DESIGN AND PERFORMANCE OF THE MARX GENERATOR FOR THE DARHT SECOND AXIS ELECTRON INJECTOR*

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Abstract

The injector for the second axis of the Dual-Axis Radiographic Hydrotest Facility (DARHT II) is now undergoing commissioning tests at Los Alamos National Laboratory. A Marx generator develops a 3.2 MV, 2 μs pulse that is applied to the diode through a high voltage (or Marx) dome, current stalk and high voltage insulator column. The 2 kA electron beam source is a 165-mm-diameter thermionic dispenser cathode operating near 120 kV/cm. The extracted beam enters a series of eight pulsed power-driven injector induction cells that accelerate the beam to approximately 4.5 MeV. The beam then passes through a beamhead clean-up zone (BCUZ) to “scrape off” the off-energy portion of the beam (the beam leading edge and, to a lesser extent, the beam trailing edge). A crowbar switch fired at the end of 2 μs produces a short fall time.

This paper focuses on the electrical and mechanical design and testing of the Marx generator. The Marx consists of 88 stages, each half stage of which is a +/- 50 kV type E PFN. The Marx was tested for over 8000 shots before shipment to Los Alamos and demonstrated 6 ns jitter and good reliability with only 8 prefires out of 5000 shots. At the end of December 2002, nearly 800 shots have been fired in the process of commissioning the DARHT machine. The results of both series of these tests are given in this paper.

I. INTRODUCTION

The first axis of DARHT utilizes a well-engineered conventional Linear Induction Accelerator (LIA) to produce a single high-resolution x-ray image. Hydrotesting needs require production of four high-quality images over a time-span of 2-microseconds with the second axis of DARHT. This requirement is met with a 2-microsecond pulse-width injector and LIA whose output is chopped into four pulses of variable pulse-width and spacing. A layout of the second axis is shown in Fig. 1.

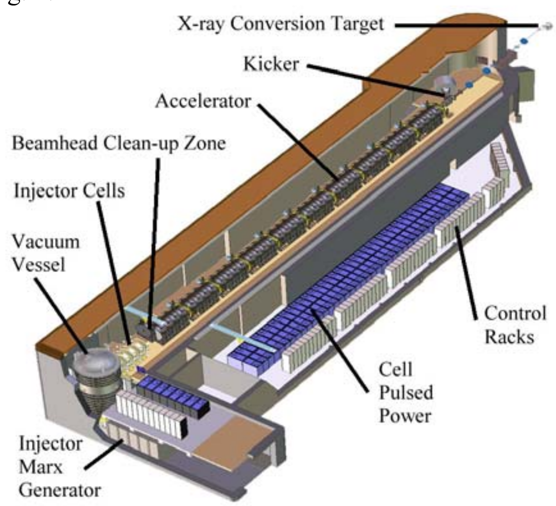

Figure 1. Layout of the 2-microsecond pulse-width DARHT second axis accelerator system.

Space restrictions within the existing DARHT facility forced the injector [1] to occupy two levels. On the bottom level is the Marx prime power feeding a vertical insulating column and stalk that drives a flat, 165-mm dia. thermionic dispenser-cathode [2] with polished stainless steel electrodes. The 444.5-cm tall, oil-filled insulator

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14. ABSTRACT

The injector for the second axis of the Dual-Axis Radiographic Hydrotest Facility (DARHT II) is now undergoing commissioning tests at Los Alamos National Laboratory. A Marx generator develops a 3.2 MV, 2 ìs pulse that is applied to the diode through a high voltage (or Marx) dome, current stalk and high voltage insulator column. The 2 kA electron beam source is a 165-mmdiameter thermionic dispenser cathode operating near 120 kV/cm. The extracted beam enters a series of eight pulsed power-driven injector induction cells that accelerate the beam to approximately 4.5 MeV. The beam then passes through a beamhead clean-up zone (BCUZ) to scrape off the off-energy portion of the beam (the beam leading edge and, to a lesser extent, the beam trailing edge). A crowbar switch fired at the end of 2 ìs produces a short fall time. This paper focuses on the electrical and mechanical design and testing of the Marx generator. The Marx consists of 88 stages, each half stage of which is a +/- 50 kV type E PFN. The Marx was tested for over 8000 shots before shipment to Los Alamos and demonstrated 6 ns jitter and good reliability with only 8 prefires out of 5000 shots. At the end of December 2002, nearly 800 shots have been fired in the process of commissioning the DARHT machine. The results of both series of these tests are given in this paper.

