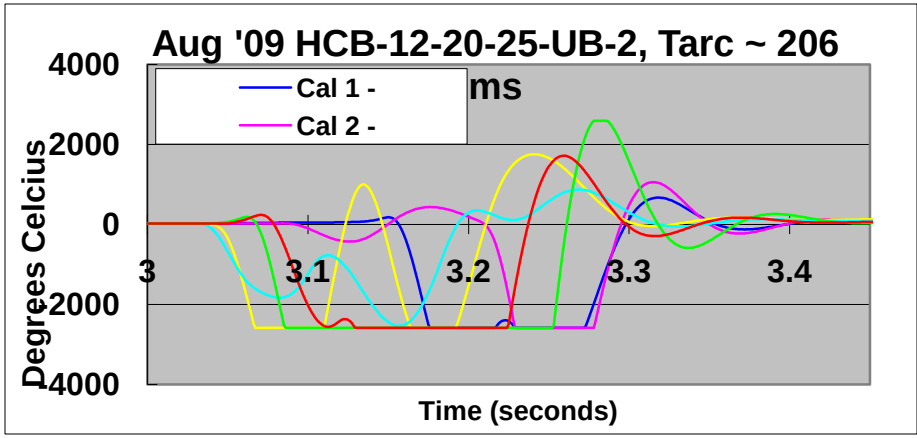
- Incident Energy
  - Different size of thermocouples.

