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Time Delay from Corona to Breakdown

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Time Delay from Corona to Breakdown

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Abstract

This report describes measurements of the time delay between the onset of corona and complete electrical breakdown between a point and a plane in dry air near atmospheric pressure as a function of the distance between the point and the plane. The large variation in these time delays is representative of the stochastic nature of electrical breakdown and the many possible phenomena that occur between the initiation and completion of electrical breakdown, including initiation without complete electrical breakdown. The purpose of this work is to provide data which will be accurately modeled when a model contains the appropriate mechanisms with the proper priorities to describe this fundamental electrical breakdown configuration.

The acquisition of these measurements completes a level three milestone for the WSEAT program which sponsors this research. Also included in this report is a description of our plans to "automate" the experimental procedure, protect the high sensitivity fast-gated camera, and add diagnostics and new experimental techniques to the test facility. This will provide measurements of the time delay distributions with improved statistics and additional experimental information about the processes that occur during electrical breakdown.

ACKNOWLEDGMENTS

These results were recorded using an experimental facility designed and initiated by Jane Lehr (now at the Department of Electrical Engineering and Computer Science, University of New Mexico, Albuquerque, NM) to measure fundamental electrical breakdown phenomena in gases near atmospheric pressure. We would like to acknowledge her invaluable wisdom and experience in planning and starting this unique facility to record the properties of electrical breakdown which will provide a better foundation for modeling and predicting these phenomena these phenomena.

We also would like to acknowledge the assistance of Raymond J. Martinez and Mark A. Winet (with Leidos, formerly SAIC), who recently joined this group and will be contributing to many of the plans listed at the end of this report.

CONTENTS

FIGURES

NOMENCLATURE

CCD	charged couple device – a semiconductor digital camera
corona	the ionization of a fluid or gas produced by an applied electric field
CVT	current viewing transformer to monitor current
CVT	current viewing resistor to monitor current
D-dot	electric field time derivative monitor
LDRD	Laboratory Directed Research and Development – internal R&D

1. INTRODUCTION

The properties of electrical breakdown have been recorded for hundreds of years [1-4]. Yet predictive models only yield accurate results for extremely simplified and specific situations. Electrical breakdown, in real world situations with complicated configurations and complex materials, is not accurately modeled. Testing is the most reliable way to estimate the probability of an electrical breakdown. However, testing of every configuration for all types of materials with enough measurements to provide statistically accurate predictions is not practical. Models of electrical breakdown phenomena need to be broadened and improved to provide accurate estimates of the probably of electrical breakdown for systems that need to avoid electrical breakdown (explosives, high voltage power systems, high voltage electronics, expensive electronics in high field environments, …) and systems that need to induce electrical breakdown (circuit breakers, surge protectors, lightening arrestors, gas gap switches, avalanche semiconductor switches, …).

Electrical breakdown properties have a large range of variation because many particles are involved with many possible mechanisms, which can lead to breakdown. A lot of progress has been made with simple geometries where one breakdown mechanism dominates, such as pulsed electrical breakdown where the applied field is significantly higher than the breakdown strength of the material. These situations generally lead to uniform avalanche charge carrier multiplication, often called "Townsend" discharge, named for a scientist who studied electrical breakdown in the late 1800s [1]. A more difficult, but still very simplified situation is when a simple geometry is used, but the applied field is raised slowly to the nominal electrical breakdown strength, and many possible channels and mechanisms to breakdown are allowed to proceed. The problem with taking measurements in this regime is that there is a very large variation in the time between the onset of ionization (corona) [2] and the complete breakdown arc.

This project is considering the simple point-plane configuration in dry air at near atmospheric pressure, because it is simplified, yet commonly encountered with high voltage electronics and systems that need lightning protection. We are trying to obtain more information about the many channels and many mechanisms to electrical breakdown, increasing the voltage slowly across the point-plane gap until it is high enough to initiate electrical breakdown after a significant delay, so that many mechanisms have time to form. This report serves to document a level 3 milestone for the WSEAT program by describing the measurements we have made and analyzing the distributions that we have observed by analyzing the time variation between the onset of corona and complete electrical breakdown.

2. EXPERIMENTAL FACILITY

The measurements, described in this report, were obtained with a high voltage test apparatus called the Larsson Long Pulse electrical breakdown chamber [3]. Figures 1 and 2 show the apparatus with electrical diagnostics and an adjustable “point-plane gap”, where electrical breakdown is initiated.