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column [3] has both alumina and Mycalex insulating rings. Fig. 2 shows a layout of the injector. Hydraulic umbilical cables run along the length of the Marx tank and drive an AC generator and power supplies inside the Marx dome to heat the cathode. The aluminum stalk connecting the Marx and cathode domes not only connects the two electrically but also contains cabling for the heater current, the bucking coil solenoid and temperature sensors as well as water cooling for the cathode dome and a hydraulic hexapod system for positioning the cathode. The vacuum vessel is 4 meters diameter and 9 meters tall.

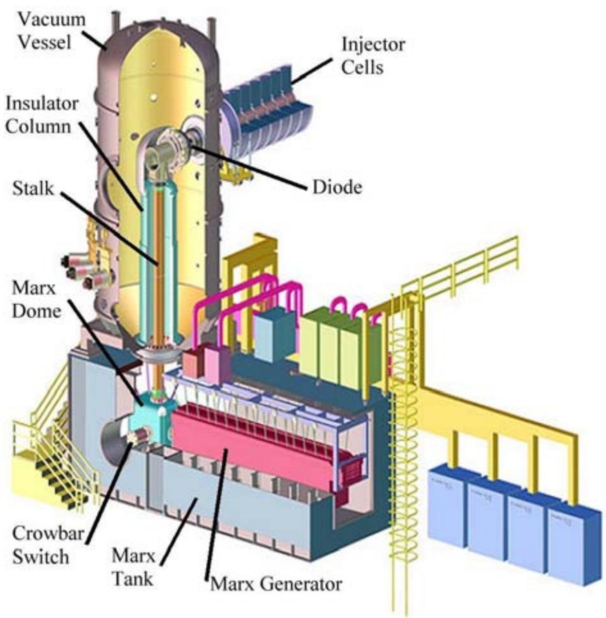

Figure 2. Layout of the DARHT second axis injector. The current/electronics stalk is inside the insulator column, between the Marx and cathode domes.

Since the injector provides the electron beam with its initial energy to the accelerator, its performance is crucial to the performance of the system. Reliability is important because of the high cost of each hydrodynamics test. Injector voltage waveform flatness is necessary to provide the required injected electron beam quality. Finally, low jitter is essential in providing proper timing of the injected beam to the accelerating pulse in the LIA and ultimately to the hydrodynamic test.

The DARHT-II injector Marx was designed and constructed by Titan PSD under subcontract to LBNL. Titan PSD, LBNL and LANL personnel from May through August 2000 tested it into a dummy load in California. Testing by LANL personnel at LANL began in June 2002 and testing with beam began in July 2002.

II.MARX DESIGN

The Marx is constructed in 88 stages. Each half stage is a 7 section PFN that has operated up to +/- 45.5 kV. Sections 1 & 2 are a damped Gibbs network to quickly charge injector stray capacitance. The next 5 sections form a 3.65 Ω, type E PFN to produce a flattop pulse. The Marx is therefore a 643 Ω PFN delivering a 2.1 µs pulse and up to 4.0 MV to a matched load. Matched load and crowbar limit late time diode energy. A ballast resistor at the Marx dome can be external adjusted to provide a matched load. An 83 Ω Marx series resistor limits capacitor reversal to 84 % in case of a shorted load fault or early crowbar closure. The Marx system is designed to accommodate diode impedances from open circuit to 714 Ω. A varistor stack on the side of the Marx limits overvoltage to 3.7 MV or 117 % of normal, 3.2 MV.

The Marx series resistor, ballast and crowbar series resistor are all externally adjustable liquid resistors. All use sodium thiosulphate electrolyte with passivated 304 stainless steel electrodes. Continuous solution flow is provided with inlet and outlet flow tubes routed from the Marx dome to ground. No conductive solution is routed along the Marx umbilical because of uncertainty of voltage distribution during the Marx erection. Resistivity and temperature of each solution is measured at its external cooling unit. Solid plastic tubes are used to define each resistor's geometry.

Pulse width at flat top can be adjusted from 2.1 µs to 60 ns in 6 discrete steps by sequentially disconnecting PFN sections. Pulse flatness is tuned by adjustment of PFN inductors. The crowbar switch minimizes pulse fall time and late time energy to the load. The Marx is laid out in two columns to minimize stray capacitance of sequential gaps and produce low jitter at a low percentage of self-break and therefore a low prefire rate.

