THOR, A LONG-PULSE ELECTRON BEAM GENERATOR: DESIGN AND PERFORMANCE CHARACTERISTICS

R. F. Schneider, J. D. Miller, W. C. Freeman, M. J. Rhee,[a),b)]
D. J. Weidman,[a)] J. Pasour[c)], and K. T. Nguyen[c)]

Naval Surface Warfare Center, White Oak Laboratory
10901 New Hampshire Avenue
Silver Spring, Maryland 20903-5000 USA

[a)]Advanced Technology and Research
[b)]University of Maryland
[c)]Mission Research Corporation

Summary

Thor is a long pulse electron beam generator. The pulse generator portion of the machine is based on a 4 MV, 27 stage resistive-capacitively coupled (hybrid) Marx bank. The total Marx capacitance is 24 nH. When the Marx erects, the full voltage is applied to a 1.29 μH inductance and 21 Ω resistance in series with the load. In parallel with the resistor and load is a capacitive filter stack. In parallel with the load is a resistive voltage divider/monitor, and a triggerable crowbar switch. The pulse generator is capable of supplying 4 MV, 10 kA, for a variable pulselength from 250 ns to 2 μs. The overshoot on this pulse is approximately 15% with a droop of 5% over 1 μs into a 400 Ω resistive load.

A diode has been attatched to this pulser. This diode is similar to one that has been used on a pulser with comparable parameters. The pulser and diode together comprise Thor. Preliminary experiments are underway to characterize the electron beam produced by the Thor diode. In particular, electron beam current, energy, and emittance are studied. The current is measured with a conventional Rogowski coil and Faraday cups. The emittance is measured with a slit-hole emittance meter. The results of these measurements reveal information about the physics of the long pulse field emission diode. The details of the experimental results will be presented and compared with simulations.

Introduction

Thor is a long-pulse electron beam generator which was built for Directed Energy (DE) research at the Naval Surface Warfare Center, White Oak Laboratory. The pulse power generator[1] is based on Marx technology. It is composed of 54-1.3 μF, 85 kV capacitors, arranged in a configuration developed at Sandia which has generally been referred to as a PBFA style Marx. The Marx output is fed into a 1.29-μH inductor which is connected in series with a 21-Ω resistor and a variable load resistor to ground. In parallel with the 21-Ω and load resistors is a 300-Ω resistor and a capacitive filter stack. See Fig. (1). The purpose of the inductor and the filter stack is to correct for overshoot and droop in the Marx output voltage. An externally triggerable crowbar switch is connected in parallel with the load through an 8-Ω resistor in order to provide a controllable pulsewidth from 0.25 to 2 μs. The generator has been tested at up to 80 kV capacitor charging voltage which gives a 4 MV, 10 kA output pulse into a 400-Ω load resistance.

In parallel with the load resistor, an electron beam diode load has been attached. This diode was designed at Sandia[2] for electron beam propagation research. The cathode is a field emission type using velvet. The cathode emitting surface is approximately 10 cm diameter, with an anode-cathode gap spacing of 40 cm. The electron beam is extracted into drift tubes with a focussing coil immediately downstream of the anode. This coil may be used to match the electron beam onto a pre-formed Ion Focused Regime (IFR) plasma channel.

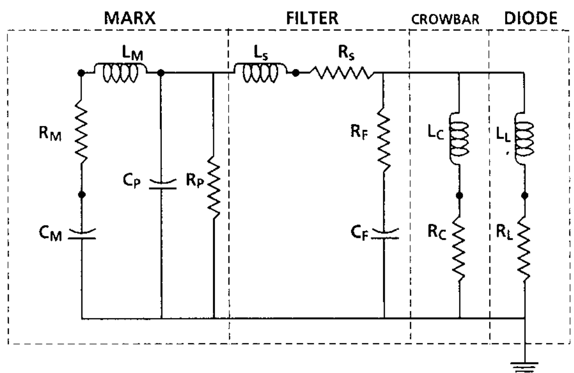

Fig. (1). Basic circuit description of the long pulse generator. The Marx capacitor bank, pulse waveform filter, crowbar and diode load elements are identified.

Particle Simulations

A fully electromagnetic 2-1/2-dimensional Particle-in-Cell code[3] has been used to simulate the Thor diode.[4] The simulation geometry and electron trajectories are shown in Fig. (2). An anode-cathode gap spacing of 40 cm, cathode diameter of 10 cm, a 10 cm drift tube diameter, and an anode diameter of 20 cm are assumed. The electron beam is focused by a magnetic field coil placed at z=95 cm, just downstream of the anode. The trajectories shown in the figure are for a focussing field of 850 Gauss, in addition simulations were performed for focussing fields of 700 Gauss and 1000 Gauss. As can be seen from Fig. (2), the beam seems slightly overfocussed with 850 Gauss, however this case gives the largest current, 1.6 kA at 2.5 MV compared to 1.1 kA at both 700 and 1000 Gauss. This is due to the beam intercepting

