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DESIGN OF A REVERSIBLE POLARITY LTD FOR ELECTRON BEAM DIODE RESEARCH

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Abstract

Linear transformer driver accelerator designs have been proposed and constructed for a number of pulsed power experiments. The accelerators are typically optimized for one type of load with a specific load impedance profile. A LTD accelerator has been designed that is capable of generating -3.5-MV pulses for self-magnetic pinch diode experiments, and +2.5-MV pulses for rod pinch diode experiments. In positive polarity, the field stress on the outer cathode conductor is below the electron emission threshold and the output transmission line is a vacuum insulated line without electron flow. Conversion from positive to negative polarity requires a simple change of power supply polarity. A prototype cavity has been designed.

I. INTRODUCTION

Pulsed power driven electron beam diode research is conducted with the goal of producing high intensity x-ray sources with small diameter. Several diode configurations have been studied, each with different advantages [1]. These diodes are typically fielded at the end of a coaxial transmission line with the pulse polarity determined by the polarity of the center conductor of the coaxial line. Positive polarity accelerators are typically coupled to a rod-pinch diode [2], [3]. Negative polarity accelerators have been used for research with self magnetic pinch (SMP), paraxial, negative polarity rod pinch, and magnetically immersed diodes [1], [4]–[6]. Accelerators are typically designed and optimized for one polarity and conversion to run in the opposite polarity requires significant reconfiguration [7].

There are several design features that are typically optimized for the desired accelerator polarity. Pulsed electrical hold-off strength of water insulated components and vacuum insulator stacks are highly polarity dependent. In both cases, components designed for negative polarity operation can only withstand approximately half the field stress if used in the opposite polarity without changing the geometries. In the case of self-breaking water insulated spark gaps, the jitter is highly dependent on the polarity of the electrode with the highest field stress. Operation of the output coaxial transmission line connecting the accelerator to the diode is also significantly affected by polarity.

Linear transformer driver (LTD) accelerators used for e-beam diode research do not typically have water insulated components that are sensitive to polarity. The 21-cell Ursa Minor LTD was designed for negative polarity e-beam research and provides peak output voltage greater than 2.0 MV. The design of the Ursa Minor cells does not allow operation in positive polarity above about 1 MV without electron emission in the vacuum transmission line. This report describes the design of an LTD accelerator that can be fired in positive or negative polarity by changing only the polarity of the capacitor charge and trigger generator. The accelerator will generate 2.5 MV pulses in positive polarity and 3.5 MV pulses in negative polarity.

II. ACCELERATOR DESIGN AND SIMULATION

An accelerator is desired that can be used for positive polarity rod pinch and negative polarity SMP diode research. These diodes require the accelerator drive similar diode impedances with opposite polarities. In both cases the diode impedance is about 50 Ω as the pulse reaches peak voltage and drops to 30-40 Ω at the end of the pulse [2], [4]. Table 1 lists some of the design requirements for the accelerator in each polarity.

The majority of published rod pinch data has been collected when driven with a vacuum insulated transmission line designed to prevent electron emission in the transmission line [3]. As a result, the accelerator design should operate in positive polarity up to 2.5 MV without electron emission in the output line. The accelerator should be capable of higher voltage operation in positive polarity if electron emission is allowed.

In negative polarity the electric field stress on the cathode center conductor exceeds the electron emission

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Table 1. Accelerator Requirements

Positive Polarity Requirements	
Peak Voltage	2.0-2.5 MV
Load Impedance	50 Ω
Pulse Width (FWHM)	40-70 ns
Output Transmission Line Type	Vacuum Insulated
Output Line Impedance (Vacuum)	40 - 60 Ω
Negative Polarity Requirements	
Peak Voltage	>3 MV
Load Impedance	50 Ω
Pulse Width (FWHM)	40-70 ns
Output Transmission Line Type	MITL
Output Line Impedance (MITL)	40 - 60 Ω

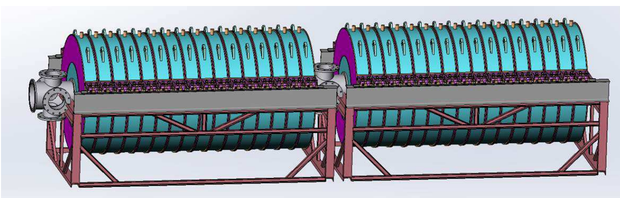

Figure 1. Conceptual drawing of the 32-cavity accelerator.

threshold. Electrons emitted from the cathode are prevented from crossing the radial gap to the anode by the magnetic fields, forming a magnetically insulated transmission line (MITL). With the presence of electron flow in the MITL, the impedance of the output line is lower than the impedance determined by the conductor dimensions in the vacuum line [8]. A transmission line with a geometric vacuum impedance of 55 Ω will have a MITL operating impedance of 40 Ω when run at 3.5 MV.

