

GENERATION, PROPAGATION AND DIAGNOSTICS OF A LONG PULSE ANNULAR ELECTRON BEAM FOR AN HPM SOURCE

K.J. Hendricks, Jack Watrous¹, Stan Humphries², Jeff Heggemeier, Jerry Baca, Mike Haworth, Don Shiffler, and Tom Spencer, Keith Cartwright and Peter Mardahl, Cletus Scharle³, Matt LaCour³, and Ken Golby³

Air Force Research Laboratory, Directed Energy Directorate/High Power Microwave Division, 3550 Aberdeen Ave, SE Kirtland AFB, New Mexico, United States of America

Abstract

We are in the process of re-assembling the Injection-Locked Relativistic Klystron Oscillator to increase the duration of the high power microwave pulse. This HPM source is designed to use a 500 kV, 10 kA annular electron beam and generate ~1.5 GW microwave pulse. Previously we published that the microwave pulse length was experimentally observed to be limited to a finite change in the beam current. These initial experiments focus on controlling the total variation of the emitted beam current. That is, our goal is to have the vacuum diode behave as a resistive load at the desired voltage. We will be presenting results of experiments on the materials used to fabricate the cathode and its emission surface, results from X-ray and optical diagnostics of the unmodulated electron beam position and thickness, and finally results from X-ray and optical diagnostics of the modulated electron beam position and thickness. These results will be compared with different time dependent and steady state computational tools.

I. INTRODUCTION

The Air Force Research Laboratory's (AFRL) Injection-Locked Relativistic Klystron Oscillator (RKO) [1] is a High Power Microwave (HPM) source. During previous experiments the HPM pulse duration was found to be limited by the time required to increase from a start current to a maximum critical total electron beam current. The observation was that microwave pulse would only be generated while the electron beam current was greater than 7 kA and less than or equal to 10 kA. At this time we do not completely understand the cause of the current increase when a constant voltage (less than 5% variation) is applied to the anode-cathode (A-K) gap. During previous experiments we found the material used for the cathode had an impact on the magnitude of the current increase.

In order to understand the limitations to the HPM pulse being generated we need to understand why the electron beam current is not constant for any constant applied voltage. Toward that end we have put together an experimental and theoretical study on the generation of the annular electron beam. We are using previously validated codes: 1) TRAK Steady State Gun Code[2] and 2) ICEPIC[3] Particle-in-Cell Code. These tools are coupled with an experiment to look at the generation and propagation of an annular electron beam through the RKO structure and magnetic field coils.

II. RKO DIODE EXPERIMENT

The experimental arrangement is shown in Figure 1. The center-line of the system is indicated by the symmetry axis of the drawing. A long shaft to the pulsed power system supports the cathode. The electron beam is generated in a converging magnetic field (maximum axial field ~8 kG) and accelerated toward the hollow beam line. The annular electron beam is to be 5 mm in thickness and be confined by the magnetic field 5 mm from the wall. The microwave modulating cavities are part of the brazed structure forming the beam line. However, they are not used in this set of experiments. These cavities are blocked to preclude modulation of the electron beam.

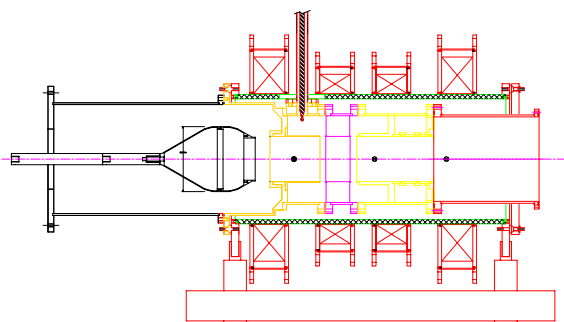


Figure 1 Drawing of the RKO diode experiment.

¹ Numerex, 2309 Renard Pl, SE, Albuquerque, NM 87106-4259

² Field Precision, P.O. Box 13595, Albuquerque, NM 87192

³ SAIC, Space and Directed Energy Tech. Div., 2109 Air Park Rd., SE, Albuquerque, NM 87106