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14. ABSTRACT
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B-Field (Gauss)	Minimum Radius (cm)	Current (kA)	Normalized Emittance (rad-cm)
700	2.0	1.1	0.25
850	1.0	1.6	0.7
1000	0.8	1.1	1.0

Table (1). Summary of PIC simulation results for initial 2.5 MeV, 1.8 kA, 0.2 rad-cm beam.

the 10 cm diameter drift tube (which begins at z= 1.25 m) for the 700 Gauss case, whereas for 1000 Gauss, the beam is overfocussed with a resulting loss of beam electrons. In all of these cases the current emitted from the cathode is 1.8 kA. The minimum beam radius is 1.0 cm with 1000 Gauss field, and 1.25 cm with a 850 Gauss field. In order to avoid the beam loss in the 10 cm diameter drift tube at 700 Gauss, a 15 cm diameter was chosen for

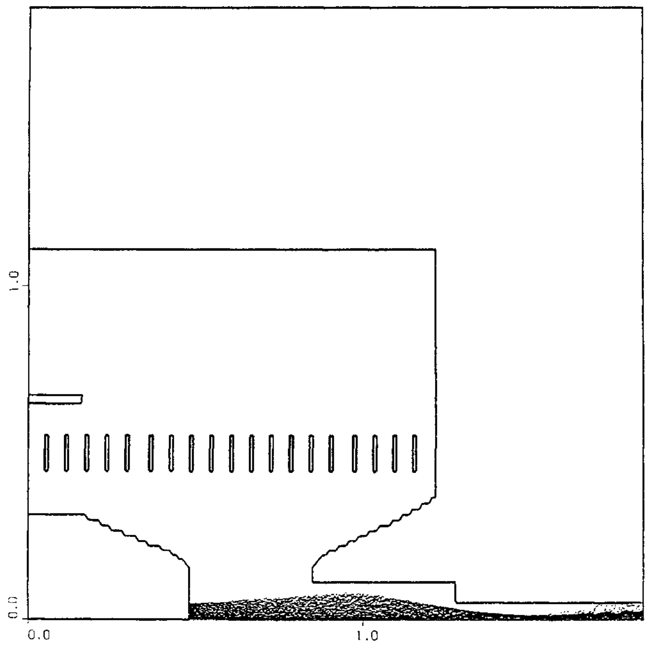

Fig. (2). PIC simulation geometry and electron trajectories for a 850 Gauss focussing field centered at z=95 cm. The bottom of the figure is the diode axis. The electrons are emitted from the cathode at z=47 cm, the anode is at z=87 cm, and the magnetic field is centered at z=95 cm.

The nonlinear focussing of the coil has a negative impact on beam quality or emittance. The initial normalized beam emittance is 0.2 rad-cm for all cases. The emittance increases the least for the 700 Gauss field, as expected, to about 0.4 rad-cm. The simulation results are summarized in Table (1).

Experiments

The Thor electron beam is extracted through a 20 cm diameter anode aperture. A Rogowski coil has been placed in the anode to measure the net beam current. The Rogowski consists of 120 turns with a cross sectional area of 0.435 cm^2. The risetime of the coil is estimated to be 25 ns. A 7.5 cm diameter graphite disc connected to a 10.3 mΩ current viewing resistor is placed downstream approximately 70 cm from the anode. The risetime of this diagnostic is 2 ns and is determined by the resistor response. Figure (3) shows the Marx voltage, Marx trigger, Rogowski and current viewing resistor waveforms for a 2.5 MV, 1 μs pulse.