The accelerator design shown in Fig. 1 and the circuit models of the accelerator are based on the Ursa Minor accelerator [9], [10]. Circuit simulations were used to select the number of switches per cavity, capacitance, and number of cavities required to meet the design requirement. Based on these simulations, an accelerator design is proposed with 32 series cavities with 10 parallel bricks in each cavity. Each brick contains two 12-nF capacitors and one spark gap switch. The output transmission line has a vacuum impedance of 55 Ω for positive polarity operation and a MITL impedance of 40 Ω in negative polarity. The circuit simulations model the load as a 50 Ω resistance for the positive polarity simulations and as a matched 40 Ω resistance in negative polarity. The positive polarity simulation gives a good estimate of the load voltage when coupled to a rod-pinch diode. The negative polarity simulation gives an estimate of the MITL forward going voltage, shown in Fig. 2. The diode voltage in negative polarity is estimated to be 3.2 MV using the method described in Ref. [11], [12].

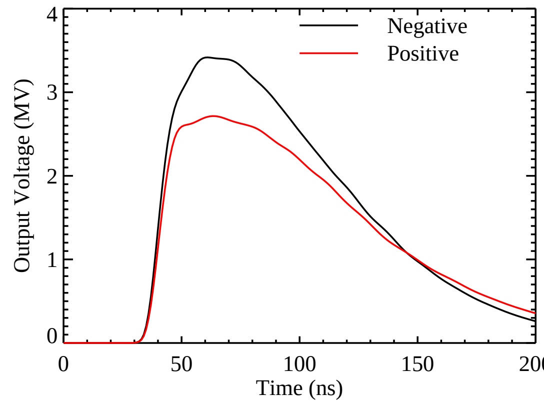

Figure 2. Simulated output voltage of the 32-cell accelerator in positive and negative polarity.

III. POLARITY REVERSAL

The internal configuration of the LTD cavity including the switches, capacitors, and isolation cores are symmetric relative to the charge polarity. In addition, there is no significant difference in insulation strength with charge polarity. As a result, the LTD cavities can be charged and fired in either polarity by changing the power supply and trigger polarity and no physical reconfiguration of the components in the cavities is required.

The only components affected by a change in polarity are the output transmission line and the vacuum insulators on each cavity. Research in vacuum insulator flashover with insulating discs has shown that the highest strength is obtained for an insulator with a $45°$ taper with the larger diameter side of the insulator at the anode [13], [14]. The flashover voltage is typically lowest for straight insulators or insulators with a very small angle. Vacuum insulator designs typically take advantage of this improved electrical strength and include insulators with $\sim 45°$ angled surfaces. If the polarity of the electrodes is reversed, the flashover voltage decreases to 50-75% of the original value, but is still at least as high as the flashover voltage for a straight insulator. For Rexolite (C-Lec cross-linked styrene) the reverse voltage flashover strength is about 75% of the forward voltage strength [14]. Based on this research, a $45°$ Rexolite insulator is used in the LTD cavity design.

A statistical model of insulator flashover was developed by Stygar, et al. for $45°$ vacuum insulator interfaces [15]. This model is appropriate for analyzing the vacuum insulators when the accelerator is run in negative polarity. For positive polarity operation we assume based on previous insulator flashover research, that the flashover voltage is 75% of the flashover voltage in negative polarity. As a conservative approximation of the probability of flashover in positive polarity, we use the analysis method presented by Stygar and use two times the actual electric field stress

