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MULTI-PULSE ELECTRON DIODE DEVELOPMENT FOR FLASH RADIOGRAPHY.

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Abstract

Presently the Self Magnetic Pinch (SMP) diode is successfully utilized for flash radiography with pulsed power drivers. However, it is not capable of more than one pulse. Multi-pulse single-axis radiography is most preferred since it provides images of time-evolving dynamic targets. In an SMP diode, because the anode cathode (A-K) gap is very small (~1-2 cm), the debris from the anode converter target arrives soon after the first pulse and completely destroy the cathode electron emitter, and thus the diode cannot produce a second pulse. We propose a feasibility study to scientifically evaluate the idea of decoupling the anode converter from the cathode electron emitter. This work will be based on two successful previous works we have accomplished: first, making a very small pencil-like beam in a magnetically immersed foilless diode (M .G. Mazarakis *et al.,* Applied Physics Letters, 7, pp. 832 (1996)); and second, successfully demonstrating the two-pulse operation of a foilless diode with the RIIM accelerator (M. G. Mazarakis *et al.,* Applied Physics **64** part I pp. 4815, (1988) Our approach will combine the above experimentally demonstrated successful work. The generated beam of 40 -50 kA will be propagated in the same diode magnetic solenoid for a sufficient distance before striking the converter target. This way the diode could be multi-pulsed before the target debris reaches the cathode. Although the above describes the option of a foilless diode and a solenoidal transport system, a similar design could be made for a non-immersed low emittance 10 kA velvet emitter foilless diode.

1. TECHNICAL APPROACH AND LEADING EDGE NATURE OF WORK

Presently the most successful and simplest electron diode for flash radiography is the Self Magnetic Pinch (SMP) diode extensively studied at Sandia. A stable diode operation at 8-10 MV accelerating voltage is achieved with a cathode tip diameter and an Anode-Cathode (A-K) gap which are a few cm in size. A small beam spot size on the Ta x-ray converter is routinely achieved. Although this diode performs reasonably well and meets most of the radiographic requirements, it is not capable of more than one pulse. Multi-pulse single-axis radiography is most desired by the radiographic community. Having a train of two or more pulses closely spaced together with variable inter-pulse separation along the same line of sight is of paramount importance for following the evolution of dynamic objects during hydro test implosion experiments. In an SMP diode the (A-K) gap is very small, and the focusing of the beam relies on the space charge neutralization of the ions emitted from the anode target. Anode and cathode plasmas move in opposite directions towards each other and eventually and completely short the A-K gap at about 100ns. In addition, the pressure wave and debris released from the anode converter target damage the cathode electron emitter, and the diode cannot produce a second pulse. Furthermore, if this diode is coupled to a vacuum insulated voltage adder, the sheath electrode current can find its way to the A-K gap and disrupt the diode performance. We propose a feasibility study to scientifically evaluate the idea of decoupling the anode converter from the cathode electron emitter, thus making the diode capable of producing more than one pulse. This work will be based on our vast experience in designing and fielding magnetically immersed foilles diodes [1-10] and specifically on two successful previous works we have accomplished: first, making a very small pencil-like beam in a magnetically immersed foilless diode [1,2,5]; and second, the successful demonstration of two-pulse operation of a foilles diode with the RIIM accelerator [3]. Our approach will combine the above experimentally demonstrated successful work. We will start with a similarly sized cathode tip presently used in the SMP diode (a few cm in diameter)) in a magnetically immersed diode configuration. Based on our previous work [4], a modest magnetic field of 2 Tesla will be enough to confine the beam. The generated beam of 40-50 kA will be annular and have a 1mm annulus thickness. The electron beam will be propagated in the same solenoid for a sufficient distance before striking the converter target. Assuming that the pressure shock wave released from the target propagates towards the cathode with the speed of sound (~340m/sec), achieving a multi-pulse train spread in a one millisecond interval could require a minimum cathode-target distance of 34 cm. However, estimates of reference [3] suggest a much faster pressure shock velocity of the order of 2.5×10^6 cm/sec. This number may be seriously affected by outgassing of the vacuum vessel since on those experiments a large number of plastic insulators surrounding the diode were present. Although we do not know exactly the source of the pressure increase, we estimate that the above anode target separation may allow at least a 10 microsecond train of pulses. This will be one of the present work research goals: Study and alleviate the system outgassing. Near the target we will adiabatically increase the magnetic field of the solenoid to 30 Tesla, and together with the space charge neutralization by the target we will compress the beam to the smaller radiographic sizes of the order 1mm. Those electron diodes could be easily installed at the front end of a conventional Induction Voltage Adder (IVA) like HERMES III or RITS 6 and a Linear Transformer Driver (LTD) voltage adder like Ursa Minor or utilized as an injector of a Linear Induction Accelerator (LIA).