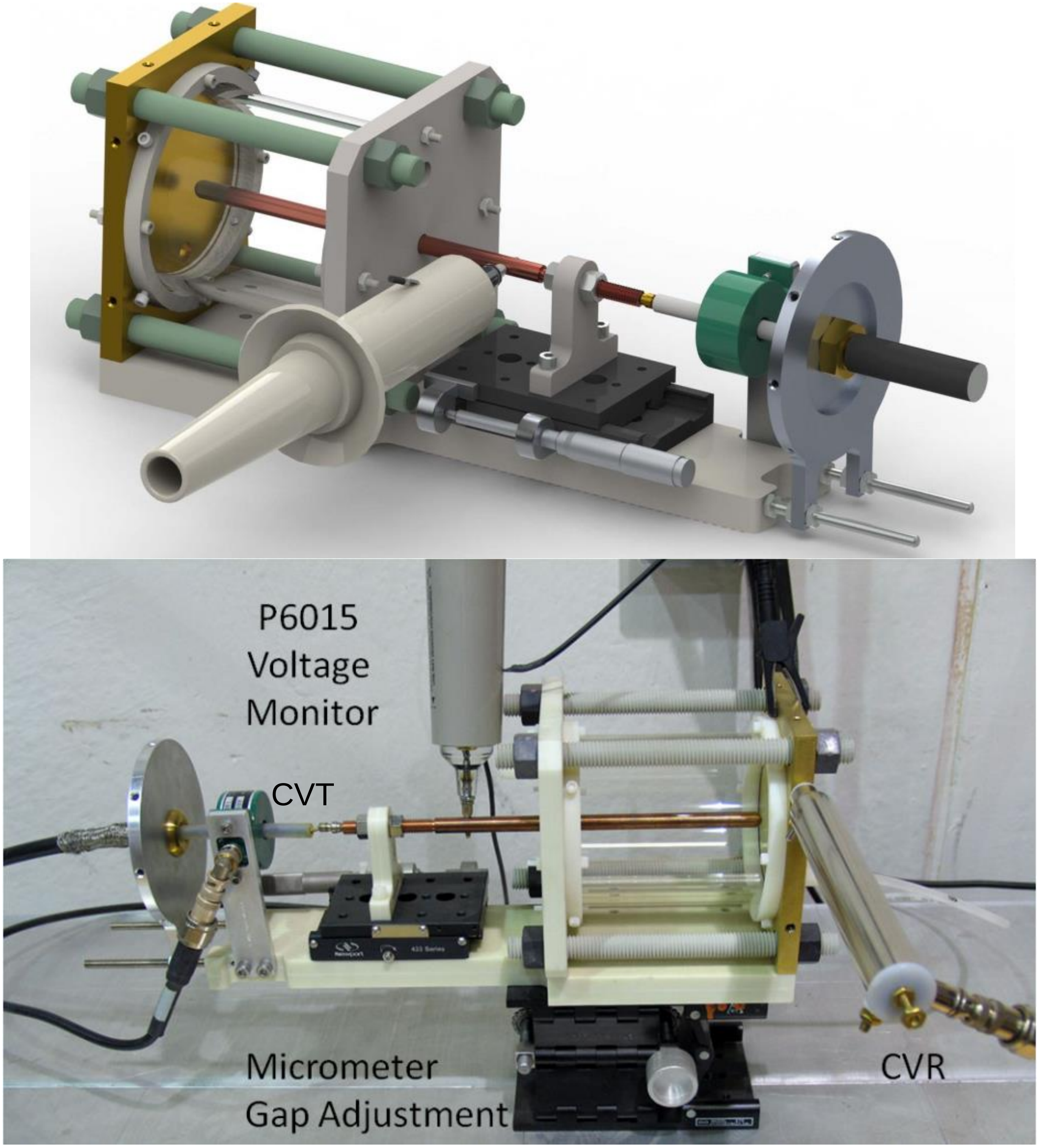


Figure 1. The Lorentz Long Pulse test chamber is shown in the two photographs above. Diagnostics include current monitors, a current viewing resistor and a current viewing transformer (CVR and CVT), and a resistive high voltage monitor.

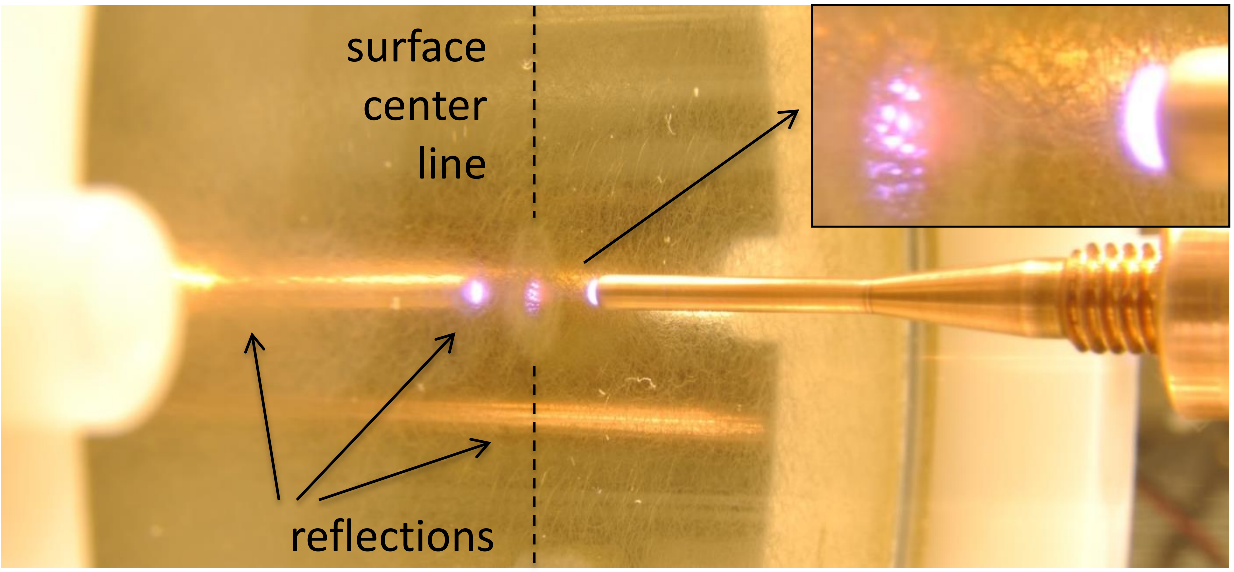


Figure 2. An enlargement of the "point-plane" configuration shows where the breakdown is initiated. The point is actually a 1.5 mm diameter hemispherical tip of a copper rod and the plane is a brass surface which in this photograph reflects the image of the tip.