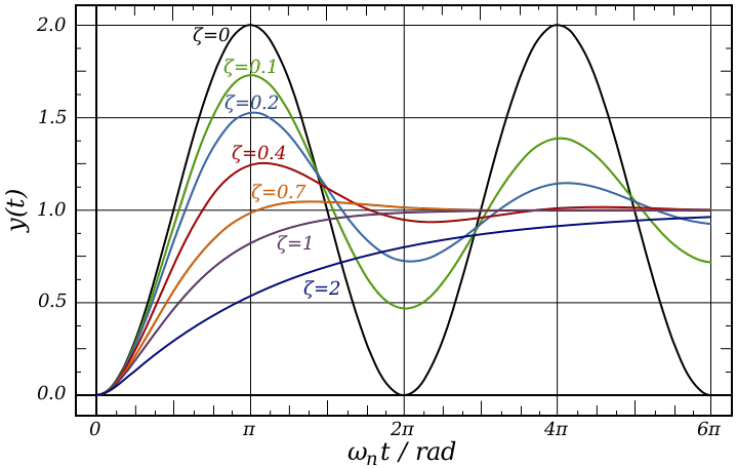
Data Measurement and Analysis

- Transient Response of Heat Measurement



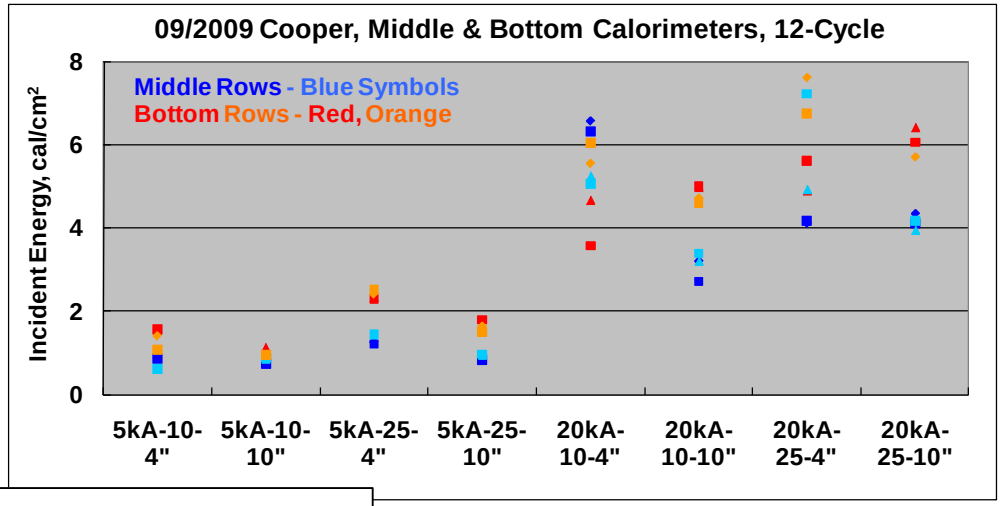


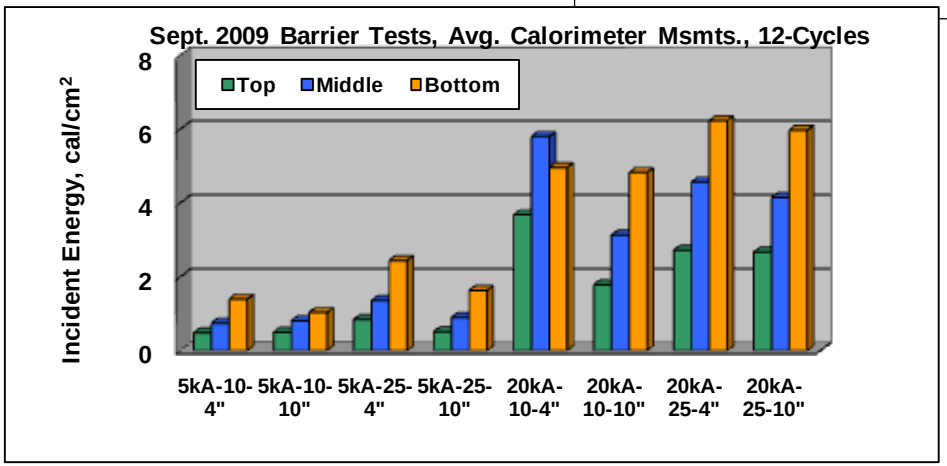




Data Measurement and Analysis

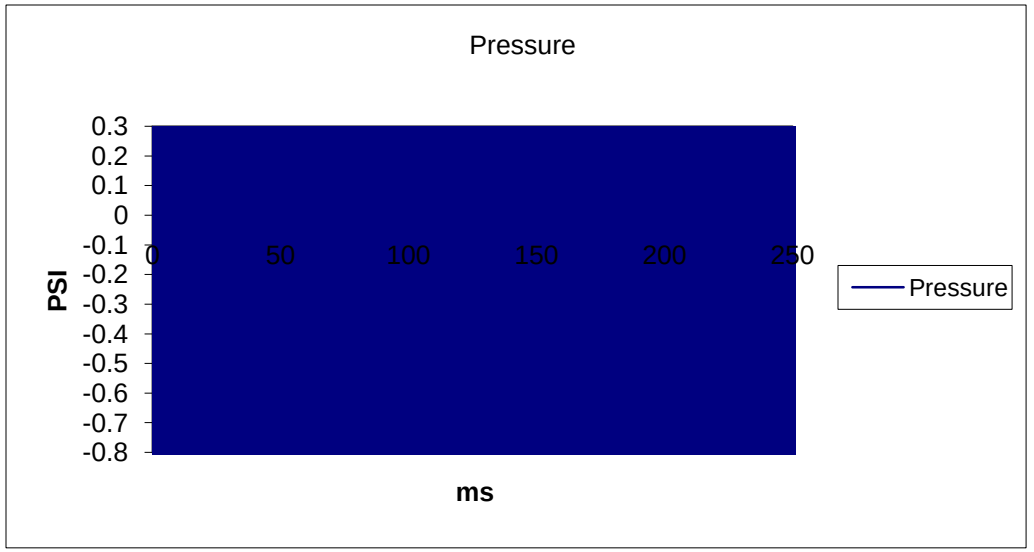
- Incident Energy
  - Cooper Barrier Test.