Report Documentation Page				Form Approved OMB No. 0704-0188	
Public reporting burden for the collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington VA 22202-4302. Respondents should be aware that notwithstanding any other provision of law, no person shall be subject to a penalty for failing to comply with a collection of information if it does not display a currently valid OMB control number.					
1. REPORT DATE JUN 2003		2. REPORT TYPE N/A		3. DATES COVERED -	
4. TITLE AND SUBTITLE Generation, Propagation And Diagnostics Of A Long Pulse Annular Electron Beam For An Hpm Source				5a. CONTRACT NUMBER	
				5b. GRANT NUMBER	
				5c. PROGRAM ELEMENT NUMBER	
6. AUTHOR(S)				5d. PROJECT NUMBER	
				5e. TASK NUMBER	
				5f. WORK UNIT NUMBER	
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) Air Force Research Laboratory, Directed Energy Directorate/High Power Microwave Division, 3550 Aberdeen Ave, SE Kirtland AFB, NewMexico, United States of America				8. PERFORMING ORGANIZATION REPORT NUMBER	
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)				10. SPONSOR/MONITOR'S ACRONYM(S)	
				11. SPONSOR/MONITOR'S REPORT NUMBER(S)	
12. DISTRIBUTION/AVAILABILITY STATEMENT Approved for public release, distribution unlimited					
13. SUPPLEMENTARY NOTES See also ADM002371. 2013 IEEE Pulsed Power Conference, Digest of Technical Papers 1976-2013, and Abstracts of the 2013 IEEE International Conference on Plasma Science. IEEE International Pulsed Power Conference (19th). Held in San Francisco, CA on 16-21 June 2013. U.S. Government or Federal Purpose Rights License., The original document contains color images.					
14. ABSTRACT We are in the process of re-assembling the Injection-Locked Relativistic Klystron Oscillator to increase the duration of the high power microwave pulse. This HPM source is designed to use a 500 kV, 10 kA annular electron beam and generate ~1.5 GW microwave pulse. Previously we published that the microwave pulse length was experimentally observed to be limited to a finite change in the beam current. These initial experiments focus on controlling the total variation of the emitted beam current. That is, our goal is to have the vacuum diode behave as a resistive load at the desired voltage. We will be presenting results of experiments on the materials used to fabricate the cathode and its emission surface, results from X-ray and optical diagnostics of the unmodulated electron beam position and thickness, and finally results from X-ray and optical diagnostics of the modulated electron beam position and thickness. These results will be compared with different time dependent and steady state computational tools.					
15. SUBJECT TERMS					
16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT SAR	18. NUMBER OF PAGES 3	19a. NAME OF RESPONSIBLE PERSON
a. REPORT unclassified	b. ABSTRACT unclassified	c. THIS PAGE unclassified			

III. DIAGNOSTICS

A voltage derivative probe(V-dot or penny probe) and Rogowskii coil (I-dot probe) are located on the upstream (left-hand) end of the experiment. We have placed PIN diode detector on the downstream end of the center-line to monitor the generated X-ray pulse due to the collection of the electron beam pulse with a POCO graphite witness plate.

The electron beam diagnostics are used as a self-consistency check with traditional pulsed power diagnostics. For instance, IMP pulsed power system (10 stage, 1 MV maximum, 30 kJ stored) has a resistive voltage divider to monitor the charge of a 600 nsec, 5 Ω pulse forming line (PFL). The PFL is switched to the vacuum diode by a self-breaking, gas insulated, closing switch. By monitoring the switch out point in the charge of the PFL we may estimate how the flatness of the voltage waveform. For example, the time required for the PFL to reach maximum charge is ~ 3.5 μ sec. We typically pressurize the output switch to close ~ 3.2 to 3.4 μ sec. Operation in this mode ensures the voltage waveform should be moderately constant at 50% of the IMP erected Marx voltage.

IV. SIMULATIONS

To gain insight into the vacuum diode behavior and electron beam propagation we make use of an assortment of computational tools. These include electric and magnetic field solvers[2] in addition to the gun and particle codes mentioned earlier. These codes will indicate regions of high electric field stress or non-uniformity in the applied magnetic field. Following the steady state fields calculations, then we begin to look at how the electron beam is generated and propagated through the structure. These simulation results are shown in Figure 2. The results are from Trak and ICEPIC, respectively. You will notice from the plots the same qualitative transport of the electron beam. We also make quantitative comparisons between the codes.

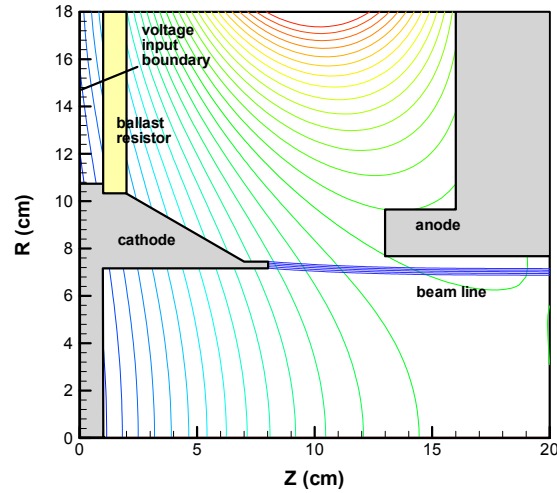
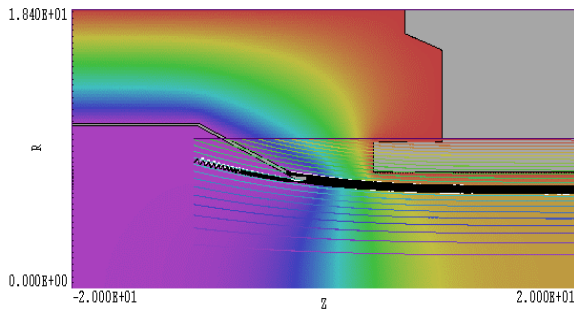


Figure 2 Sample simulation results, TRAK and ICEPIC respectively.