The chamber surrounding the point-plane gap can be pressurized. To measure breakdown properties that are common to most operating environments, it is filled with dry air and held very close to atmospheric pressure.

Present monitors (not all shown in the photographs) include**:**

1. An open-shutter high-resolution camera
2. A fast-framing (ns), intensified CCD camera
3. A high bandwidth (5 GHz) current viewing resistor (CVR)
4. A current viewing transformer (CVT)
5. A high voltage (20 kV) resistive probe (40 MHz bandwidth)
6. A high bandwidth (20 GHz) D-dot that records the derivative of the electric field
7. A high bandwidth (3 GHz) photo-diode (PD) or a sensitive photomultiplier tube (PMT)

The CVR and the photodiode can be used to trigger the onset of Corona at low currents or low light emission levels. The waveforms from these sensors are record a 1 s/div, 1 μs/div, and 100 ns /div so the delay time from the onset of corona to complete breakdown can be measured accurately over 10 orders of magnitude in time range. The open shutter camera records an image of the entire event, often dominated by the high intensity arc. The fast-framing, intensified charged coupled device (CCD), is triggered with the onset of corona and remains open for a preset short time interval. To protect the high sensitivity, intensified CCD from too much light, the time interval is supposed to be set to end before the breakdown arc occurs. As the measurements will show, this time delay has so much variation that it is impossible to record complete images of the initiation of breakdown without frequently recording the breakdown arc. To solve this problem, we are developing a low latency trigger system that will trigger the intensifier on at a low current threshold and off at a high current threshold. This should protect the intensifier and allow us to capture images of the entire pre-breakdown regime.

3. MEASUREMENTS

Typical measurements from the voltage, current, and photo-multiplier tube sensors during a breakdown event are shown in figure 3. During the tests, the voltage is ramped up slowly (~ 2 kV/s) until the voltage reaches a preset value near the electrical breakdown strength of the point-plane gap (upper left plot). On a faster time scale, the first breakdown arc is detected with the current monitor (upper right plot). The high band width D-dot monitor records the derivative of the electrical field radiated during the corona onset (lower left plot), and the photo-multiplier tube records the optical emission (lower right plot). Multiple breakdown events can be seen on the longer time scale charging voltage plot (upper left plot), but only the first event is recorded in the other plots.

