LONG PULSE ELECTRON BEAMS

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Abstract

Pulsed power accelerators used for intense relativistic electron beam applications have generally had pulse lengths of 10 - 100 ns. There are research areas where a pulse length of several 100's of nanoseconds is required or might be advantageous (e.g. long distance propagation, microwave generation, free electron lasers). In the last 4 years several long pulse accelerators have come on line [1,2,3]. In this report the emphasis is on measurement of the parameters of a long-pulse beam. The Troll accelerator produces the beam, and a conditioning cell is used to adjust beam parameters. This system has typically been operated with the following output parameters: 2.5 MV, 1-2 kA, 0.5-1 μs.

I. System Elements

A schematic of Troll [3] and the conditioning cell is given in Fig. 1. The basic elements of Troll are a Marx generator and a long-pulse diode. A long pulse is obtained by connecting the Marx directly to the diode without the traditional intermediate pulse forming line. The Marx output is shaped so as to obtain a relatively square pulse.

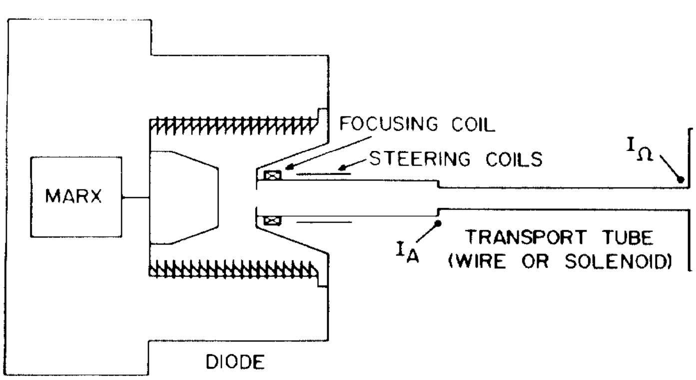

Figure 1. Troll and conditioning cell.

The pulse leading edge is adjusted with an external RC circuit, and the pulse trailing edge is defined with a crowbar switch. The Troll beam has been mainly used for long-pulse beam propagation research where beam initial conditions are frequently critical [4]. Therefore, a conditioning cell is attached at the diode output which allows adjustment of beam parameters. The conditioning cell may be divided into two regions. The first region contains a focusing coil and steering coils. The focusing coil is used to select beam size, and steering coils are used to correct minor errors in beam centering. The second region contains a transport tube, where two different modes of operation have been used. In the first mode, wire conditioning is used to improve beam quality in terms of beam centering [5]. In the second mode, solenoidal transport is used to optimize current amplitude and pulse flatness.

The long-duration, high-voltage Marx generator was supplied by Maxwell Laboratories [6]. A simplified schematic, Fig. 2, shows three major components: Marx capacitor bank, snubber network, and diverter switch. The Marx bank contains 44 stages; stage 1 consists of two 1 μF capacitors connected in parallel, stages 2 through 44 consist of two 0.5 μF capacitors connected in series through spark gaps. All 44 stages are connected in series during Marx erection, giving an open circuit voltage of 4.35 MV at the maximum capacitor charging voltage of 50 kV. The Marx capacitor bank output is connected in series with a 20 ohm resistor. This is a liquid resistor which absorbs the stored energy when the Marx is crowbarred with the diverter. Timing of the diverter trigger is adjusted to control the pulse width. Stray capacitance from the Marx generator to ground causes voltage overshoot and ringing at the pulse leading edge. The snubber network is an RC circuit which damps these oscillations. The snubber RC time constant is 140 ns. The Marx generator voltage pulse is monitored by a resistive divider.

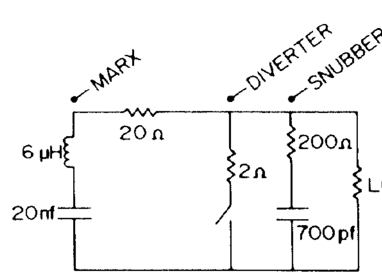

Figure 2. Troll circuit elements.