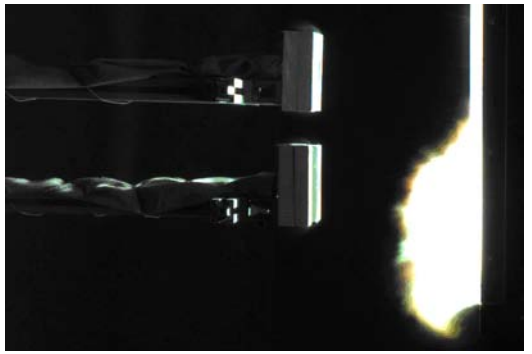
Data Measurement and Analysis

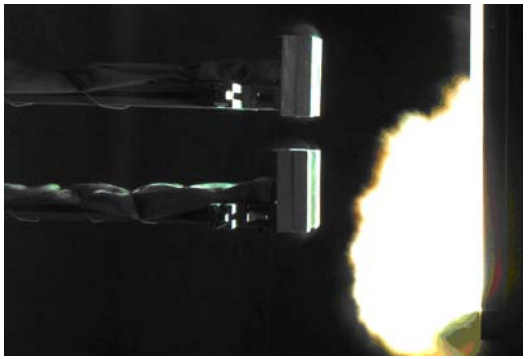
- Pressure Measurement
  - Pressure Transducer (100” from arc flash)



Data Measurement and Analysis

- Pressure Measurement
  - Consecutive frames of high speed video
    - Frame-by-frame of 1000 fps, video recording (VCB-12cyc-20kA-25mm)
    - Hot air moves around 3” to 4” between 2 consecutive frames
      - Wind Speed = 170 ~ 227 miles/hr
      - Pressure = 74~132 psf = 0.5~0.9 psi*
      - Person facing incoming force will receive 110 ~ 200 lbs force at the initial blast (impact on 1ft. x 1.5 ft.).
      - Due to the air temperature and its contents, the actual pressure may be different.



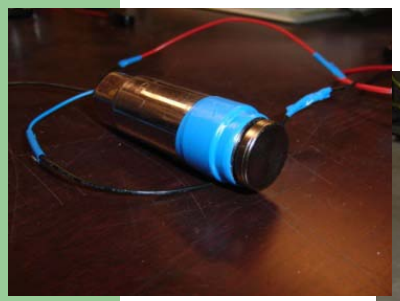


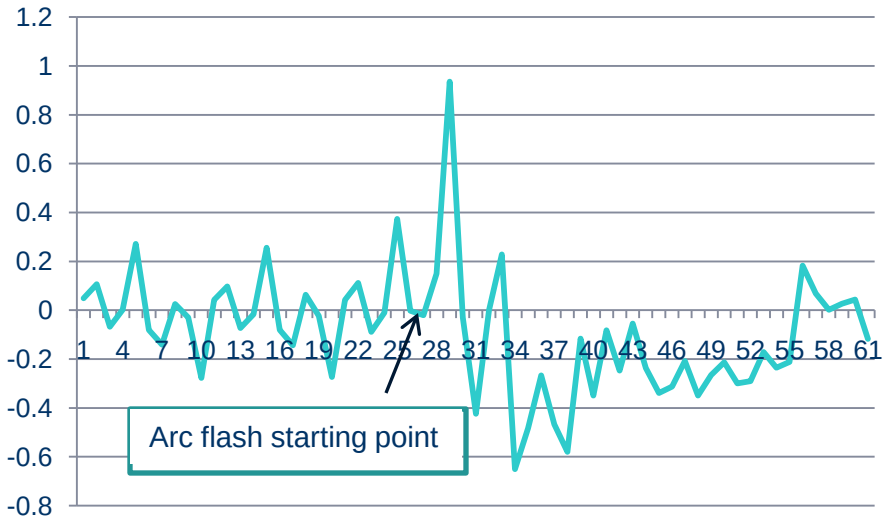
Data Measurement and Analysis

- Pressure Measurement
  - Pendulum (VCB-12-20-25)
    - Preliminary analysis reveals that average pressure is around 0.6 to 0.8 psi.