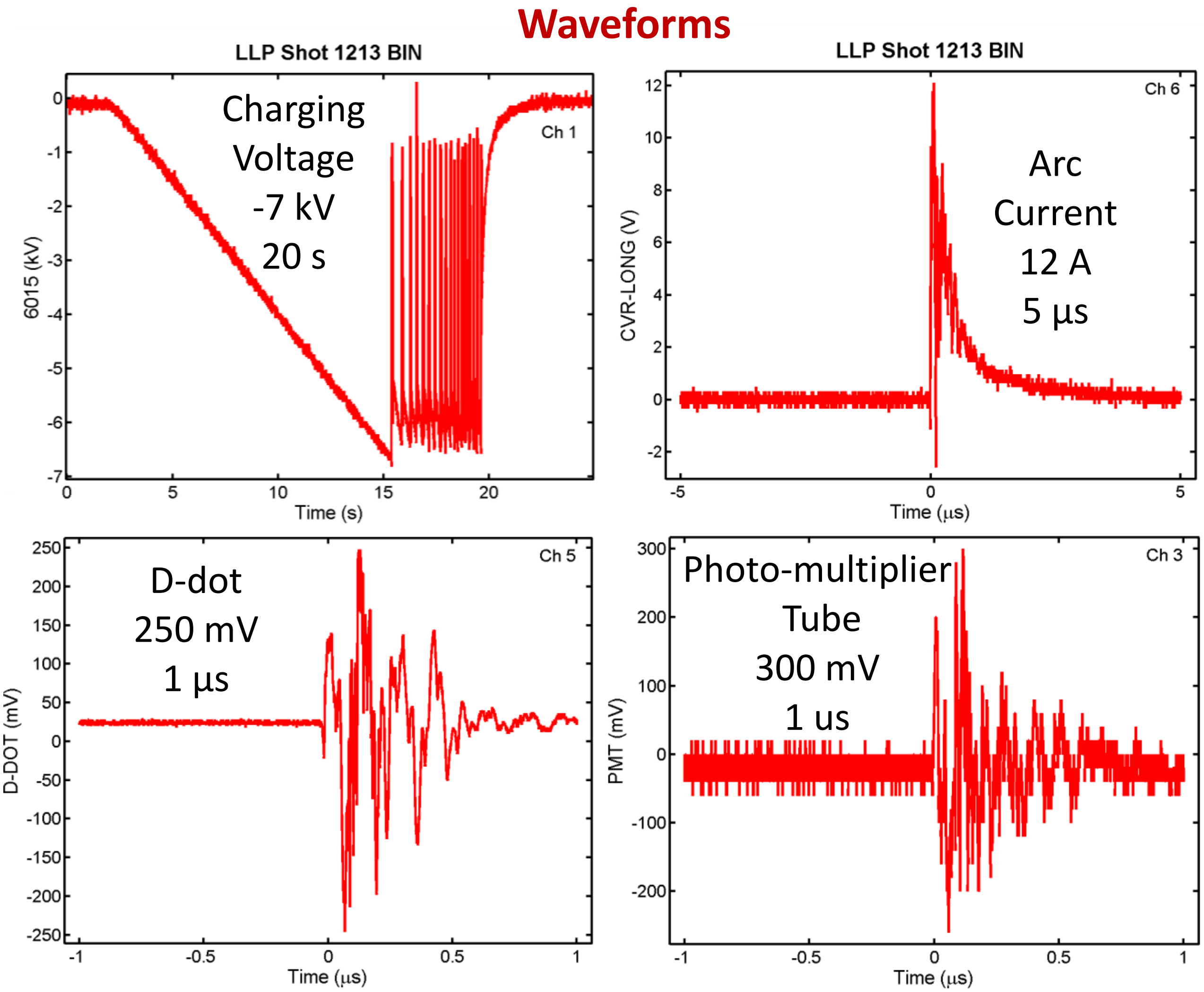


Figure 3. Examples of waveforms recorded during a typical breakdown event.

The combined waveforms in figure 4 show both the onset of low current corona (200 ma) and the high current breakdown arc (15A). In this case the time between the initiation of corona and the arc is only about 300 µs, so they can both be displayed on the same linear axis. However, the delay can be many seconds or not detected at all. Presumably breakdown would occur if enough time elapsed. In the case that the delay interval is larger than the scope time-scale of one scope, the trigger delay between the scopes must be taken into account.