[a]Titan/Spectron
[b]Mission Research Corporation
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The long-pulse diode was supplied by Sandia National Laboratories [7]. It is an axial stacked-ring diode.The anode-cathode gap is adjustable by attachment of cathode supports with different lengths. The results obtained in this report used a 27 cm gap setting. The electron source is a 10 cm diameter velvet disk positioned in the center of the cathode holder. The cathode holder is painted with an emission suppressant. The foilless anode has a 10 cm diameter aperture.

The focusing coil is a pancake coil which is 10 cm long with a 21 cm bore. For standard operating conditions the focusing coil is adjusted to produce a peak field on axis of 700 Gauss, which gives a 5 cm beam radius at the entrance to the transport tube. This radius was measured with an x-ray pinhole camera and represents the spot radius which contains all of the beam electrons. The corresponding Gaussian radius would be smaller. The sensitivity of beam radius to magnetic field for the focussing coil (Δ radius/Δ B-field) was measured as 3 mm/10 Gauss. The focusing coil is a pulsed coil which has a 0.5 second period. Timing is adjusted so that the beam is produced at the peak of the coil's current pulse.

The steering coils are two pairs of Helmholtz-like coils, one pair for horizontal deflection, and one pair for vertical deflection. Each coil is shaped in a rectangle, 50 cm long x 26 cm wide. For standard operating conditions it was found the beam was best centered with a vertical field of 2.5 Gauss, and a horizontal field of 0 Gauss. The steering coil fields are operated steady state.

Rogowski coils are located at the entrance and exit of the transport tube to measure beam currents I_A and I_Ω. Performance of the conditioning cell with wire conditioning and solenoidal conditioning is discussed in Sections III and IV.

II. WAVEFORMS

Voltage and current waveforms are given in Fig. 3. The voltage is measured at the Marx output. The current waveform is the beam current measured at the entrance to the transport tube. It has been highly repeatable over hundreds of shots.

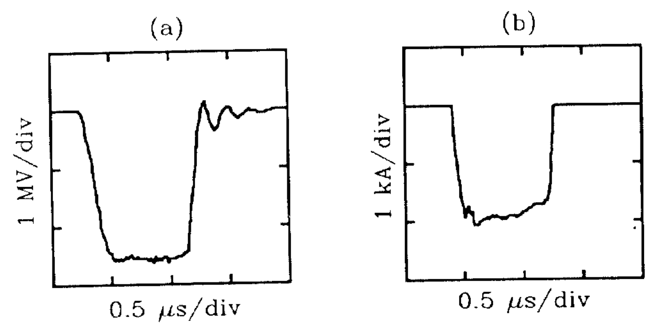

Figure 3. (a) Marx generator voltage, (b) beam current.

III. WIRE CONDITIONING MODE

For operation in the wire conditioning mode, the transport region contains a 0.1 mm diameter wire which both electrostatically focuses the beam and damps transverse oscillations. The wire is held on axis with a tripod configuration of wires at either end. Upstream, the wire was grounded to the vacuum drift tube; downstream, the wire was connected to ground through an inductor. The wire typically survives from 10 to 30 shots. Figure 4a shows the beam current, I_A, where the diverter was triggered to terminate the pulse at 500 ns. The corresponding current at the exit of the transport tube, I_Ω, is given in Fig 4b. Almost 50 % of the total current has been lost and pulse flatness has degraded. However, transverse oscillations were suppressed.

Beam radius was measured at the exit of the transport tube (the end of the wire) by imaging the light emitted from a Cherenkov target[4]. Beam emittance was measured by observation of radius expansion vs propagation distance for vacuum propagation. For an initial beam segment, beam radius was 3.0±0.5 cm, and beam emittance was 0.3±0.03 rad cm. The initial beam offset was ±0.4 mm, and the angular offset was less than 21 mrad.

IV. SOLENOIDAL CONDITIONING MODE

For operation in the solenoidal conditioning mode, a solenoidal magnetic field was used to confine the beam in the transport tube. The solenoid is 1.5 m long. The solenoidal field which gave optimum results was 300 Gauss. Figure 4c gives I_Ω which is almost identical to I_A.

