REBLE, A RADIALLY CONVERGING ELECTRON BEAM ACCELERATOR*

by

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ABSTRACT

The Reble accelerator at Sandia Laboratories is described. This accelerator was developed to provide an experimental source for studying the relevant diode physics, beam propagation, beam energy deposition in a gas using a radially converging e-beam. The nominal parameters for Reble are 1 MV, 200 kA, 20 ns e-beam pulse. The anode and cathode are concentric cylinders with the anode as the inner cylinder. The radial beam can be propagated through the thin foil anode into the laser gas volume. The design and performance of the various components of the accelerator are presented.

Introduction

The excitations of gas lasers with relativistic electron beams has received increasing attention in recent years because of many successful demonstrations of efficient conversion of e-beam energy into laser energy.[1] The attractive feature of e-beam pumping schemes for high power gas lasers is the high power capabilities of the e-beams. The development of short pulse e-beam accelerators suitable for laser excitation are required for high gain laser systems such as hydrogen flouride.[2]

Three e-beam geometrical configurations have been applied to gas laser excitations: transverse, coaxial and converging radial beams. In the transverse scheme, the axis of propagation of the e-beam is perpendicular to the laser axis. For the coaxial mode, the two axes are parallel. In the radial mode, the electron beam converges radially into the laser gas. Of these three geometries, the radial e-beam mode possess a number of inherent advantages for the excitation of high power lasers. Rebel is a test facility presently being used for experimental studies of e-beam excitation of gas lasers using short pulse, high power, radially converging e-beams. Among the topics to be investigated are: the diode emission characteristics for this geometry, e-beam propagation, and beam energy deposition in the gas.

General description of Reble accelerator

Figure 1 is an artist's rendition of the Reble facility. The design for this accelerator is an application of the pulse power technology being developed at Sandia for the e-beam fusion program.[3,4] The main components of the accelerator consist of a Marx generator which

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pulse charges an intermediate energy storage capacitor through a 5 μH inductor. The intermediate store is discharged via a selfbreaking gas switch into two sets of oil dielectric pulse-forming transmission lines (PFL). Each of the PFL's is equipped with a selfbreaking, multichannel, oil switch. The output of the PFL's is fed to the diode via parallel plate, oil dielectric transmission lines. Because Reble uses a pre-existing Marx generator, substantially more energy is stored in the Marx than is required to charge the intermediate store and PFL's. A crowbar system is used to divert the remaining energy in the Marx into a resistive load.

The Marx generator

The Marx generator is an adaptation of the Reba[5] Marx generator. The relevant characteristics are summarized in Table 1.

TABLE 1
Marx Generator Parameters

Number of stages	20	
Capacitance per stage	0.5	μF
Maximum charge voltage	±100	kV
Maximum total energy	50	kJ
Output capacitance	25	nF
Series resistance	10	Ω
Series inductance	5	μH

The Reble Marx has a slightly different configuration that results in a lower inductance per stage than the Reba Marx.

Intermediate energy storage capacitor

The dielectric strength of liquids is strongly time dependent. If the Marx generator charged the PFL's, the charge time would be 800 ns. With an intermediate storage capacitor, the PFL can be charged in 120 ns allowing the use of lower impedance PFL's constructed with electrodes that have substantially higher field enhancement at the edges. This storage capacitor is a modified version of those used in Proto I [3,4] and Proto II.[6] The modification consisted of removing the straight cylindrical section of the inner electrode to reduce the capacity from 7.5 nF to 2.9 nF. This capacitor was installed 10 months ago; since then, it has operated reliably at the maximum charge voltage of 2 MV and has not required any maintenance or further deionization of the water.

The intermediate store charges the pulse-forming lines via a self-breaking SF_6 gas switch. This switch uses a segmented insulator housing developed by Physics International Inc. and was designed for a maximum operating voltage of 3 MV.[7]

The pulse-forming lines (PFL) and oil switches

The design for the PFL is based on work done originally by D. L. Johnson[8] at Sandia. The rapid charging of the PFL's allow the use of thin aluminum plates as electrodes. They are arranged in a configura tion of two sets of double transmission lines as is shown in Fig. 1.

This arrangement was chosen to provide as symmetric a feed to the diode as was possible within the constraints of the main oil tank. The relevant characteristics of the PFL are summarized in Table 2.

TABLE 2
Oil Dielectric PFL Characteristics

Electrode dimensions	122 cm x 203 cm x 0.95 cm
Spacing	10.2 cm
Single-line impedance	22 Ω
Output impedance	5.5 Ω
Two-way transit time	20 ns
Characteristic charge times	120 ns
Maximum charge voltage	2 MV

The lines are supported with polyethylene spacers equipped with metal rings to shield the triple point edges. This design has proven reliable up to the maximum charge voltage.

