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HARP, A SHORT PULSE, HIGH CURRENT ELECTRON BEAM ACCELERATOR†

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Summary

A 3 MV, 800 kA, 24 ns electron beam accelerator is described and the results of initial switching experiments are discussed. The generator will provide a source for studying the physics of processes leading to electron beam driven, inertially confined fusion. The major components of the accelerator are two diodes with a common anode, twelve oil-dielectric Blumleins with low jitter (< 2 ns) multichannel switches, three intermediate storage capacitors, a trigger pulse generator and two Marx generators.

Introduction

At Sandia Laboratories, we are investigating the possibilities of producing inertially confined pulsed fusion driven by high power electron beams.[1,2] This fusion scheme requires development of electron beam accelerators with peak powers of 10^{13} - 10^{14} W.[3] The Harp accelerator represents an initial scalable effort to decrease the pulse width and increase the peak power of relativistic electron beam (REB) generators that utilize transformer oil as the principle dielectric. It will provide an accelerator for studying diode physics, beam pinching and energy deposition as well as provide practical experience on utilizing low jitter switch systems.

General Description

An artist's sketch of the accelerator is shown in Fig. 1. Energy is supplied to each of the two diodes from six sets of parallel plate transmission lines connected in a Blumlein configuration. The transmission lines can be charged to 2 MV by a Marx generator or to 3 MV by utilizing intermediate storage capacitors. The output pulse is initiated by triggered oil dielectric, rail switches that require large amplitude, fast-rising trigger pulses for low jitter operation. The trigger pulse is generated from a Marx generator and a water dielectric pulse-forming line (PFL). It is then transmitted to the twelve switches through oil-insulated transmission lines. Initial construction of the accelerator has been completed and experiments to determine the simultaneity of six untriggered, multichannel oil switches have been performed. In the following, the results of these experiments and design details of each of the major components are discussed.

Diode

Figure 2 is a sketch of the diodes. The vacuum envelope is constructed with a stack of four 1.2 m diameter, 5 m thick, acrylic insulators and interspersed with 6.4 mm thick aluminum grading rings. Equipotential plots of this structure indicate the voltage is uniformly distributed across each insulator within 3 percent. Since vacuum flashover is time dependent, with the short pulse duration and the well-graded insulator stack, the flashover electric field is estimated to be 160 kV/cm and the flashover voltage for this diode should be 3.3 MV. The estimated inductance is 26 nH with a 61 cm diameter cathode and 49 nH with a 15 cm diameter cathode. Possible inductive effects of the pinching beam have been neglected in these estimates. Thus, for a matched 7.3 Ω diode impedance, the diode 10-90 percent current risetime should be 4 ns. Since the Blumlein switches will produce approximately a 10 ns output voltage risetime, the voltage across the insulator should not