Although above we describe in some detail the option of a foilless diode and a solenoid transport system, a similar design could be made for a non-immersed low emittance 10 kA velvet emitter foilless diode and for a beam transport with quadrupole or solenoid lenses. In this case the target and the cathode would be magnetic field free. We have designed and built similar diodes for our Recirculating Linear Accelerator (RLA) and a diode version for DARHT I.

2. PREVIOUS EXPERIMENTAL WORK

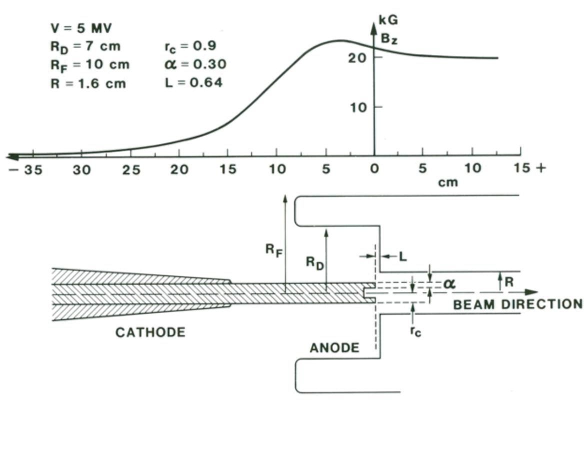

Figure 1. RADLAC II foilless electron diode injector

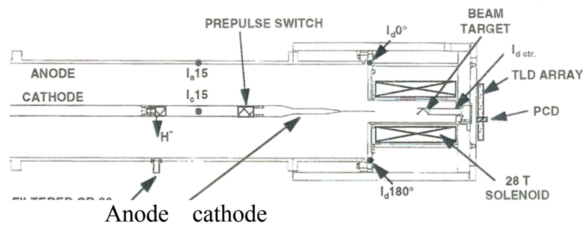

Figure 2. SABER and HERMES III radiographic foilless diode (From [1])

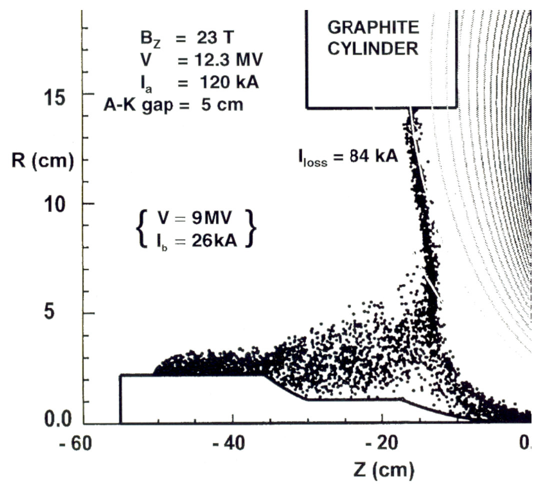

Figure 3. SABER and HERMES II foilless electron diode design simulations. The fringe field of the magnetic solenoid prevents the sheath electron coming from upstream from entering the A-K gap. (From [1])

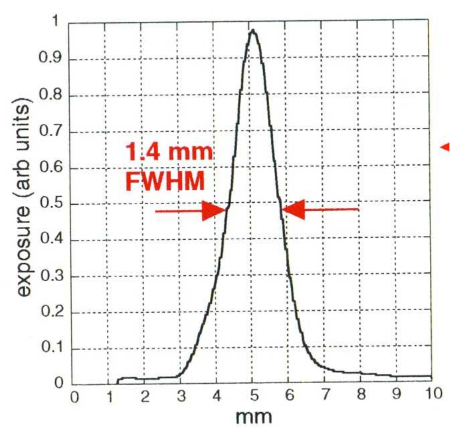

Figure 4. SABER foilless electron diode beam spot size on target (From [1])