Data Measurement and Analysis

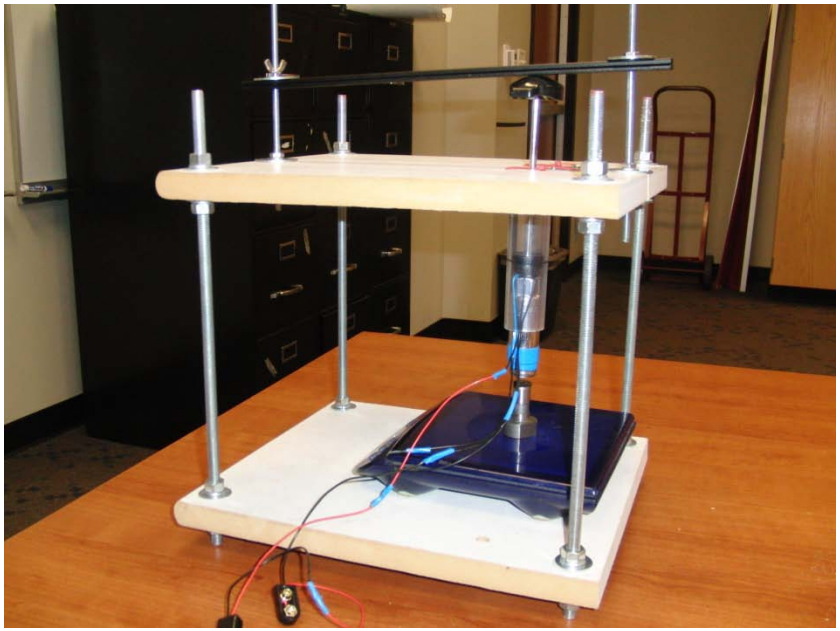
- Pressure Measurement
  - Pressure Transducer (Honeywell 19C030PG2K)
    - Preliminary analysis reveals that peak pressure may reach 0.93 psi (VCB-12-20-12.5-27). This is similar to the previous estimation.
    - Need more tests





Data Measurement and Analysis

- Pressure Measurement
  - Pressure Transducer (Honeywell 19C030PG2K)
    - A testbed is built to check the output of the pressure sensor.



Data Measurement and Analysis

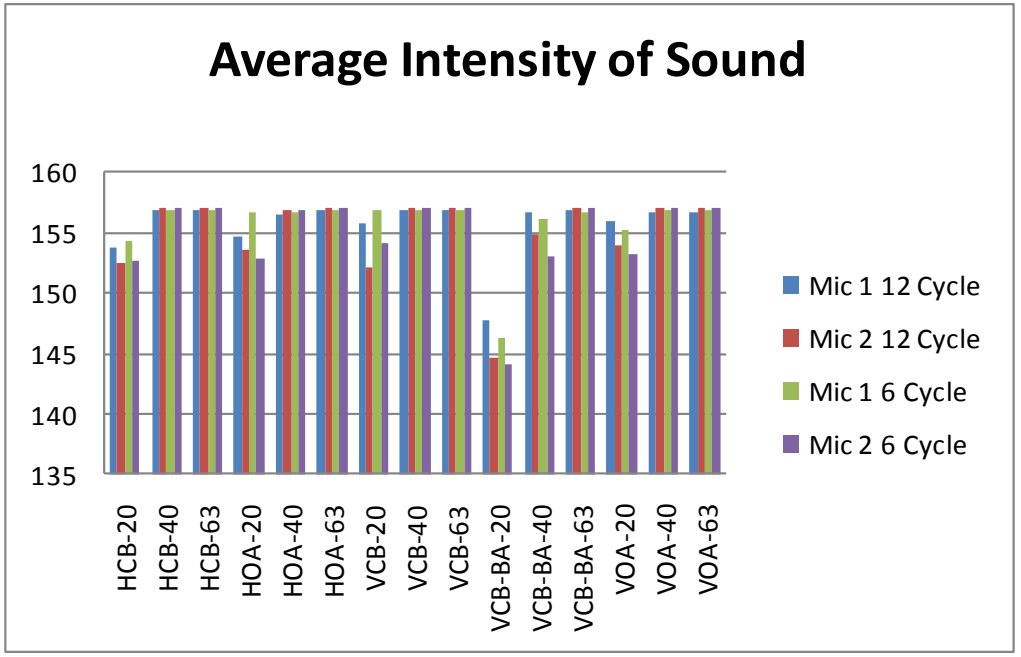
- Sound Level Measurement
  - Different sound level measurement devices are used in different tests.
  - The measurement complies with ANSI S1.4.
  - Since the whole event is less than 200ms, Weighted C peak (50 μs) is recorded
  - Sound levels are affected by:
    - Size and shape of testing labs.
    - The magnitude of short circuit current.
  - Correlation between sound level and arc duration is small.