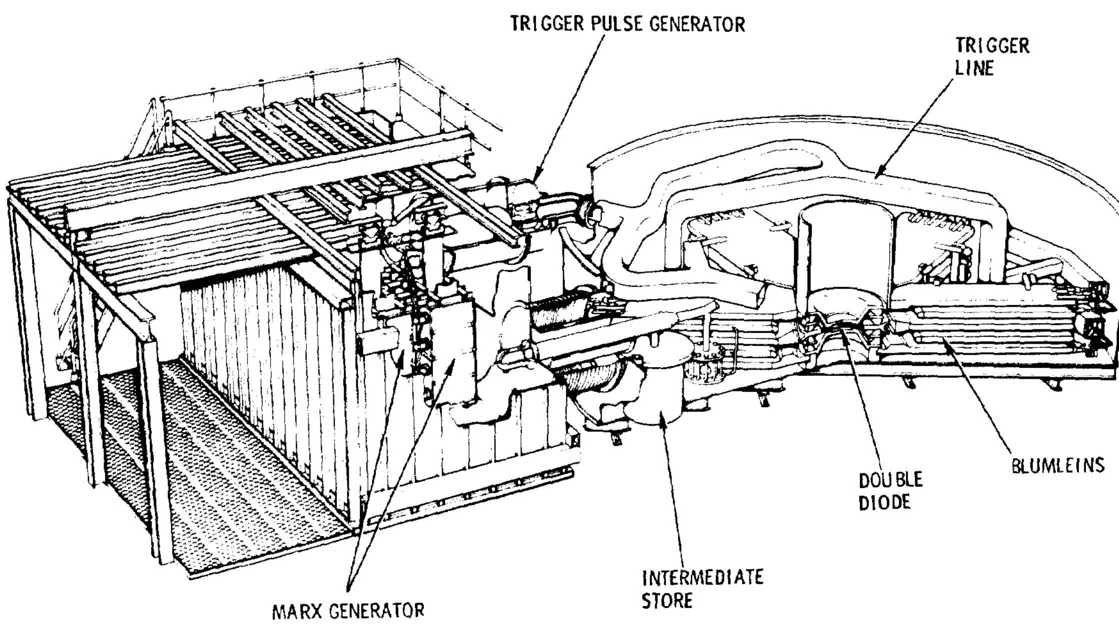

Figure 1. - Harp Electron Beam Generator

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exceed 3 MV. Each diode should produce a 3 MV, 400 kA, 24 ns pulse of electrons or, if operated in a mismatched mode for better pinching conditions, a 1 MV, 650 kA beam. A 6-19 nH diode has been designed for operation in this mismatched mode. It is constructed with six 1.3 cm thick, 1.2 m diameter insulators and should have a flashover voltage slightly greater than 1.5 MV.

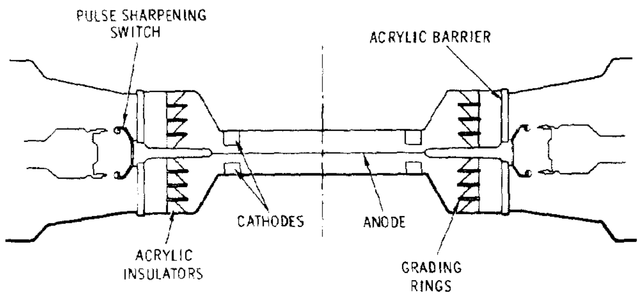


Figure 2. - Diode Sketch

Blumleins

The voltage pulses that are applied to the diode are generated from twelve pairs of transmission lines connected in a Blumlein configuration. These 22 Ω, oil-dielectric transmission lines are 1.2 m wide and 2.4 m long with a 10 cm separation between the electrodes. The electrodes are 3.2 mm thick steel plates welded onto one-half section of 10 cm diameter pipe with adequate supports to maintain a 1.6 mm flatness across the sheets. The 5 cm edge radius with a 10 cm spacing lowers the field enhancement at the edge to the point where the probability of breakdown at the edge is less than within the main body of the transmission lines due to the area dependence of the dielectric strength. Figure 3 is a photograph of the six stacks of the transmission lines.

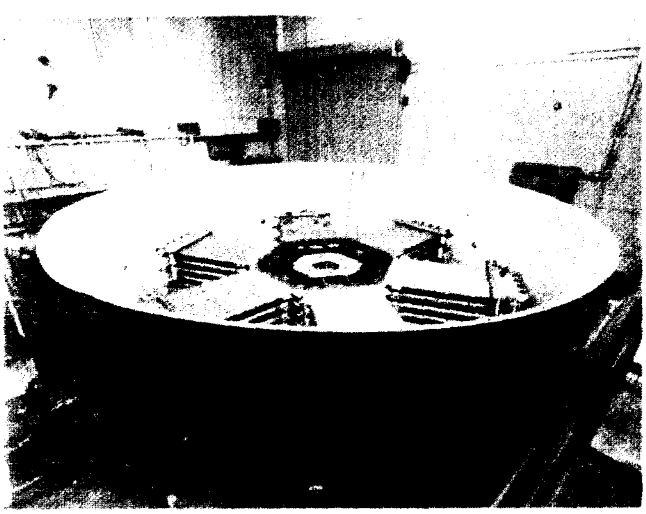


Figure 3. - Photograph of Harp Blumleins and Load Resistor

Each stack has five electrodes and forms two Blumleins with a common electrode in the center of the stack. This common electrode becomes the high-voltage terminal during the time while the Blumleins are being discharged. This arrangement minimizes any capacitive loading from the high voltage terminal to ground during discharge. Six Blumleins are connected in parallel around the circumference of each diode, as shown in Fig. 1 and 3. This arrangement produces an effective impedance at the diode of 7.3 Ω. If the transmission lines are charged directly from the Marx generator in 760 ns, the breakdown voltage of the transmission lines is 2.3 MV. By using intermediate storage capacitors, the charge time can be reduced to < 200 ns and the breakdown voltage can be increased to 3.7 MV. The supports for the transmission lines are polyethylene straps connected as shown in Fig. 3. Tests to determine the tracking voltage of the insulators resulted in arcs occurring between the electrodes of the transmission line rather than the insulator tracking. The Blumleins will be switched with 12 low-jitter, oil-dielectric rail switches recently developed at Sandia Laboratories for this application.[4] The configuration of these switches is shown in Fig. 4.

