SLATT UNDERGRADUATE RESEARCH FELLOWSHIP
FINAL REPORT

SCHOLAR NAME:	Thomas Coates
FACULTY ADVISOR:	Dr. Sergey Leonov
PROJECT PERIOD:	Fall 2020
PROJECT TITLE:	*Nanosecond resolution camera imaging of a single-pin streamer electric discharge*
CONNECTION TO ONE OR MORE ENERGY-RELATED RESEARCH AREAS (CHECK ALL THAT APPLY):	**(X) Energy Conversion and Efficiency** **( ) Smart Storage and Distribution** **( ) Sustainable Bio/Fossil Fuels** **( ) Sustainable and Secure Nuclear** **( ) Transformation Solar** **( ) Transformative Wind**

MAJOR GOALS AND ACCOMPLISHMENTS

Summarize your research goals and provide a brief statement of your accomplishments (no more than 1-2 sentences). Indicate whether you were able to accomplish your goals by estimating the percentage completed for each one. Use the next page for your written report.

RESEARCH GOALS	ACTUAL PERFORMANCE AND ACCOMPLISHMENTS	% OF GOAL COMPLETED
Measurements of the triggering system jitter	Measurements were taken of actual spark gap trigger time depending on test conditions with a time resolution not worse than 10ns. The data was processed to evaluate the jitter value, see the report below.	100
Imaging of the corona discharge with high resolution	The streamer corona electrical discharge pattern was acquired using a high-speed ISSD Andor iStar camera calibrated to fire in conjunction with an alternating-current spark ignitor. The data was processed to recognize any common and variable features, including corona shape and size.	100

RESEARCH OUTPUT

Please provide any output that may have resulted from your research project. You may leave any and all categories blank or check with your faculty advisor if you are unsure how to respond.

CATEGORY	INFORMATION
EXTERNAL PROPOSALS SUBMITTED	(Sponsor, Project Title, PIs, Submission Date, Proposal Amount)
EXTERNAL AWARDS RECEIVED	(Sponsor, Project Title, PIs, Award Date, Award Amount)
JOURNAL ARTICLES IN PROCESS OR PUBLISHED	The Journal paper is discussed to be submitted to "Plasma Physics" Journal
BOOKS AND CHAPTERS RELATED TO YOUR RESEARCH	(Book Title, Chapter Title, Authors, Submission Date, Publication Date, Volume #, Page #s)
PUBLIC PRESENTATIONS YOU MADE ABOUT YOUR RESEARCH	(Event, Presentation Title, Presentation Date, Location)
AWARDS OR RECOGNITIONS YOU RECEIVED FOR YOUR RESEARCH PROJECT	(Purpose, Title, Date Received)
INTERNAL COLLABORATIONS FOSTERED	(Name, Organization, Purpose of Affiliation, and Frequency of Interactions)
EXTERNAL COLLABORATIONS FOSTERED	(Name, Organization, Purpose of Affiliation, and Frequency of Interactions)
WEBSITE(S) FEATURING RESEARCH PROJECT	(URL)
OTHER PRODUCTS AND SERVICES (e.g., media reports, databases, software, models, curricula, instruments, education programs, outreach for ND Energy and other groups)	(Please describe each item in detail)

RESEARCH EXPERIENCE

Please let us know what you thought of your research experience: Did this experience meet your expectations? Were lab personnel helpful and responsive to your needs? What else could have been done to improve your experience or achieve additional results?

I enjoyed my time in the lab, and found the research very enlightening. One benefit of this research is that it supplemented my studies in my Physics E&M class, giving me a unique experience of circuit designs in action. It has definitely met my expectations, providing engaging research.

Dr. Leonov and other personnel I worked with were very helpful, guiding me in my project and showing genuine support of my scholarly development inside and outside of my research. Dr. Leonov provided clear expectations of what he hoped for me to achieve in the lab, and always made sure to remind me that I can take time off to focus on my studies at any time. I could not ask for a better experience; I am glad to feel proud of my work and fulfilled by it.

