CRADA # JSA 2020S010
CRADA Final Report

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Releasing Official information (if different from above):
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CRADA Title: <u>Ultrafast High Voltage Kicker System Hardware for Ion Clearing Gaps</u>
CRADA Objective: Develop a MHz high voltage nanosecond kicker system that enables the time structure required by the ion traps for high current electron beam cooling.

CRADA Statement of Work:

Jefferson Lab (JLab) will collaborate with Radiabeam, LLC in a DOE SBIR Phase II Project (DOE Grant No. DE-SC0019684, title: "Ultrafast High Voltage Kicker System Hardware for Ion Clearing Gaps") to develop and test a MHz high voltage nanosecond kicker system that enables the time structure required by the ion traps for high current electron beam cooling. High current (in particular energy recovery) linac based electron cooling facilities for medium to high energy bunched proton or ion beams are of great interest for the recently funded Electron-Ion Collider (EIC) to which Jefferson Lab plays a critical role. The successful execution of this project will enable the capability to mitigate the ion trapping effect and circumvent a major obstacle preventing reliable operation of the crucial cooling facilities.

The collaboration includes the following activities:

- Radiabeam will deliver to JLab a complete prototype of the kicker as specified in the proposal, with relevant technical instructions, operation support and $175K from the SBIR Phase II funds for purchase of experimental materials, modification of the existing test facility and to cover necessary labor cost. Fund will also be used to assist a graduate student for research related to the project at JLab and support academic degree thesis activity and publications.
- JLab will provide information and guidance to help Radiabeam during the design and fabrication of the kicker system, and integrate the kicker assembly into test facility at JLab. JLab and Radiabeam will jointly perform test and characterization and data analysis. It is expected that the test could extend beyond the two-year time period allotted for the SBIR Phase II proposal, in which case, JLab would request an extended loan period of the hardware built during the period of this Phase II project.

Tasks:

<u>Jefferson Lab Tasks:</u>

1) Participate in all the collaboration meetings and technical discussions
2) Make work plan, communicate with collaborators, organize and provide technical support including lab space and experimental facility on Jlab site
3) Provide beam parameters and technical advice during the kicker design, assembly/de-assembly hardwares at

JLab and perform test with Radiabeam

4) Provide trainings to collaborators and participate in critical measurements and data analysis
5) Assist in reports and publish results on journals and to scientific conferences
6) Supervise a graduate student who will participate in the project as part of the thesis work

Raytum Tasks: (as defined in the DOE SBIR Phase II Project (DOE Grant No. DE-SC0015149):

1) Participate in all collaboration meetings and technical discussions
2) Advance and finalize the vacuum insert (kicker) including wakefield effects and the requirements for the power driver jointly with JLab.
3) Develop the circuitry for the pulser feeding the kicker.
4) Fabricate the kicker, perform all necessary testing: vacuum leak test, cold RF testing etc.
5) Fabricate and perform in-house testing of the complete kicker prototype
6) Fabricate the kicker and perform high-power tests under vacuum
7) Deliver the kicker and pulser to JLab and provide guidance to JLab for preparation of experimental facility
8) Receive necessary trainings and participate in system test and characterization in JLab.

STI Product Type (patents, journal articles, books, technical reports, thesis):

Smirnov, A.Y.; Agustsson, R.; Benson, S.V.; Gavryushkin, D.; Guo, J.; Kutsaev, S.V.; Moro, A.; Park, G.T.; Smirnov, A.V.; Wang, H.; and Zhang, S.. "Ultrafast High-Voltage Kicker System for Ion-Clearing Gaps." Photonics 2021, 8, 507. https://doi.org/10.3390/photonics8110507

Smirnov, A.Y.; Agustsson, R.; Benson, Kutsaev, S.V. Park, G.T.; Smirnov, A.V.; Wang, H.; and Zhang, S.. "Ultrafast High-Voltage Kicker System for Ion-Clearing Gaps.", IPAC-2024 Proceedings

As per DOE O 241.1B, the following information is required:
CRADA Products

Data that Non-Federal Collaborator Indicated as Proprietary: None
Data Marked Restricted Access Information: None
Invention Disclosures Made: None
Patent Applications: None
Copyrights Filed: None
Trademarks: None
Licenses Granted: None

Medium (e.g., format and related technical requirements, textual, multimedia, audiovisual, and digital): None

CRADA Outcomes
Describe the Results of the Collaboration.
Were Objectives met? How?

We performed following critical tasks:

- Completed the beam dynamic study and EM optimization based on the specific accelerator beamline configurations and the electron beam parameters from JLab, obtained optimal beam injection parameters with minimal beam loss in the kicker cavity.

- Based on the beam dynamic study, completed mechanical design of a stripline cavity including vacuum interface, the adjustment and alignment system.
- Developed a pulse driver with new GaN-based switches. Performed extensive tests and improvements achieved ~100ns flat-top pulse with 4ns rise/11ns fall time, 1000V at 1.4MHz rep rate.
- We published our research results in a journal paper and also presented at IPAC-24 conference.

It should be mentioned, this project was unfortunately impacted by the unexpected Covid pandemic that broke out at the same time when we started our work. We experienced severe supply shortage of critical materials and components, for example, the GaN switches, which significantly hampered the progress. The surge of cost of materials was another important factor adversely contributed to the project. As a result, we were not able to perform a planned high-power test under vacuum.

<u>What was Demonstrated, or Developed?</u>

A critical system, a pulse driver was developed using new GaN-based switching components. We performed extensive tests and made substantial improvements, resulting in ~100ns flat-top pulse with 4ns rise/11ns fall time, 1000V at 1.4MHz rep rate.

<u>Will this Result in a Commercial Product by the Participant? If So, Describe.</u>

The technique and systems developed under this project are highly desired in some applications beyond the accelerator community such as laser optics where nano-second kilo-volt MHz electrical pulses are required to drive EO modulators. Most EO switches in high power lasers are limited to 100s kHz, stable MHz operation is needed in many applications including scientific research and defense industry. The pulser we developed serves as a prototype of high voltage ultrafast pulse generator that can be turned into a very useful commercial product.

<u>What was the Value of the Collaboration to your Lab and the Jefferson Lab?</u>

The collaboration is extremely valuable to both parties. It provided a good opportunity for RadiaBeam to learn the research needs from JLab as well as other national labs in the nuclear physics and accelerator communities. The project allowed RadiaBeam to effectively utilize its expertise to contribute to the frontier scientific research at JLab while opens up the chance to develop new products with broader applications and promising market potential which helps small business companies to grow.

<u>If this CRADA is related to Software & Technology or datasets the following is also required:</u>

Description: None
Legal Notices and Disclaimers: None
Hardware Requirements: None
Related Resources: None
Contributing Organizations: None
Software or Data Contact: None