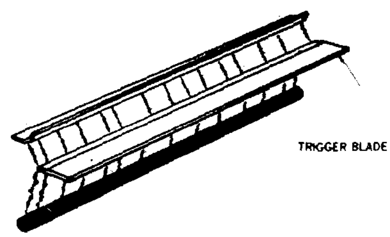


Figure 4. - Oil Rail Switch Electrodes

The trigger electrode (blade in Fig. 4) is a sharp edged, 3.2 mm thick brass plate. It is biased at approximately one-third of the transmission line charge voltage (-V) and geometrically located for minimum electric field enhancement during charge. For triggering, this electrode is rapidly (~ 20 ns) pulsed to +V. Both of the gaps between the main electrodes and the trigger blade are overvolted and close nearly simultaneously. At 2 MV an average of 10 channels closed, producing an 8 ns, 10-90 percent current risetime. The closure time of the switch varies with the voltage across the switch, as shown in Fig. 5.

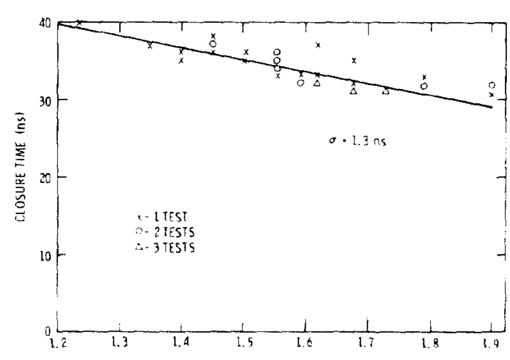


Figure 5. - Triggered Oil Switch Closure Times vs. Voltage Across Main Electrodes

The jitter is 1.3 ns. Spacing between the main electrodes is 6.9 cm and the self-breakdown voltage is 2.3 MV. Experiments also indicated that a trigger pulse amplitude as low as 0.44 V can be used and a jitter of < 2 ns maintained if the trigger electrode is located nearer to the ground electrode and biased accordingly (0.19 V). The low jitter operation of these switches should allow twelve Blumleins in parallel to be switched with minimal degradation to the output pulse waveshape. When the intermediate storage capacitors are used and the Blumleins are charged more rapidly, the switch will be operated at higher electric fields and should produce even faster current pulse risetimes.

As mentioned above, the low-jitter triggered switch operation is dependent on rapidly pulsing the trigger electrode with a +V voltage. In Harp, this voltage pulse must be applied to the twelve switches simultaneously. The pulses are produced by charging an 80 ns water dielectric PFL with a Marx generator to approximately 3 MV. An SF_6 spark gap connects this PFL to a system of oil-dielectric transmission lines that have equal length to all twelve switches, as shown in Fig. 1. The oil-transmission lines are coaxial and have a square outer electrode and cylindrical inner electrode. It has four junctions. One of these has the correct impedance match; others are mismatched due to size limitations. The transmission lines appear as open circuits before the main Blumlein switches close and voltage doubling occurs, recovering the voltage loss due to the mismatched transmission lines. The transmission lines provide 21 ns transient time isolation between each of the four nearest switches. An isolating resistor and switch separates the trigger electrode from these transmission lines. The energy left in the transmission lines after the main Blumlein switches close is absorbed in the isolation resistors.

Two-electrode, self-closing rail switches may also be used when the Blumleins are rapidly charged. Initial tests on one Blumlein with this switch produced 1.0 - 1.5 ns jitter and 10-90 percent risetimes of 6-9 ns when charged in 50-130 ns.[5] Subsequently, six of them have been tested simultaneously on one-half of the Harp Blumleins using a configuration similar to that shown in Fig. 6. The Marx generator output is attached to Line 2. The lower sets of transmission lines (1-2 and 2-3) were used as intermediate storage capacitors and charged the upper lines (3-4 and 4-5) through three gas switches,[6] one for each two stacks of transmission lines.

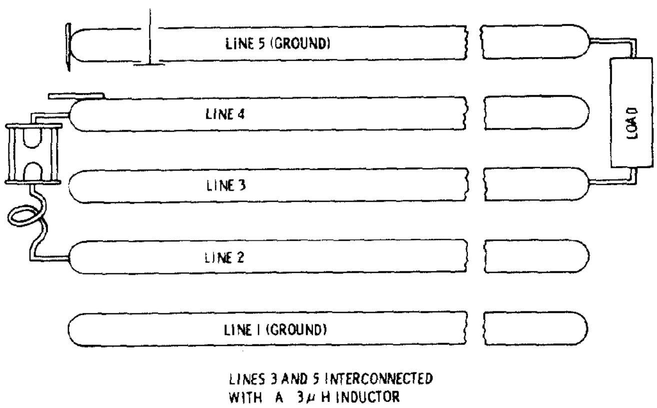


Figure 6. - Transmission Line Arrangement for Two-Electrode Switch Tests

Table I is a summary of the data from this experiment.