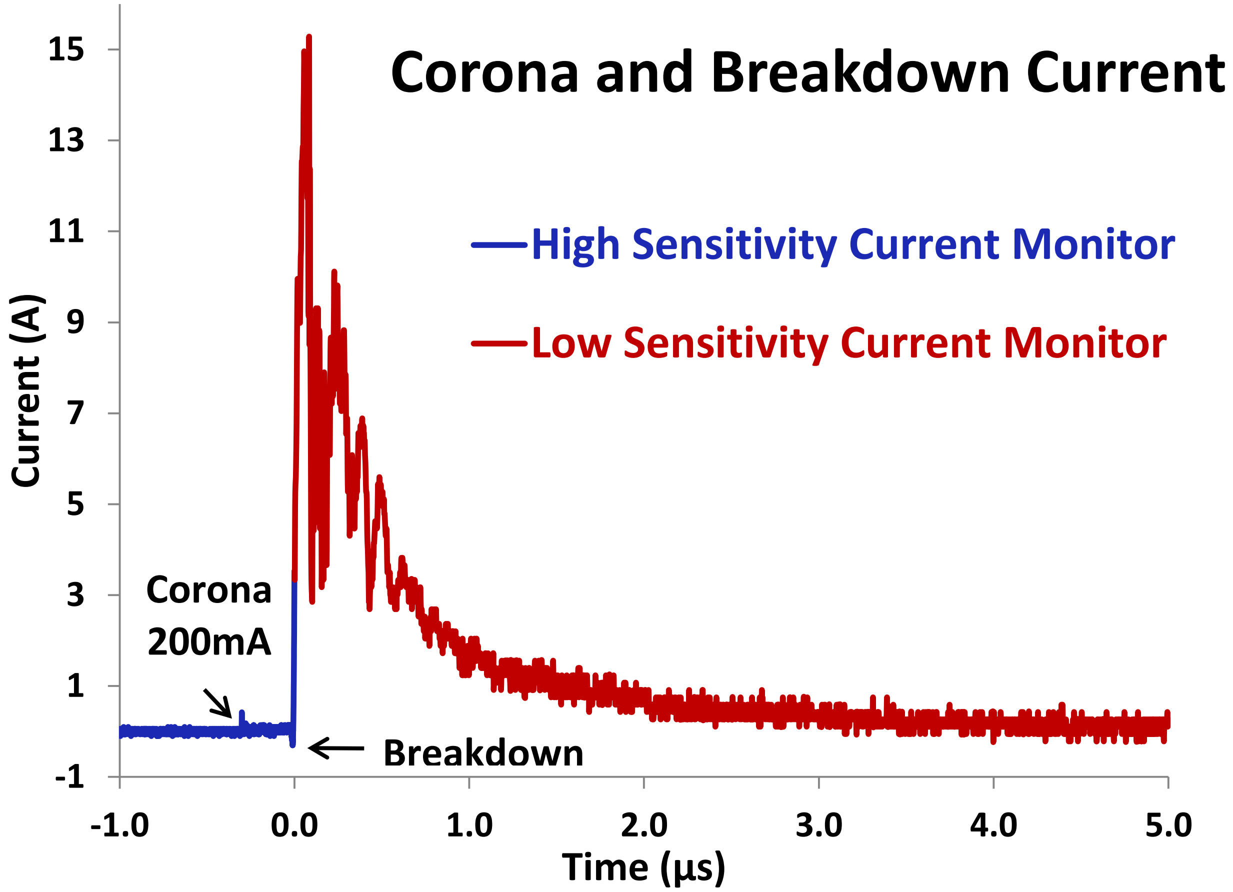
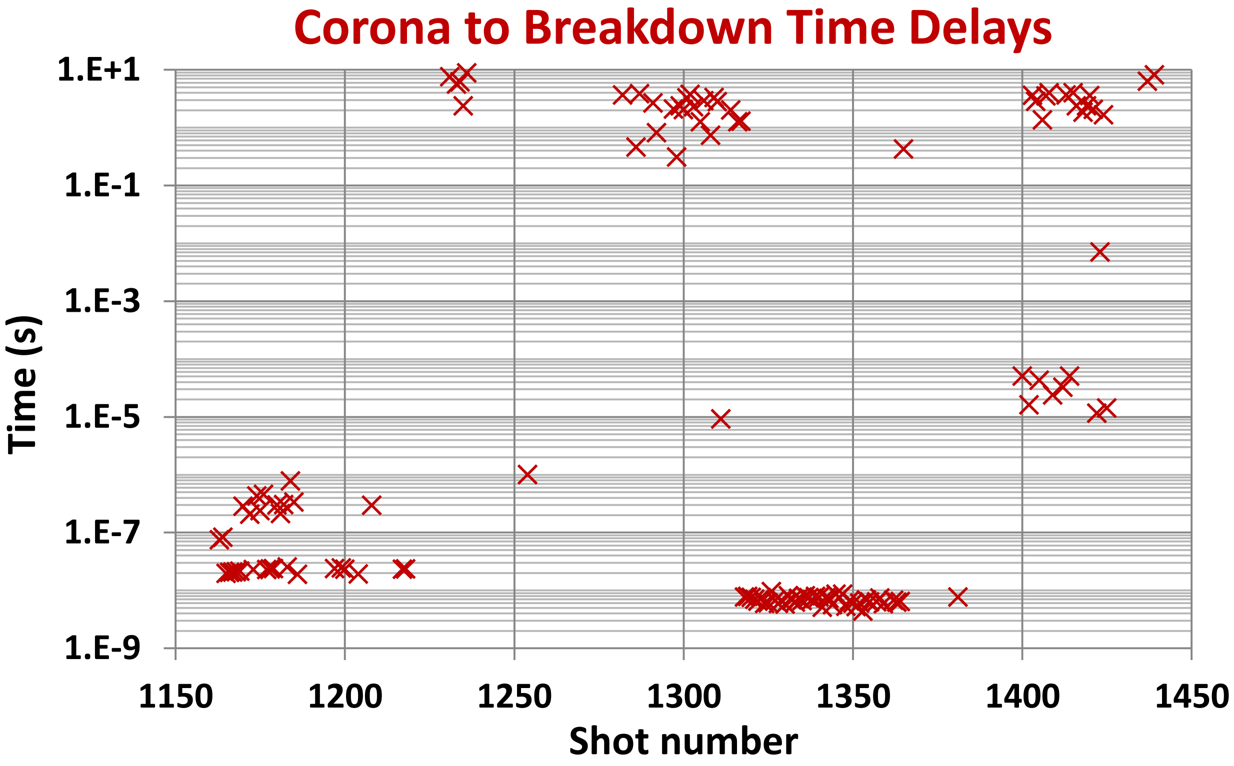


Figure 4. Both low current corona and high current breakdown are displayed in this combined waveform plot.

The time delay between the onset of corona and the breakdown arc was measured for several hundred events with a range of point-plane gaps and corresponding voltages. The results of these measurements are given in figure 5. The upper plot shows the time delays as recorded by shot number. The lower plot shows the distributions sorted by point-plane gap. Over ten orders of magnitude variation in this time delay are shown. The distributions by gap show an apparent trend for shorter delays with shorter gaps and correspondingly lower voltages.