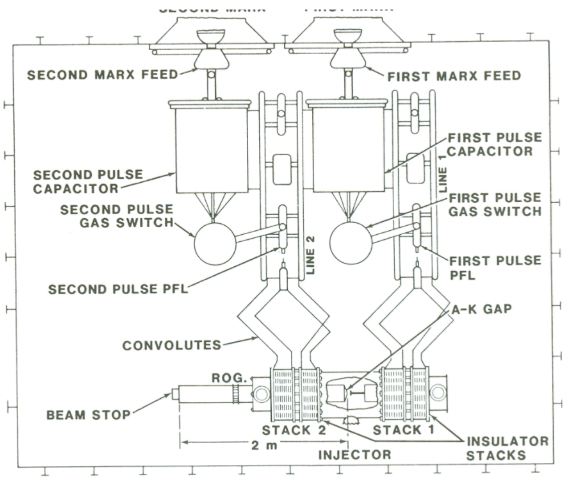

Figure 5. Double pulse RIIM accelerator (From [3])

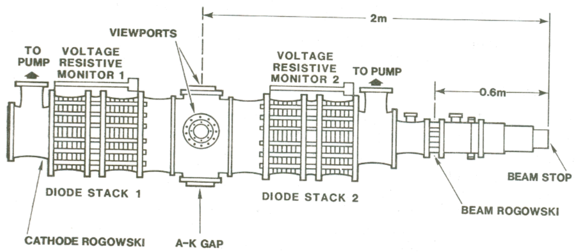

Figure 6, RIIM beam line (From[3])

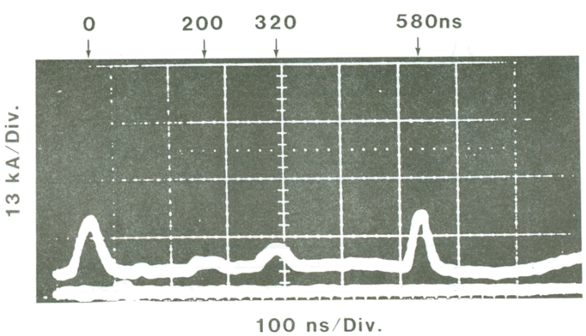

Figure 7. Double pulse results with the RIIM accelerator. Current measured on target (From [3])

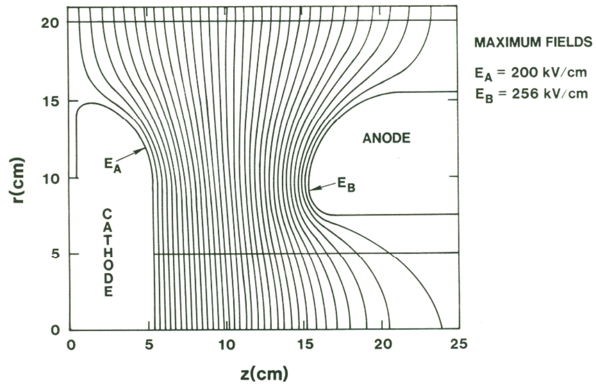

Figure 8. Recirculating Linear Accelerator diode injector design (From [6])

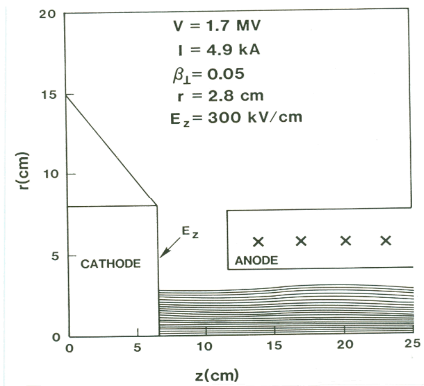

Figure 9. Electron trajectories of the Recirculating Linear Accelerator diode injector design (From [6])