V. PRESENT EXPERIMENT

Data from the present experiment are shown in Figure 3. The data show the observed constant voltage pulse, and the normalized overlay of the emitted electron beam current with the X-ray PIN diode signal. The PIN diode indicates the X-ray dose rate during the pulse. Given the relation [4] between the dose rate, voltage and current we expect the PIN signal to track the electron beam current pulse as shown. We do have data showing a disagreement between the PIN diode signal and the electron beam current, however those data were for a non-constant voltage pulse or a fault in the Rogowskii coil.

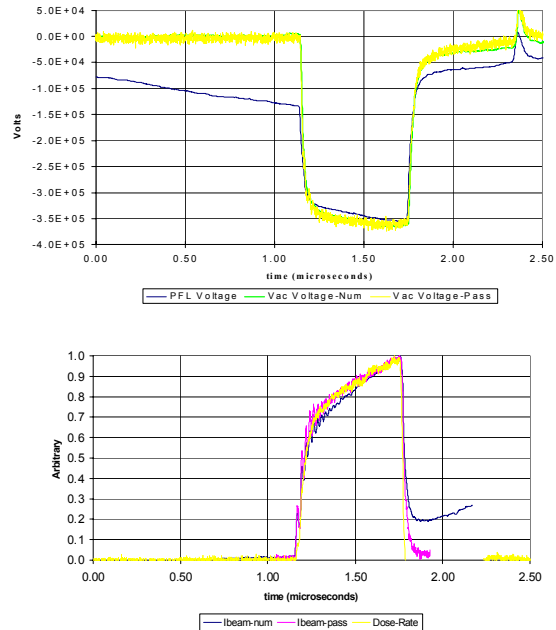


Figure 3 Data from the diode experiments.

To aid in interpretation of the data when the PIN signal doesn't track the beam current profile, we are setting up a streak camera to view the Cherenkov light generated by the beam impacting an acrylic plate. We are able to save the streak camera image and obtain a time history of the light intensity. We are still working on focusing the input optics to the streak camera so the acrylic plate is properly imaged on the streak camera input slit. We also are working on setting the various gains of the streak camera so the time history of the light intensity may be compared with the PIN signal and the electron beam current time history.

VI. SUMMARY

At this time we have begun comparison of experimental data with the various code predictions. An example is shown in Figure 4 of a prediction of the axial A-K gap that yields a 10 kA electron beam current for an applied 500 kV voltage pulse.

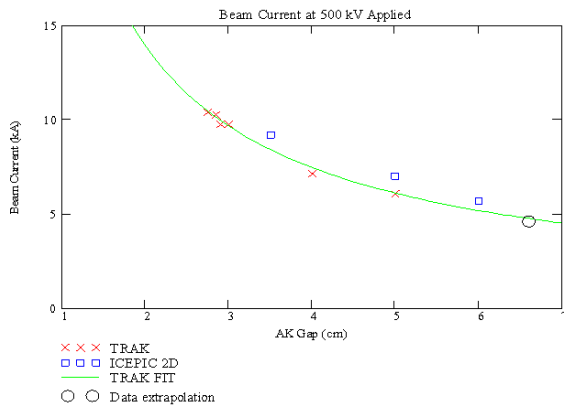


Figure 4 Comparison of simulation and experimental results.

We are also beginning to diagnose the beam spatial and temporal variations with the streak camera. This data will also be compared with other diagnostics and the various simulation tools.

VII. REFERENCES

- [1] K.J. Hendricks, M.D. Haworth, T. Englert, D. Shiffler, G. Baca, P.D. Coleman, L. Bowers, R.W. Lemke, T.A. Spencer, and M.J. Arman, "Increasing the Microwave Energy per Pulse of an RKO", IEEE Trans. Plasma Sci. 26(1998)
- [2] for the Tri-Comp Codes go to: www.fieldp.com
- [3] J.J. Havranek and B.J. Smith, "A Portable Parallel Particle in Cell Code", AIAA #96-0835, Aerospace Sciences Meeting, 34th, Reno, NV, January 15-18, 1996
- [4] NRL Plasma Formulary (NRL Publication 0084-4040), revised 1986