FINAL WRITTEN REPORT

Description of project and objectives

A streamer corona electrical discharge is commonly realized in many practical devices and technologies dealing with high-voltage electricity. In some cases, such a discharge is intentionally generated for surfaces/materials processing, plasma medicine, creation of electronic devices, and more. In many other cases, the corona discharge appears as a parasitic phenomenon, leading to malfunctions and failures. Knowledge on the streamer corona discharge pattern and dynamics is urgently required for development of proper control procedures. Recent studies show that surface electric charge deposited by the high-voltage pulse discharge greatly affects the discharge parameters and morphology. In addition, a similar behavior was found for a volumetric single-pin discharge. This type of discharge produces volumetric electric charge waves concomitant with a redistribution of the electric field that significantly influences the discharge pattern.

In general, an understanding of the effects of space charge on the discharge characteristics is important for the study of low-temperature plasmas. However, it has been largely under-explored due to the unavailability of a proper measurement tool. This work in particular includes the visualization of the discharge morphology with a nanosecond resolution by means of an advanced ISSD Andor iStar camera. The major objective of this work is to correspond the acquired images to the electric field morphology and the pulse high-voltage generator waveform. The targeting of this goal is completely within the scope of the ND Energy activity.

Research tasks consisted of experimental efforts, numerical simulations, and data analysis, including:

- streamer corona discharge imaging with a high temporal resolution, down to 10ns
- characterization and reduction of jitter in streamer formation

Findings and results

The experimental setup for this research consisted of an ISSD Andor iStar camera with a UV Nikor lens, Berkeley Nucleonics 625 DDG, LeCroy WaveJet 354 Oscilloscope, TREK 20/20C-HS high voltage amplifier, a 10kV ignitor, and a high-voltage ignitor. Other equipment includes a voltage probe and two electric field probes. The camera was set to capture an image of the corona discharge upon a trigger pulse from the DDG, and relevant probe information, as well as the camera monitor, would be displayed on the oscilloscope screen (Figure 1).