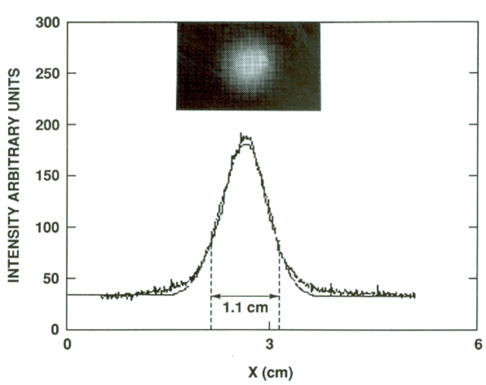

Figure 10. Recirculating Linear Accelerator (RLA) beam profile obtained with a velvet cathode. (From [6])

As mentioned above, the proposed work is based on our 20 plus years experience of magnetically immersed foilless diodes as injectors for the high energy high current pulsed power accelerators of IBEX [4], RIIM [3], and RADLAC I and RADLAC II [7] (Figures 5- 7) where the beam radius sizes were of the order of one centimeter. Additionally, small size foilless diodes were successfully installed at the front end of HERMES III and

SABER [10] (Figures 1- 4) for mm sizes flash x-ray radiography. Although the radiographic experiments with HERMES III and SABER generated millimeter size beams, the short distance between cathode tip and convertor bremsstrahlung target (smaller than 10 cm) caused diode impedance collapse at about 20-30ns in the voltage pulse. Unfortunately no longer solenoidal transport was attempted; neither were the radiographic accelerators modified to provide two pulses. We have also designed and built planar foilless diodes for our Recirculating Linear Accelerator (RLA) and a diode version for DARHT I> (Figures 8- 10).

We believe that through combining our previous experiences of producing small single pulse beam sizes of radiographic interest and also generating double pulses with the RIIM injector, we will be successful in achieving something which has never been tried before: producing high current high brightness trains of pulses of small sizes for flash x-ray radiographic applications. To our knowledge there is not any other attempt in the literature to generate high energy high brightness multi-kilamps multi-pulses with very small beam sizes for radiographic applications.

If we succeed in our effort we will be the first. DARHT II accelerator produces only 2 to 3 kA beams, and most of the 1.6 micro-second pulse duration beam is dumped to a beam dump at the kicker location. The electron source is not multi-pulsed.

If we succeed, every micro-pulse of our train of pulses will generate x-ray pulses of the order of 500 Rads.

3. DESIGN STUDY GOALS

We propose a feasibility study to scientifically evaluate the idea of decoupling the anode converter from the cathode electron emitter. 1. Analytically calculate the foilless diode characteristic parameters. Design the proper magnetic field for the beam transport from the cathode to the beam target. 2. Evaluate the length of the adiabatic magnetic beam compression to avoid instabilities. 3. Estimate the proper magnetic field strength at the cathode tip area and close to the target to achieve the required beam size. 4. Validate our analytical design with numerous LSP simulations for different cathode tip sizes and beam propagation lengths.

We will also evaluate through an extensive literature search the gas expansion velocities and vacuum propagation of the gas pressure shock in order to estimate the duration of the pulse train before the diode is shorted. The metric of success of the present proposed research is a scientific design based on physics principles, beam dynamics, and avoidance possible beam instabilities. The successful design option will be further evaluated experimentally on one of our voltage adders

4. POTENTIAL PROBLEMS TO ANALYZE AND SOLVE

The proposed approach is of high risk and very challenging since multi-pulsing a high current, electron beam diode to produce millimeter size pencil-like beams has never been attempted. We envision the following problems: **1. -** Excessive gas load near the foilless A-K could prevent the generation of more than one or two pulses. **2. -** Excessive fast ionic currents emitted from the target following the first pulse. This may affect the beam stable propagation by causing ion-electron beam hose instability. **3. -** Special design of the x-ray target converter to withstand more than one high current beam pulse. **4. -** Avoidance of dipole components of the transport solenoid to avoid beam steering, beam break-up and crock-screw behavior as function of the beam pulse energy variation. **5. –** If the vacuum is not adequate following a number of pulses, the beam may develop diocotron instability which separates azimuthally the beam into a number of clumps.

II. SUMMARY

We propose a feasibility study to scientifically evaluate the idea of decoupling the anode converter from the cathode electron emitter in both a foilless and a planar magnetic field free diode for flash radiography application. Those diodes will enable multi-pulsing in the same radiographic axis.

III. ACKNOWLEDGEMENT

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