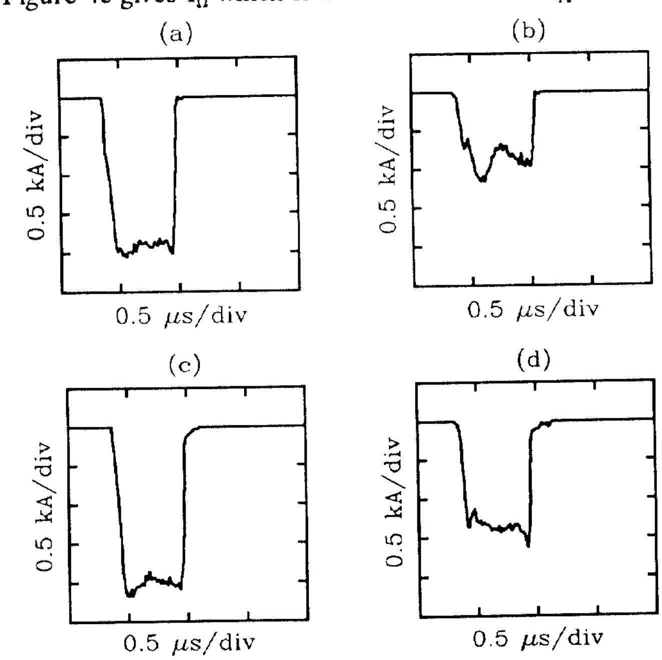

Figure 4. Beam currents: (a) I_A, (b) I_Ω with wire conditioning, (c) I_Ω with solenoidal conditioning, (d) I_Ω with solenoidal conditioning and aperture.

For some beam propagation work it has been desirable to reduce the level of beam current. For this application an 8 cm diameter aperture was inserted near the transport tube exit. Results are shown in Fig. 4d. Using solenoidal conditioning with an aperture, and the Cherenkov target diagnostic, the initial beam radius varied between 1 and 2 cm from shot to shot. A sample of the change in beam profile throughout the pulse duration is given in Fig. 5, where beam profiles corresponding to different times into the pulse (beam slice times) are shown. A segmented Faraday cup was used to obtain this data. In the shot of Fig. 5 the beam radius decreased for later times into the pulse, although this was not noted as a general trend throughout many shots. The beam profiles do consistently fit a Gaussian distribution from shot to shot.

V. SUMMARY

Numerical results are summarized in Table I. The wire conditioning mode excels in reducing transverse oscillations and in centering the beam. The solenoidal conditioning mode offers almost 100% current transport and maintains the flat pulse shape produced by the diode. The wire mode does require increased maintenance as compared with the solenoidal mode, since the wire must be replaced at frequent intervals. The attainment of square voltage and current pulses is a stressing challenge particularly encountered in the production of long pulse electron beams, as opposed to shorter pulse beams (i.e. <100 ns). Therefore, the nearly square pulse shapes shown in Fig. 3 are significant results.

Table I. Beam parameters

	Troll	Wire Mode	Solenoid Mode	Solenoid Mode (with aperture)
Beam Current (kA)	2	1	2	1.2
Beam Radius (cm)	5[a]	~3[b]		1-2[b]

[a]time integrated, spot radius
[b]initial beam slice, Gaussian radius

VI. ACKNOWLEDGEMENTS

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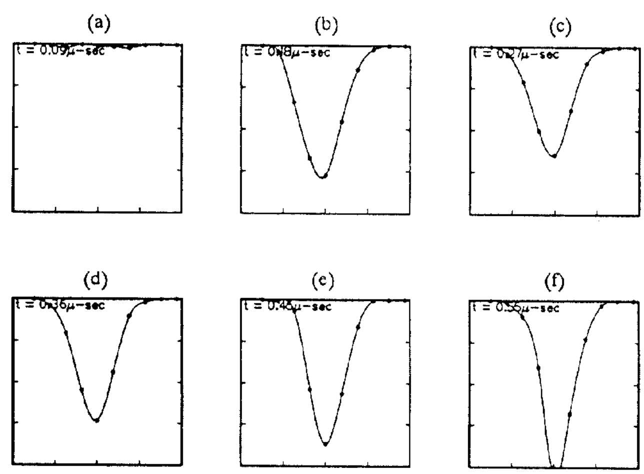

4 cm/div

Figure 5. Beam profiles for various slice times, with solenoidal conditioning.
(a) 0.09 μs (b) 0.18 μs
(c) 0.27 μs (d) 0.36 μs
(e) 0.45 μs (f) 0.55 μs