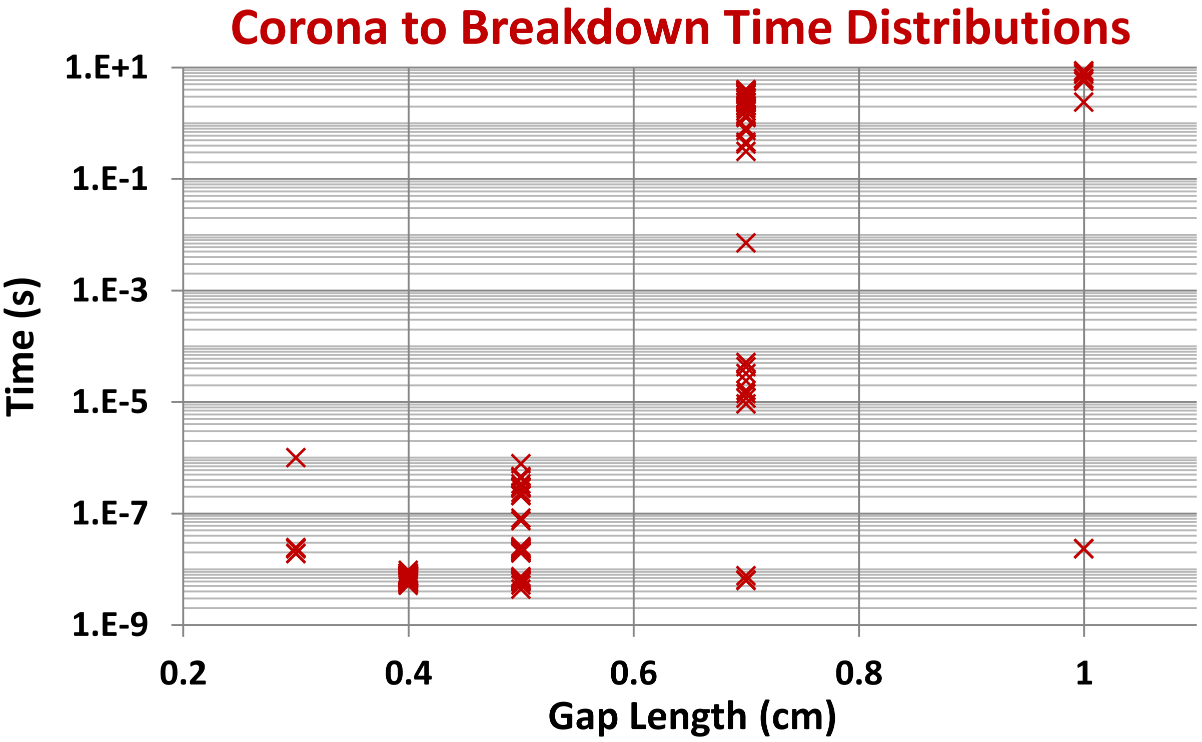


Figure 5. Time delays between the onset of corona and the breakdown arc are shown in these plots. The upper plot shows the data as recorded, the lower shows it sorted by point-plane gap.

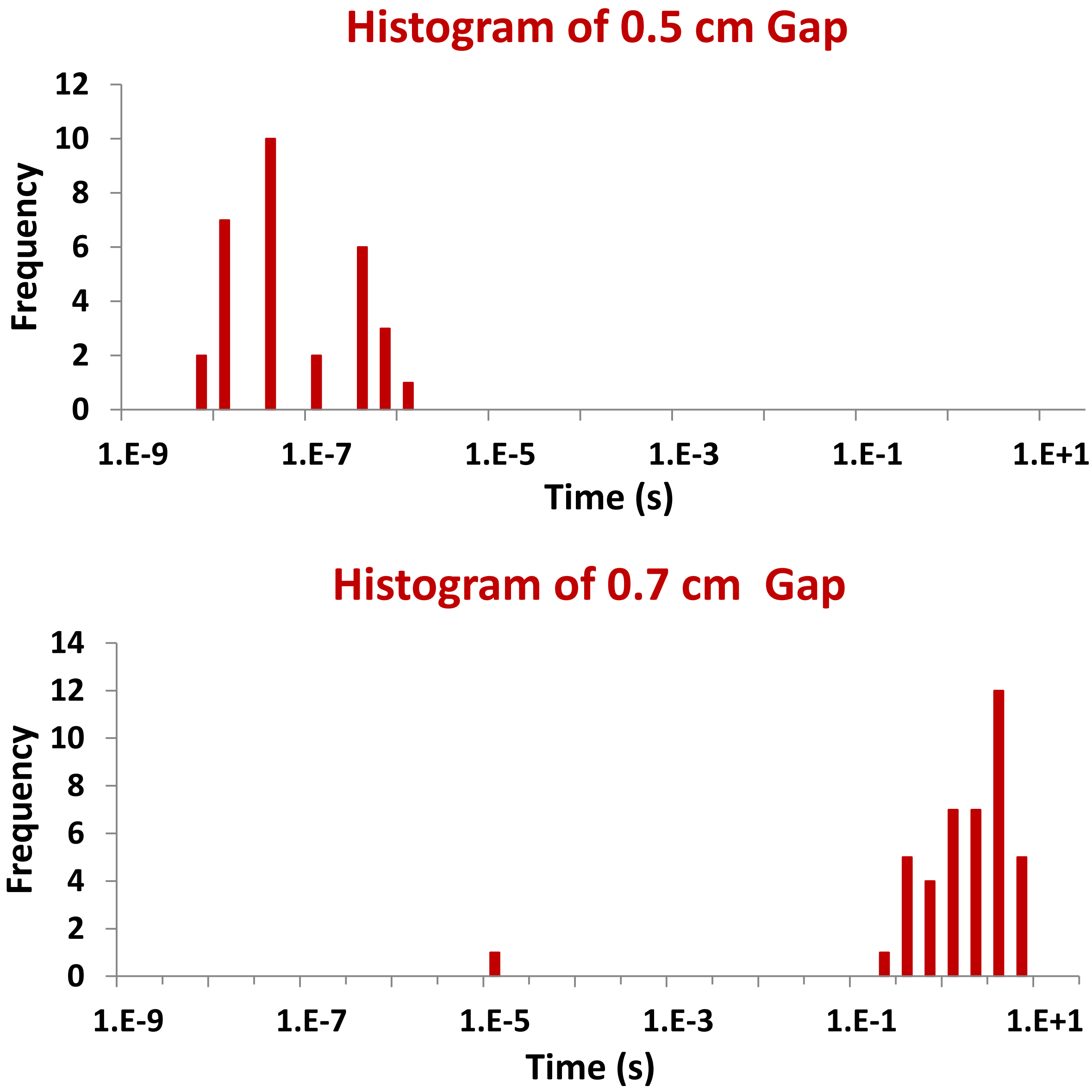


Figure 6. Time delay distributions for two gaps are shown in logarithmic histograms with four bins per decade.