Data Measurement and Analysis

- Sound Level Measurement
  - According to OSHA, exposure to impulsive or impact noise should not exceed 140 dB peak sound pressure level. At 115 dB, OSHA's permissible noise exposure is 15 minutes or less daily. (OSHA Table G-16)
  - Initial measurements indicate that hearing protection is recommended for protection against impulsive noise.

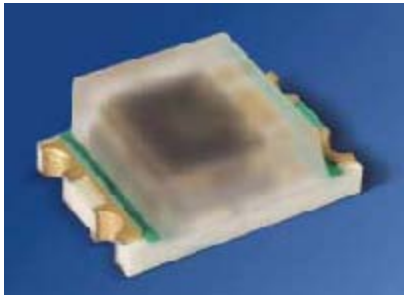
Data Measurement and Analysis

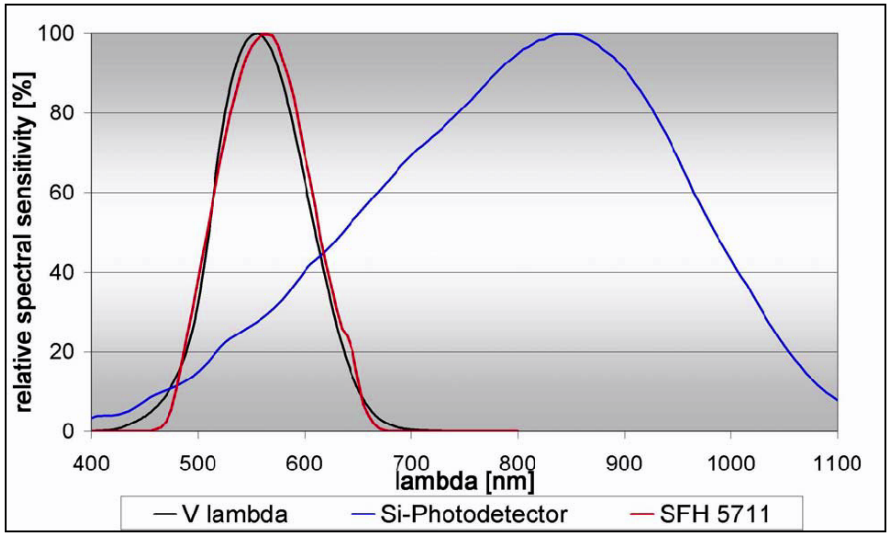
- Sound Level Measurement
  - 4160V arc flash test results (2 meters and 3 meters from the arc flash)



Data Measurement and Analysis

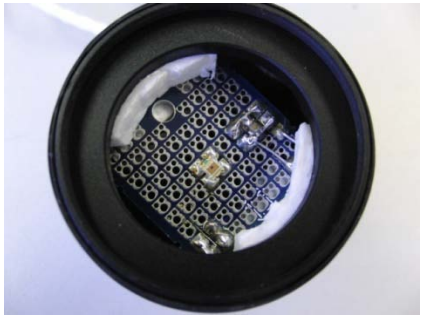
- Luminance (Light) Measurement
  - SFH 5711 High Accuracy Ambient Light Sensor is used for light level measurement.
  - This device is designed to match human eye sensitivity (Vλ).