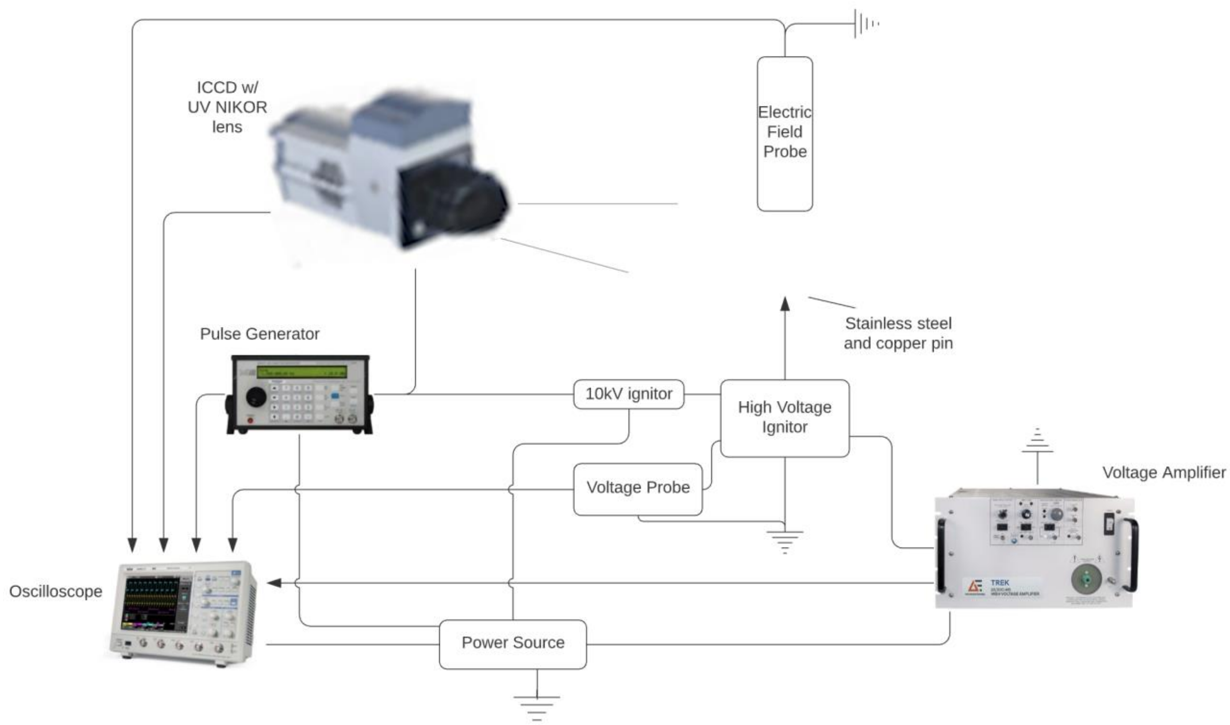

Figure 1. Schematic representation of the experimental setup

Image analysis shows the corona to have two different overarching shapes. The first, which appears in conjunction with the positive slope of the streamer waveform, takes on the form of many small streamers radiating from the pin (Figure 3). These streamers reach further out as the voltage increases, and do not form a filament upon contacting a grounded wire (Figure 4). The second shape appears in conjunction with the negative slope of the streamer waveform, forming a 'cloud' around the pin (Figure 5). Like with the other corona shape, its radius increases as the voltage increases, but unlike the other, it may form a bright filament if it contacts a grounded wire (Figure 6). Finer aspects of the corona shapes appear to be affected by the shape of the pin and general atmospheric irregularities.

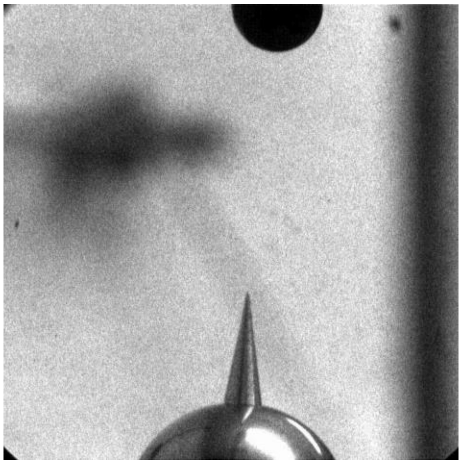

Fig. 2. Ref image; pin centered with probe above.

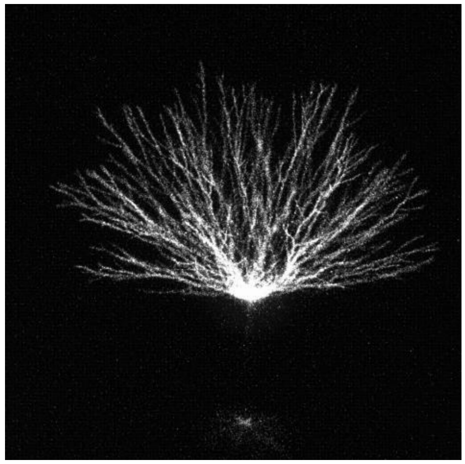

Fig. 3. Streamers form with positive slope.

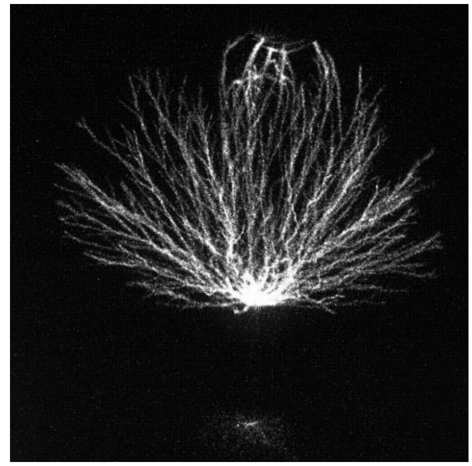

Fig. 4. Attraction to probe, but no filament forms.