Two of the distributions, for 0.5 and 0.7 cm gaps, are displayed as histograms in figure 6. These diagrams clearly show a shorter time delay distribution for the shorter gap. However, the extremely large variation in delays, and the choice of the maximum charge voltage may have produced this effect. A larger population of measurements and a more systematic approach to setting the maximum charge voltage for each gap are required to confirm this trend.

4. DISCUSSION OF RESULTS

The ten orders of magnitude variation in the time between the onset of corona and the breakdown arc is a very good indication of the number of microscopic mechanisms or channels that can lead to electrical breakdown and the number of particles involved with random selection of the physical phenomena participating in each step of the process. Modeling a stochastic process with a large number of physical mechanisms requires the identification of the most significant mechanisms and determination of their statistical priority in the process. Other indications of the wide variety of phenomena are seen in the images of electrical break down in the following figures.

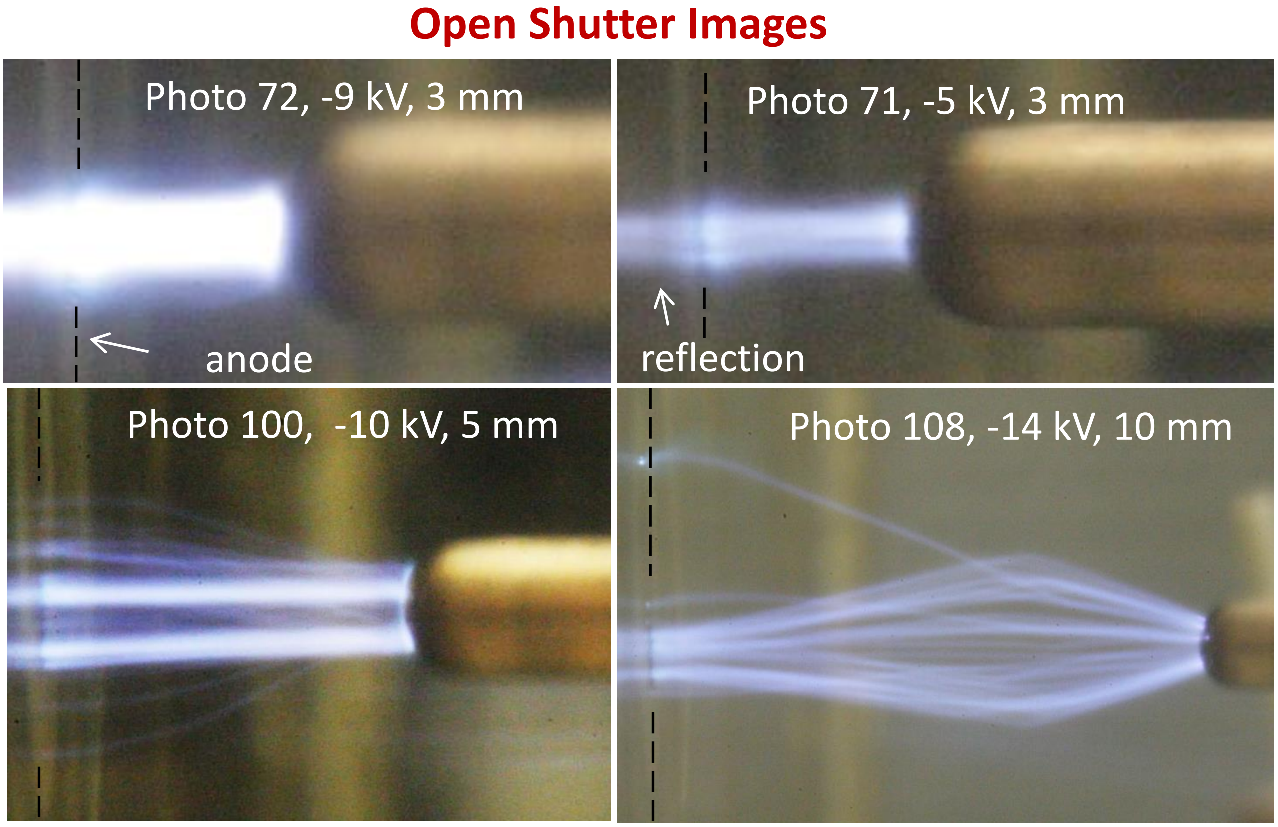


Figure 7. Enlarged images of the light emission during electrical breakdown.