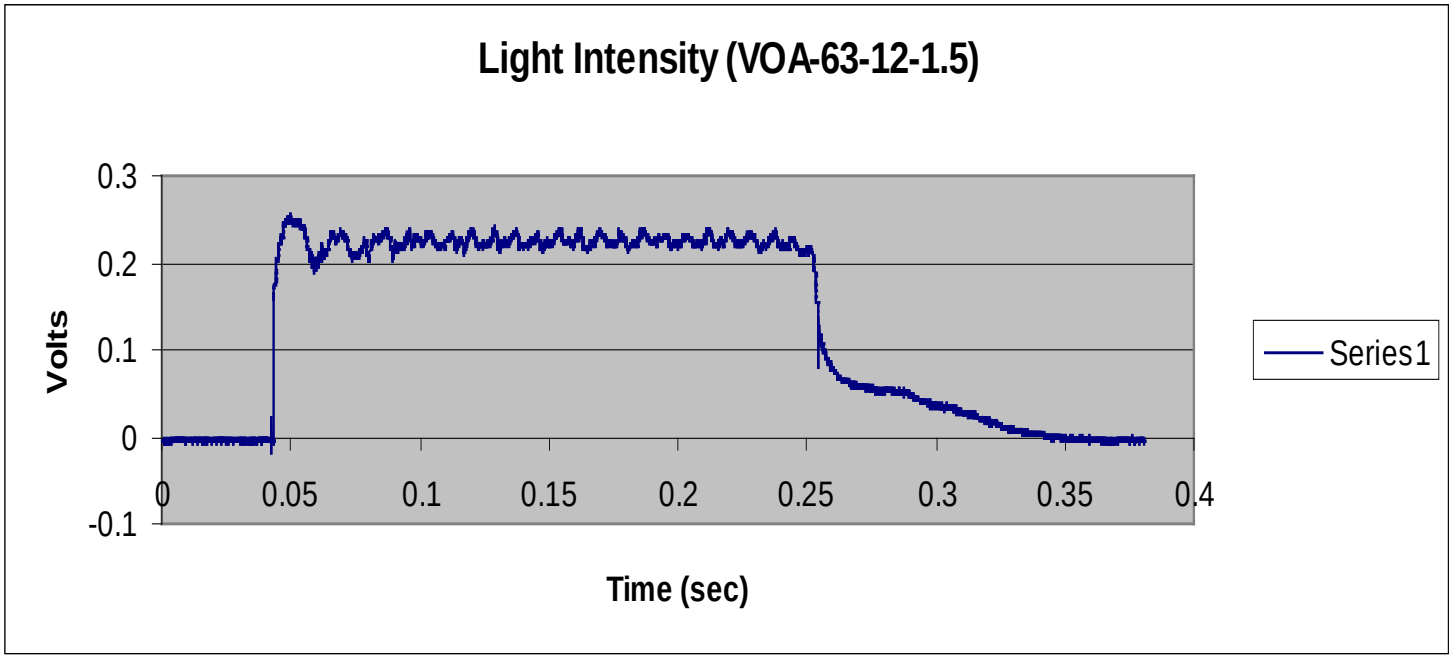
Data Measurement and Analysis

- Luminance (Light) Measurement
  - Neutral density filters are used to attenuate the light intensity.