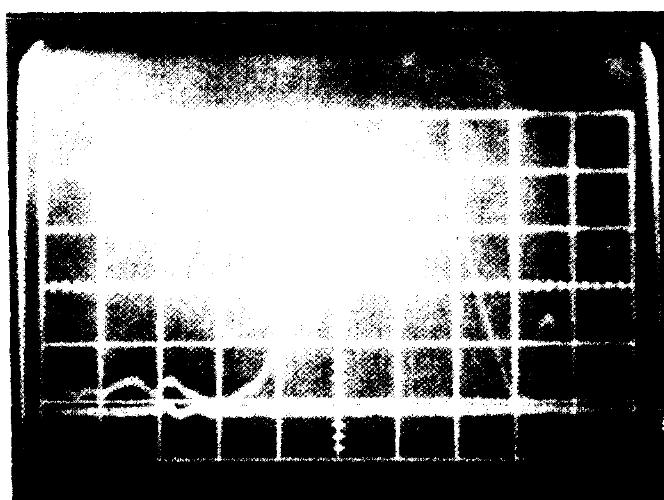
TABLE I

UNTRIGGERED MULTICHANNEL SWITCH DATA

Charge Time (ns)	Range of Closure Times (ns)	Single Switch Jitter (ns)	No. Bright Channels	Switch Risetime (ns)
90	3.9	1.6	4.2	8.8
120	4.8	2.1	4.1	9.4
130	5.5	2.6	3.2	9.7
170	7.3	3.2	2.5	11.0

The range of closure time is the average maximum time separation of the closure of the switches. The single switch jitter is inferred from this range of closure times and its standard deviation assuming a normal distribution. The jitter is slightly greater (2.6 ns as compared to 1.5 ns) than the jitter in the single Blumlein, two-switch experiment. The above data was taken at a lower voltage and includes the effects of jitter in the three gas switches.

Figure 7 is the output voltage wave shape produced across the load resistor when the lines were charged in 150 ns. The output risetime is 12 ns.



10 ns/cm

Figure 7. - Output Voltage Waveshape

Intermediate Storage Capacitors

As indicated in the discussion of the Blumleins, it is necessary to charge the transmission lines in < 200 ns to produce 3 MV output pulses. The faster charge is accomplished by utilizing three coaxial water-dielectric intermediate storage capacitors. The outer cylinder is 75 cm diameter and 1 m long. These capacitors will be charged by a Marx generator in approximately 700 ns and discharged through low-jitter 3 MV, SF_6 gas switches into the Blumlein transmission lines. The center element of the electrode stack must be connected to ground through an inductor. In Harp, one 4 μH inductor is used for each two stacks. The inductors must be at least 4 μH to minimize the discharging of the transmission lines after the Blumlein switches have closed. With this inductor and the circuit arranged to insure that the prepulse voltage remains less than 10 percent of the charge voltage, the three intermediate storage capacitors will charge the Blumleins in 175 ns. If it is desirable to charge faster than 175 ns, six intermediate storage capacitors, three positively charged and three negatively charged, could be used and connected, as shown in Fig. 8.[3] This arrangement is capacitively balanced and does not require connection from the center electrode to ground. If the prepulse voltage amplitude is maintained below 10 percent of the charge voltage, the charge time for this arrangement is estimated to be 125 ns. In this case, the prepulse voltage is generated because of the differing inductance and capacitance from the top and bottom plates to the tank. When attempts are made to balance these capacitances and inductances, the 125 ns charge time results.

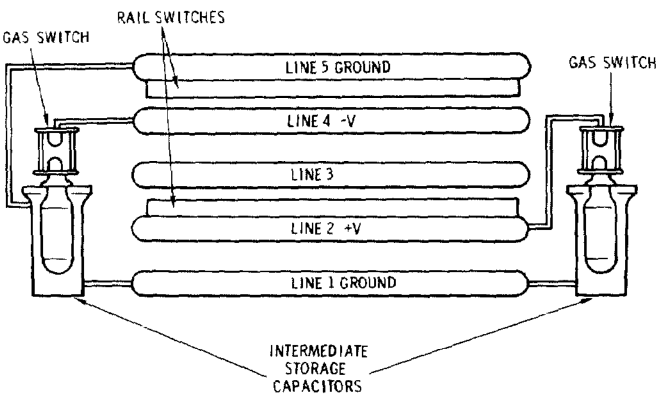


Figure 8. - Intermediate Storage Capacitor Plus-Minus Charging Arrangement.

Marx Generators

Both the Marx generator for charging the intermediate storage capacitors or Blumleins and the one for producing the trigger pulse are 2.3 MV, 125 kJ, 7 μH generators. They are constructed in the same tank with a configuration developed for the Marx generator in the Hydra electron beam generator.[6] Both sets of capacitors are charged from a single ± 60 kV, dc power supply that is connected such that one Marx has a positive output and the other a negative output. The jitter of these Marx generators was measured to be < 20 ns.

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