The edge-plane, selfbreaking oil gaps are located at the output end of the PFL's. The edge is made of brass and the plane is steel. Both are 91 cm long. The switching work by Johnson[8] indicates that the simultaneity of breakdown between two edge-plane oil gaps can be as small as 2 ns for a charging time of 130 ns or less. With the slightly different geometry of the switches in Rebel, the average difference in breakdown times are 3.8 ns, and 4.7 ns for 1 MV and 0.5 MV operation, respectively. This measurement implies that the rms jitter in the closure time of each switch is 2.7 ns at 1 MV and 3.3 ns at 0.5 MV. During the testing of these switches, it became apparent that completely symmetric charging paths must exist for the two transmission lines or the difference in closure times of the two switches can be increased substantially.

The 10-90 voltage risetime in the transmission lines is 8 ns. This risetime implies that the switches are operating in a multichannel mode and damage to switch electrodes confirms this conclusion. The PFL's were not designed to allow observation of the number of channels. In previous edge-plane experiments, multichannel operation was observed.[4,8] Johnson's analysis indicates that 9 channels must close in each switch to given an 8 ns voltage risetime.

The transmission lines

The output of the PFL's are fed to the diode via parallel plate transmission lines similar in design to the PFL. Polyethylene spacers are also used in this section. Due to the geometric constraints placed by the main oil tank, the transmission lines must make 90-degree turns before reaching the diode. Analysis of the diode current waveforms indicate that this bend does not add any significant inductance to the system.

The Marx crowbar system

As mentioned in the introduction, the large mismatch that exists between the Marx generator and the other components in the system mandates that a means be provided for discharging the energy remaining in the Marx after the pulse-forming lines have been charged. This is accomplished with a crowbar system which uses a triggered gas switch to divert the remaining Marx energy through a 5 ohm load to ground. This switch is a minitrigatron design similar to that used in Proto II. The pulse to the trigger electrode is provided by a 2-stage Marx generator charged to $\pm$ 50 kV. The crowbar triggering sequence is initiated by a signal from the output voltage monitor of the Marx and delayed the proper amount.

The Diode

Another unique feature of Reble is the diode. A sketch is shown in Fig. 2. The anode and cathode are concentric cylinders. The inner cylinder (20 cm in diameter) is grounded and acts as the anode. The interior volume is the laser gas chamber. This diode design makes it relatively easy to change the cathode configuration. Allowance for the use of sharp edge emitters is also provided. By using thin foil anodes, the radial beam generated at the cathode can be transported through the foil into the laser gas.

Typical voltage, current, power and impedance waveforms obtained are shown in Fig. 3; the corresponding electron spectrum, is also shown. The profile of the radial beam at the surface of the anode has been measured using a radiochromic material. This material undergoes a change in optical density when subjected to ionizing radiation. The experimental arrangement used for these measurements was such that only electrons with energies greater than 300 keV irradiated the material. The profile of the beam along the length of the anode obtained using a cathode with 2 blade emitters is shown in Fig. 4. Also shown in this figure is the spatially correlated position of the 2 blades. Measurements of beam profiles show that the non-uniformity of the beam at the anode can be held to less than 20 percent without much difficulty. For these measurements, a number of cathode materials and configurations were investigated. Cathodes made of 0.005 cm thick annular metal foils gave the most desirable results. They exhibited small or negligible turn-on times, gave more uniform current emission, and had better shot-to-shot reproducibility than any other cathode used. One feature which is characteristic of blade emitters was the appearance of a regular pattern in the current density measured along the circumference of the anode. This pattern appeared as strips of higher current density placed at regular intervals and running perpendicular to the plane of the blades. This feature of blade emitters has been observed previously in plane parallel diodes; and has been explained by Toepfer and Bradley as arising when the current-carrying plasma at the surface of the cathode undergoes a tearing mode instability.[9]

Discussion and Conclusions

The Reble facility at Sandia is capable of reliably delivering a 1 MV, 200 kA, 20 ns pulse in the form of a radially converging beam using a diode configuration suitable for studies involving beam propagation and energy deposition in a laser gas medium. These studies are presently under way and preliminary results will be presented elsewhere.[10] Further work on beam propagation and energy deposition is planned. These measurements will be compared to electron-photon Monte Carlo transport code calculations[11] which indicate that 50-75 percent of the e-beam energy can be uniformly deposited in the gas using this geometry.

One of the principal advantages of the radial geometry is that it lends itself readily to a modular design. Figure 5 is an artist's drawing of an accelerator which has five of these diodes located along a laser chamber. The radial discs that separate the diodes and provide the return current path serve to magnetically isolate each of these cathodes. Each of the diodes can be operated below the critical current so that a uniform current density can be generated at the anode.