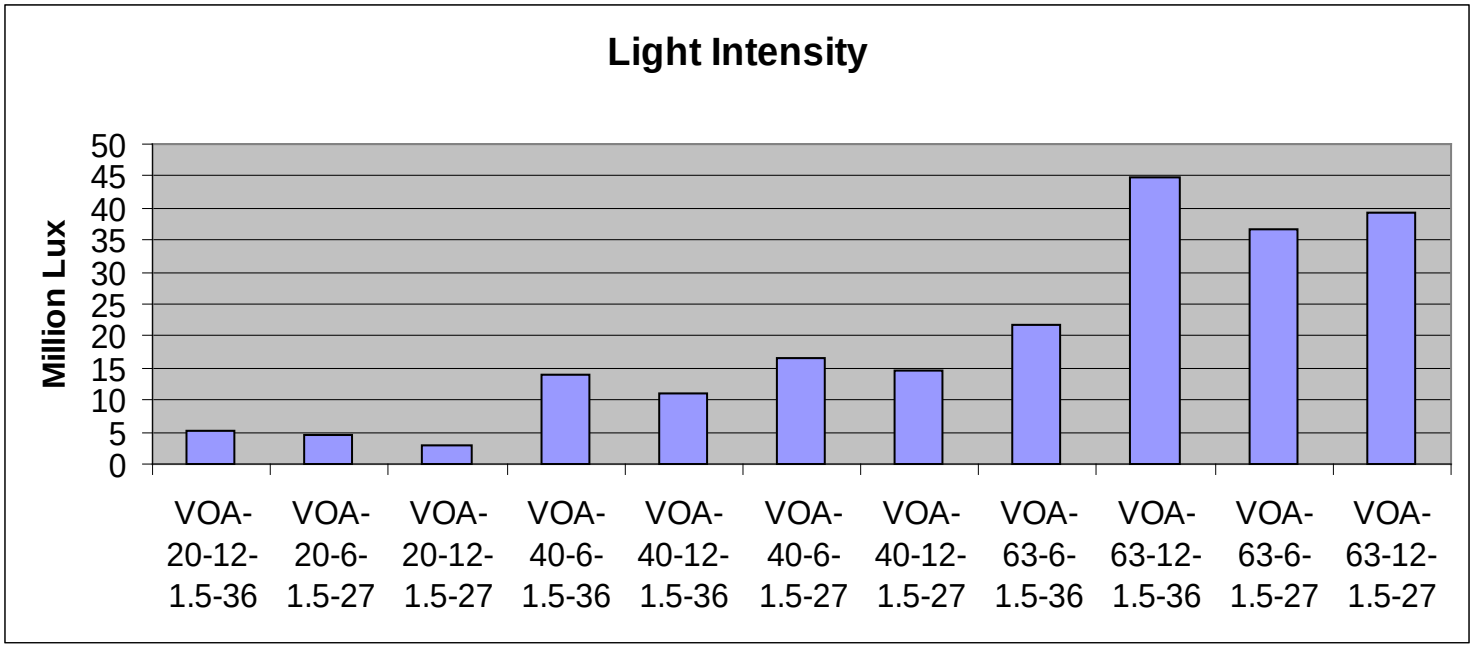
Data Measurement and Analysis

- Luminance (Light) Measurement
  - Response of the light sensor.



Data Measurement and Analysis

- Luminance (Light) Measurement
  - Luminance level. (A bright summer day will have a midday ground level illumination in the order of 100,000 lux)



Video Recording and Data Acquisition System

- Video Recording System
  - Some laboratories offer high speed video recording system.
  - Video provides valuable information for the research team to observe the arc flash activities.
  - Research team has also acquired Casio F1 high speed video camera to observe other arc flash phenomena.

Recording and Data Acquisition System

- Video Recording System
  - We are able to record the arc flash up to 1200FPS.

Recording and Data Acquisition System

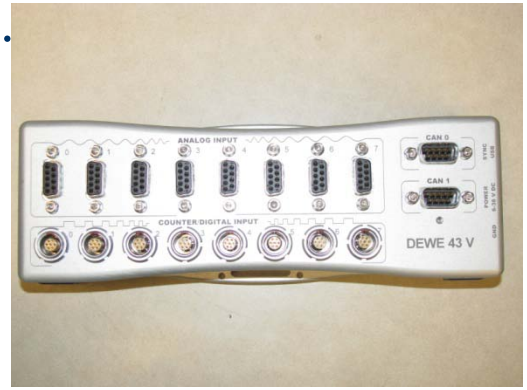
- Video Recording System
  - IR filter is used to observe the arc flash behind the smoke.