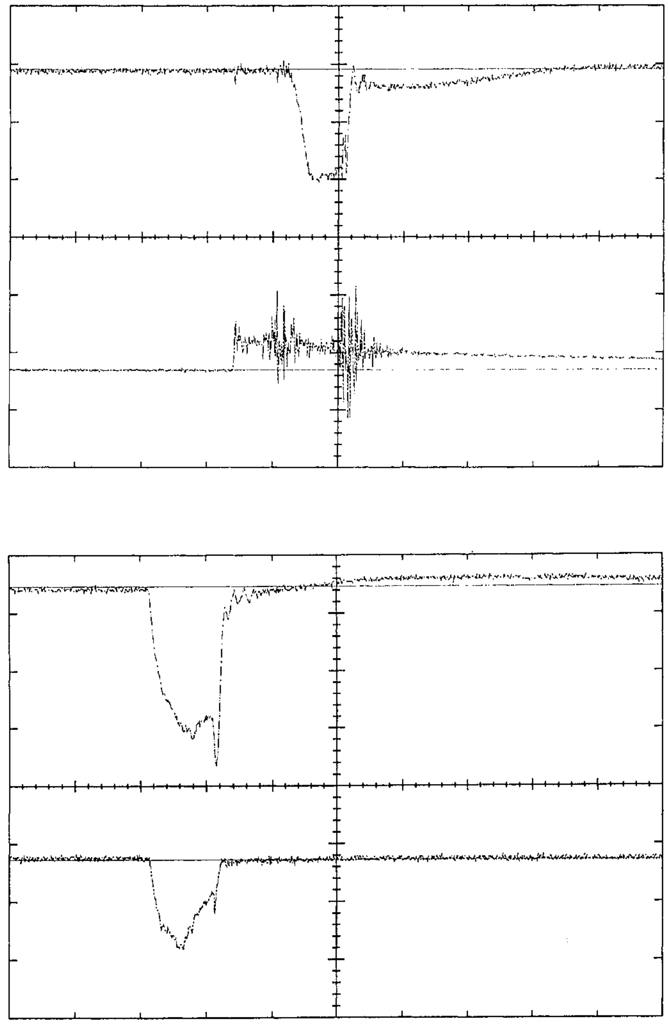

Fig. (3). Output waveforms for Thor.
Top:
Upper: Marx output voltage (984 kV/Div)
Lower: Marx trigger
Bottom:
Upper: Anode current (1 kA/Div)
Lower: Transported current (1 kA/Div)
1 μs/Div timesweep.

Beam emittance measurements are made with a slit-hole emittance meter.[5] The concept of emittance measurement using this emittance meter is shown in Fig. (4). The electron beam impacts on a series of Tantalum bars which selects a series of sheet beamlets at locations x_i which impact on a detector a distance L downstream. The beam temperature at a particular beamlet location may be inferred from σ_i/L. The overall beam profile may be determined from $\sigma_i\beta_i$. Together, these will give information about the emittance of the electron beam. Preliminary results obtained by operating this diagnostic in a time integrating mode indicate an upper bound of beam emittance to be 4 cm-rad. These results are indicative of beam motion during the microsecond pulselength and may be lower at any instantaneous time.

A simple magnetic electron energy analyzer[6] may be used to obtain the electron beam energy spectrum. See Fig. (5). This compact energy analyzer utilizes two 2.54 cm square rare earth magnets to produce a uniform 0.95 T field. the electrons strike a detector, either a phosphor, scintillator, or Cherenkov emitter. A photograph of the position of light given off from the detector will yield the kinetic energy (T) of the electrons according to the relation,

$$T = [(ecB\rho)^2+(mc^2)^2]^{1/2}-mc^2$$

where ρ is the radius of the electron trajectory, B is the magnetic field, c is the velocity of light, m is the electron rest mass, and e is the electronic charge.

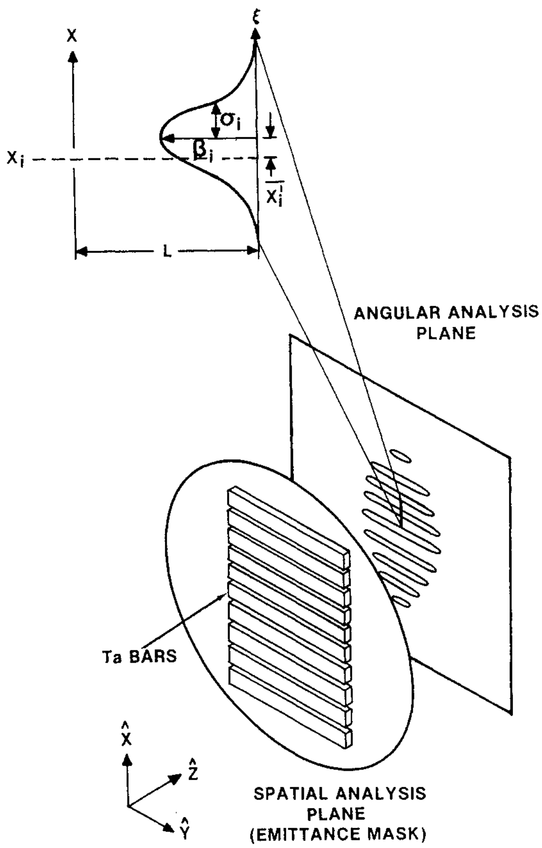

Fig. (4). Emittance meter and analysis of a scan of the peak produced by one slit. The peak height, β_i, the rms width, σ_i, and the mean displacement x_i' as well as the distance from the slit to detector are shown. The electron beam is incident along the z-axis.

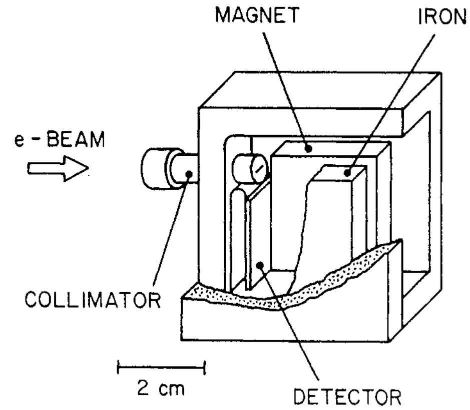

Fig. (5). A cutaway view of the magnetic electron energy analyzer.

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