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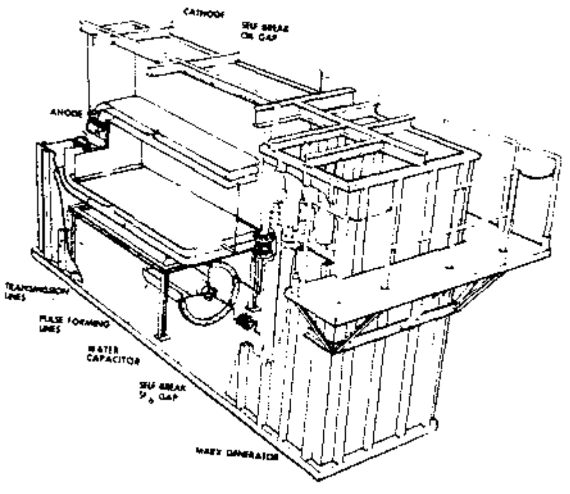

Figure 1. Reble

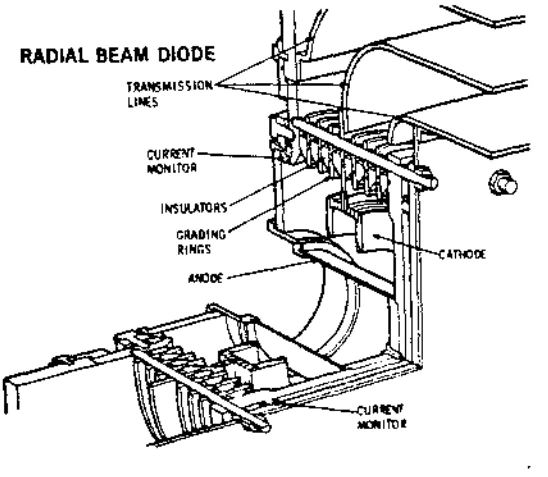

Figure 2. Reble Diode

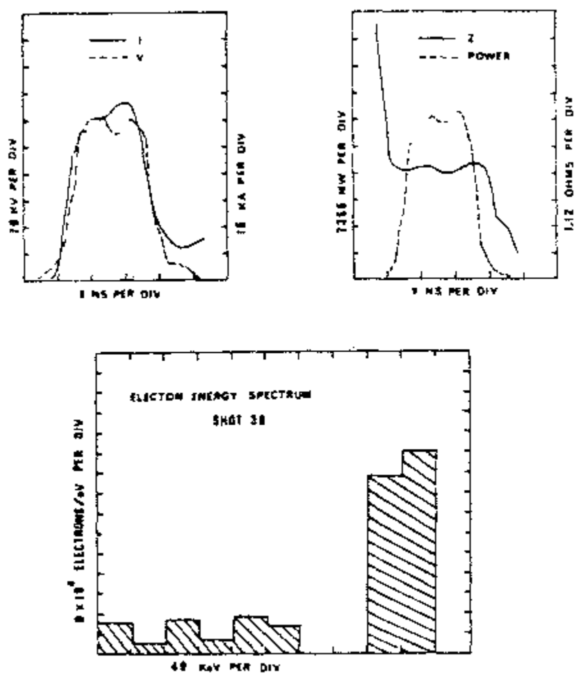

Figure 3
Typical diode waveforms. The voltage waveform has been corrected for the inductive contribution. The electron spectrum was obtained by unfolding the voltage and current waveforms.

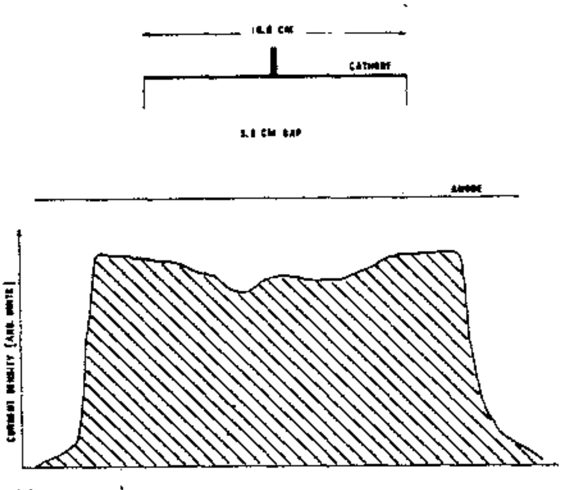

Figure 4. Beam profile at anode along Z-axis.

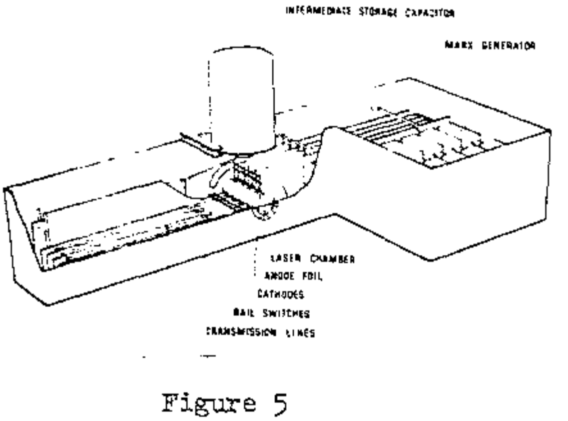

Figure 5
Modular accelerator for laser excitation using radial e-beams.