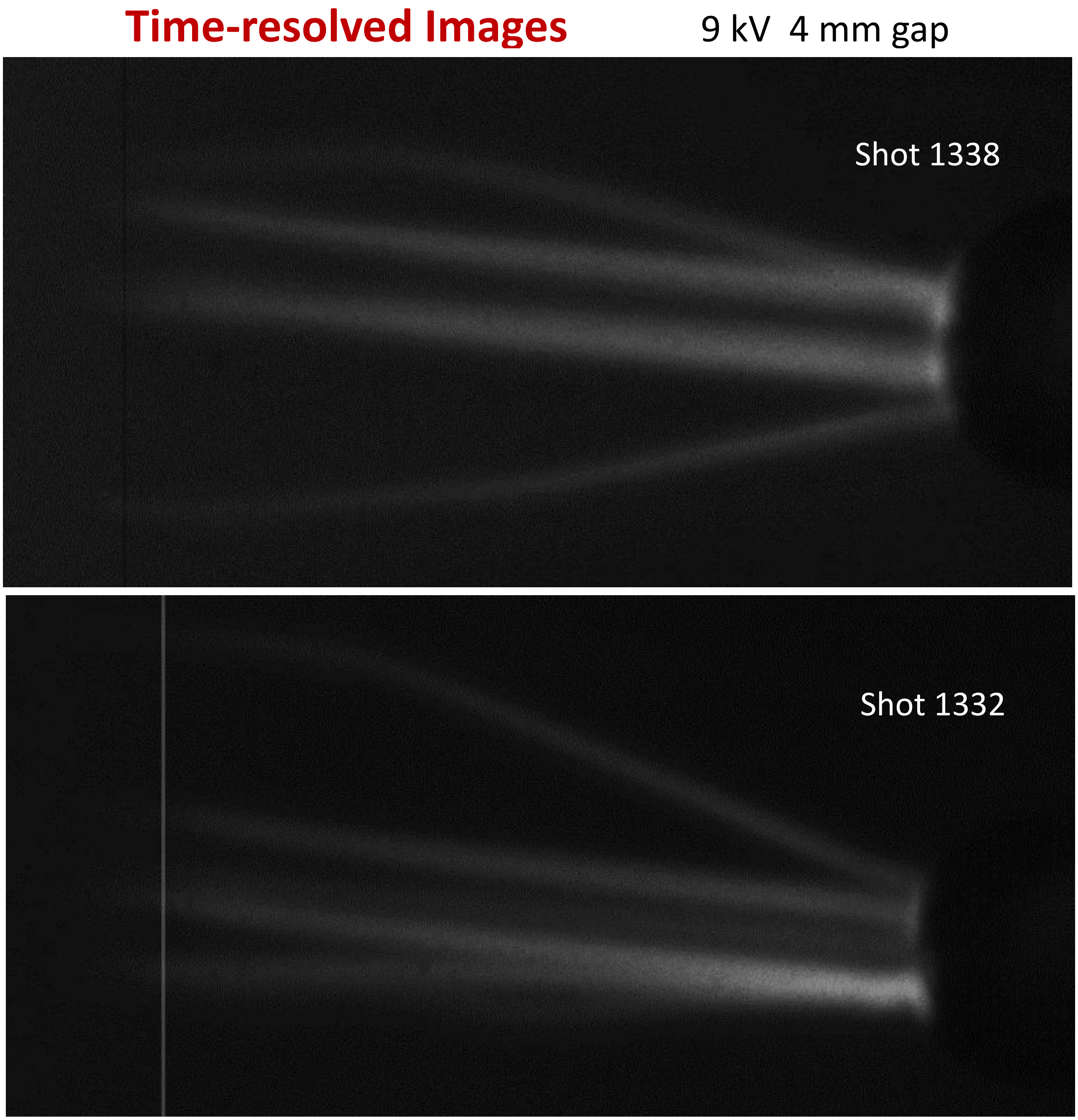


Figure 8. Intensified, time-gated images taken after initiation of corona but before high current breakdown which would saturate the camera.

5. IMPROVEMENTS & ADDITIONAL DIAGNOSTICS

As with most experiments, we learn that there is more to learn as we progress. There are many ways that these measurements can be improved and several additional ideas to obtain additional information to help us sort out the many mechanisms that lead to electrical breakdown. A list of our plans for near future improvements is given below.

Plans

- Low current trigger on, high current trigger off to protect image intensifier and capture the entire pre-breakdown time interval
- Automate testing to record larger populations of data to get statistically accurate distributions
- Set the voltage for each gap at the same point on the Paschen curve [4]
- Test the opposite polarity
- Vary impedance (resistance and inductance)
- Add fiber-coupled time-resolved spectroscopy
- Add UV windows to capture brighter images
- “Soft” laser triggering
    - 5 ns laser pulse to reduce jitter
    - Supplement plasma formation
    - Limit as laser energy → 0
- THz imaging
    - is being developed in 3rd year LDRD (FY16)
    - uses pulsed THz as a “flashlight”
    - records images of the “bare” electron distribution
    - ions are not necessary (as in recombination radiation)
    - 100 fs laser trigger and imaging time resolution

6. CONCLUSIONS

The time delay distributions that have been measured show ten orders of magnitude in range variation. More tests are required to get statistically accurate measurements of these distributions. In recording these results, many ideas have been suggested to automate the test procedure, set the initial conditions more precisely, trigger our recording instruments more rapidly to capture lager time intervals of information without damaging the sensors, and acquire additional information for electrical breakdown modeling with new sensors and new sensing techniques. We plan to pursue these ideas in the next fiscal year.

7. REFERENCES

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