Recording and Data Acquisition System

- Data Acquisition System
  - Some laboratories have data acquisition system for voltage, current, slug calorimeters, light, and pressure measurement and data recording.
  - In some case, the laboratory can only provide the recording equipment for voltage and current.
  - Research team has designed and built data acquisition system for heat flux, pressure, and light measurements.

Recording and Data Acquisition System

- Data Acquisition System
  - Current DAQ has the following set-up and capabilities:
    - Two Dewetron - DEWE 43V.
    - 8 analog inputs per module.
    - 204.8K samples/second simultaneous sampling.
    - USB extender is used to extend USB signal transfer up to 300 feet through Cat 5 cable.



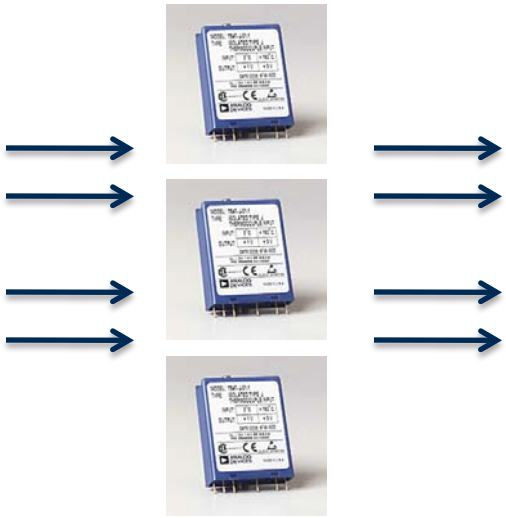
Recording and Data Acquisition System

- Data Acquisition System
  - Unfortunately, the system was damaged during January 2011 testing at Cooper Bussmann lab.
  - While trying to fix the system, research team is building second DAQ system using cRio from National Instruments.
  - The unit is IP addressable. It can communicate with host computer through internet or direct Cat 5 crossover cable.

Recording and Data Acquisition System

- Data Acquisition System
  - Configuration of new DAQ system.

Slug calorimeters and Pressure sensors



Analog Devices 7B-47-K

Cat. 5 Connection

NI cRio:
16 Differential AI
16 TTL Compatible DI/O

Complication on Data Analysis

- Arc Flash on Back of Box

Complication on Data Analysis

0.0 sec

0.00417 sec

0.00583 sec

0.1675 sec

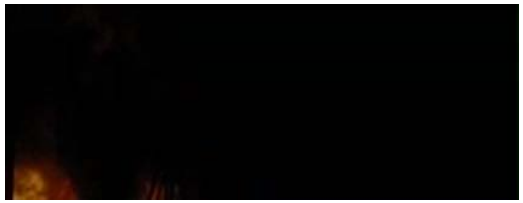
0.1717 sec

0.1783 sec

0.1858 sec

0.2058 sec

0.2108 sec



0.2117 sec

Complication on Data Analysis

- Other event: Arc Flash on Top of Box

Complication on Data Analysis

- Arc flash happens at different location

Complication on Data Analysis

- Equipment damage

Conclusion and Discussion

- In addition to heat flux, research team is exploring other arc flash related hazards.
- Research team adjusts/re-designs testing set-up continuously to obtain critical information for model verification and development.
- The results of this collaborative project will provide information to improve electrical safety standards, predict the hazards associated with arc flash, and provide practical safeguards for employees in the workplace.

Conclusion and Discussion

- The Arc Flash Project is one of the most important projects that has been carried out by IEEE and NFPA. The results will affect the safety of lives.

Acknowledgement

- Platinum
  - Underwriters Laboratories
  - Bruce Power
  - Cooper Bussmann
  - Ferraz Shawmut
  - Square D/Schneider Electric
  - Eaton
- Gold
  - Hydro One
  - Procter & Gamble, Inc
- Silver
  - Inter-National Electrical Testing Association
  - Duke Energy Foundation
  - Salisbury
  - NFPA
  - Arc Wear
  - Cadick Corporation
  - e-Hazard
  - DCM Electrical Consulting Services
  - SKM System Analysis, Inc.
  - McSquared Electrical Consulting, LLC
  - Powell Electric