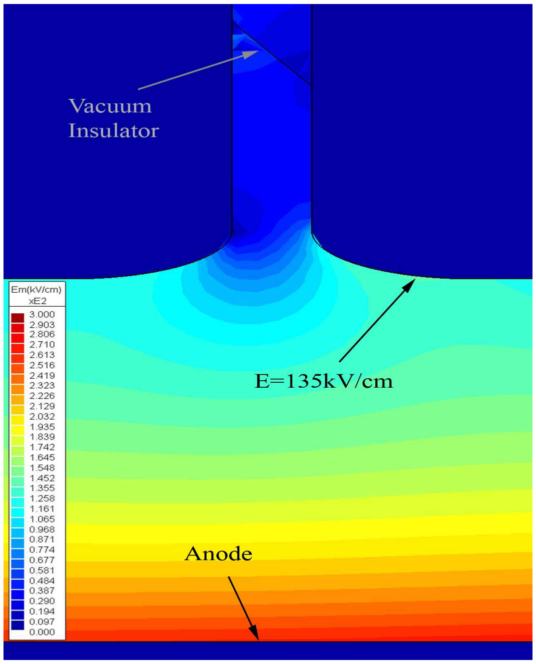

Figure 3. E-field plot of the last LTD cell. The center conductor voltage is 2.5 MV. The resulting peak field stress is 135 kV/cm.

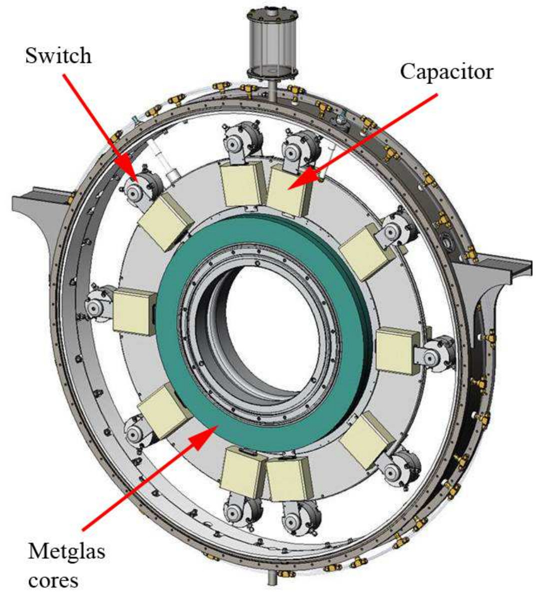

Figure 4. Drawing of the prototype LTD cell with 10 parallel bricks.

to approximate the decreased voltage hold off in positive polarity. Using this calculation method, the single insulator flashover probability in positive polarity is 1.2×10^{-5}.

Previous experiments have demonstrated electron emission from bare metal surfaces stressed as low as 200 kV/cm [16]. In the design of the Cygnus accelerator, cathode surfaces in the vacuum chamber were limited to 200 kV/cm with anodized coatings applied to any surface with electric field stress above 150 kV/cm [3]. In the proposed accelerator, it is assumed that during negative polarity operation electron loss in the MITL could damage any surface coatings. As a result, the design will not require anodized coatings and field stress should be limited to a maximum of 150 kV/cm on the cathode surfaces when running in positive polarity.

A series of two-dimensional electrostatic simulations were used to evaluate the field stress on the coaxial output transmission line. Based on the calculations, the outer diameter of the output transmission line was set at 50.8 cm. An elliptical profile was designed for the cavity output conductors to reduce the peak field stress compared to the small radius of curvature on the Ursa Minor cavities. Fields stresses at the cavity closest to the diode are shown in Fig. 3. The simulations assume a peak voltage of 80 kV per cavity and a peak voltage of 2.5 MV on the anode center conductor. The peak field stress on the cathode is 135 kV/cm.

IV. PROTOTYPE CAVITY

A prototype LTD cavity has been designed for the accelerator presented above. The design is based on the existing Ursa Minor LTD cavities and is enclosed in a round metal grounded housing filled with transformer oil. A drawing of the prototype cavity with one side plate removed is shown in Fig. 4. The outer diameter of the cavity is 1.75 m and the cavity thickness is 22 cm. The cavity includes 10 parallel switches with the capability to expand to a maximum of 18. There are two Metglas cores on each side of the cavity. Not shown in the drawing are gas lines connecting to each switch, charge and trigger resistors, and cavity voltage monitors. Two prototype cavities are being constructed and testing will begin later this year.

V. CONCLUSION

An LTD accelerator had been designed that can be used for both positive and negative polarity e-beam diode research. Polarity conversion is accomplished by reversing the charge voltage polarity, without the need for additional reconfiguration. The accelerator is designed to drive positive polarity rod pinch experiments at 2.5 MV without electron emission in the output transmission line. In negative polarity, the accelerator can drive an SMP diode at greater than 3 MV. The accelerator design is scalable to higher voltage by adding additional series cavities and increasing the number of parallel bricks.

The cavities can accommodate up to 18 parallel bricks. This would allow expansion up to a maximum of 7 MV while driving an SMP diode. A prototype cavity has been designed and will be assembled and tested later this year.

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