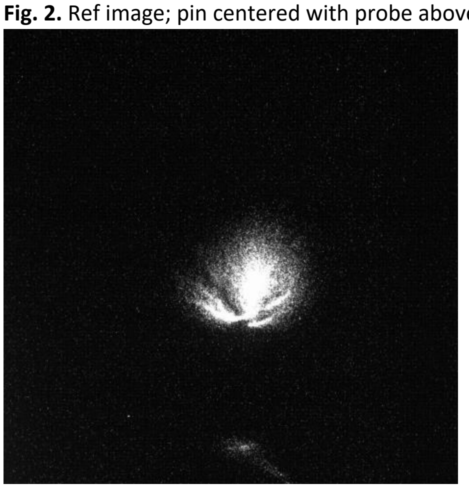

Fig. 5. Cloud forms with negative slope.

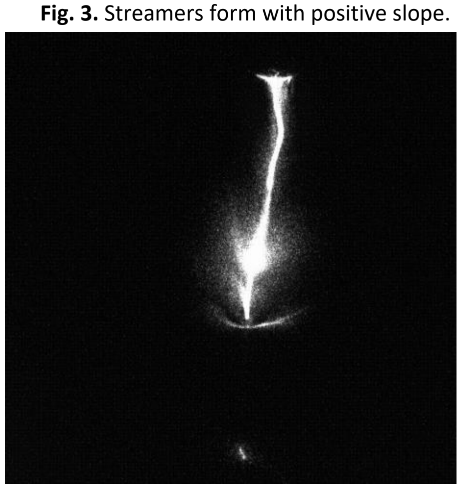

Fig. 6. Filament created upon interaction w/ probe.

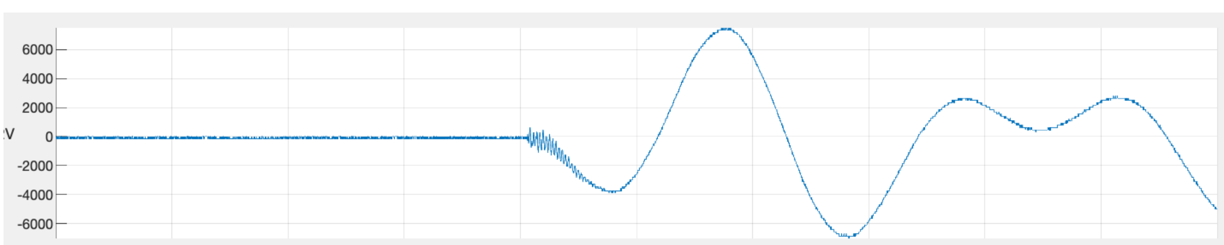

Fig. 7. Example of a measured waveform. Images were taken primarily around the central positive peak.

A large part of the work was to find the jitter in the streamer corona discharge and make changes to the system to reduce it. With initial tests, we found that the jitter was much higher than we would like: roughly ± 48.5 ns (Figure 8). This means that estimates on where parts of the waveform might appear could be nearly 100 nanoseconds off, ten times the desired temporal resolution of 10ns. In order to both reduce jitter and improve the shape of the corona discharge, we changed the discharge pin to a stainless steel ball with a pointed copper tip. This change reduced the jitter by nearly 50 percent, with the standard deviation in streamer corona discharge times diminished to ± 26.6 ns (Figure 9).

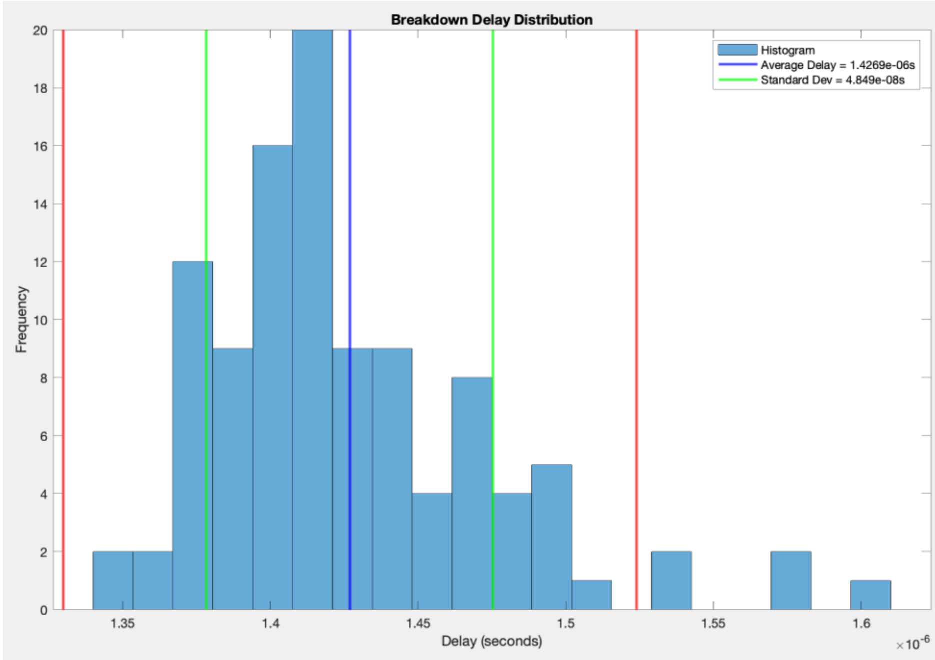

Figure 8. Time distribution of the dielectric breakdown of air, wire pin

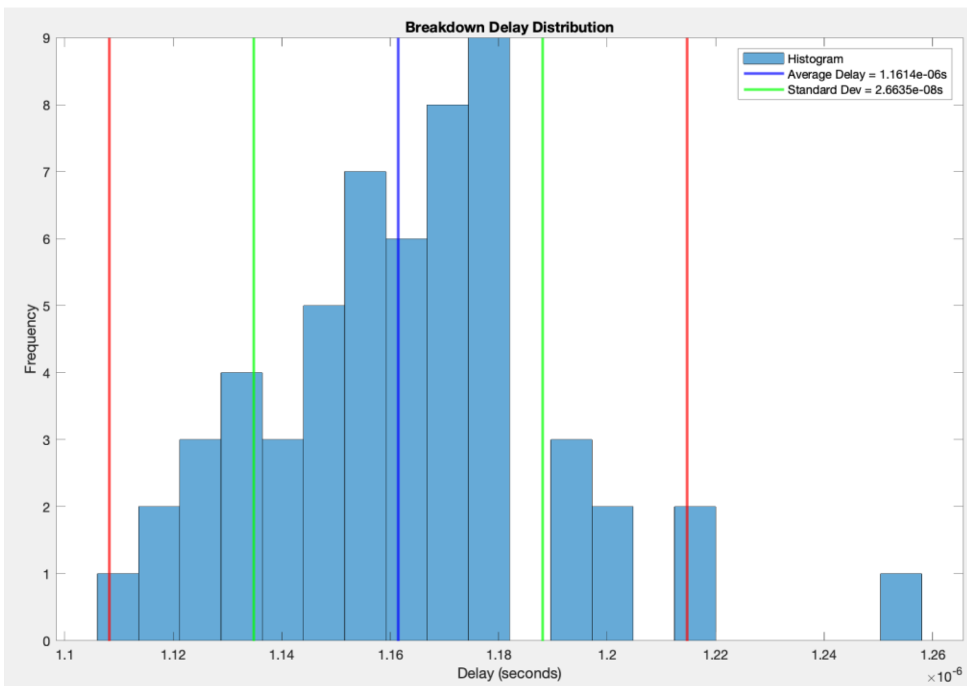

Figure 9. Time distribution of the dielectric breakdown of air, ball-and-point pin

Conclusion: the project objectives were 100% achieved, including the ones indicated below.

1. Measurements were taken of actual spark gap trigger time depending on test conditions with a time resolution not worse than 10ns. The data was processed to evaluate the jitter value.

2. The streamer corona electrical discharge pattern was acquired using a high-speed ISSD Andor iStar camera calibrated to fire in conjunction with an alternating-current spark ignitor. The data was processed to recognize any common and variable features, including corona shape and size.