The Marx is constructed with reliability and low maintenance in mind. The charging and case-to-case resistors are encapsulated ceramic HVR-C2654 and the trigger resistors are Milwaukee NS-10 wirewound. The spark gaps are Maxwell's pancake gaps, now Titan PSD's, with Swarzkopf K33S copper-tungsten electrodes. The gaps are UV illuminated and use dry air with continuous flow.

Fig. 3 shows an elevation view of the Marx. Some of the components are: (A) and (C) hydraulic and fiber optics control lines in the umbilical to the Marx dome, (B) the Marx generator, (D) flange for crowbar resistor and switch, (E) Marx dome, (F) one of four parallel ballast resistors, (G) Stalk to cathode dome, (H) Marx series resistor, (I) Torlon rod and trolley from which Marx is hung. Fig. 4 is a photo of the Marx showing the nylon support structure, field shapers tied to the Gibbs sections, case to case resistors, stainless inductors which comprise half the Marx series resistance, copper inductors and bottom field shapers. Fig. 5 is a photo of the Marx from above and shows the four rows of charging resistors and two rows of trigger resistors just above the spark gaps. The Marx is triggered by a cable trigger unit which, when the spark gap at the cable end is closed, delivers twice the charge voltage to the spark gap midplane.

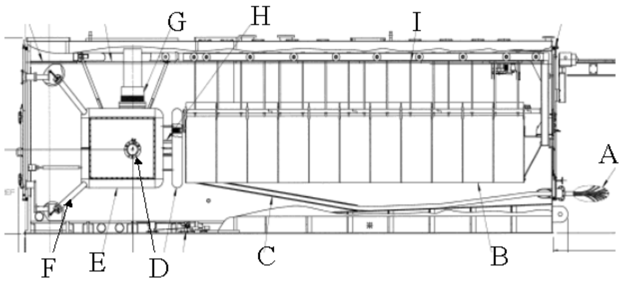

Figure 3. Elevation view of Marx.

Figure 4. Side view of Marx showing.

Figure 5. Top view of Marx showing charging and trigger resistors.

Fig. 6 is a photo of the high voltage end of the Marx. The varistors are shown on the left and the charging bars in the center. The second capacitors of the Gibbs sections are missing. The Marx output plate is shown but it is not connected to the final Marx stage. Fig. 7 shows the Marx stage configuration for a 400 ns pulse.

Figure 6. End view of Marx with second capacitors of Gibbs section missing.

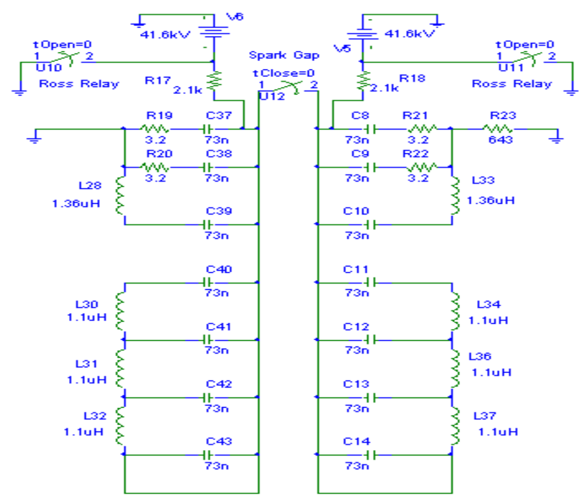

Figure 7. Configuration of injector Marx stage for 400 ns pulse. Note missing inductors and that bottom four capacitors are shorted.

III.TEST RESULTS

The Marx was tested for over 8000 shots in California before shipment to Los Alamos, and all requirements including reliability were satisfied. A dummy load capacitor of 423 pF was attached between the Marx dome and ground to replicate the combined stalk and cathode dome capacitances and the ballast resistor adjusted to 684 Ohms. The tests demonstrated 6 ns jitter and only 8 prefires out of 5000 shots with two prefires in the last

2877 shots. The crowbar switch was tested in a series of 300 shots at 3.2 MV with one prefire and no no-fires. In another series of shots the Marx was charged to normal voltage, +/- 41.6 kV, and held for 60 seconds and then erected for 10 normal output shots and dumped for another 10 shots. No prefires and no erections of the Marx, upon dumping, were experienced. Finally, the varistor stack was tested. Ten shots were fired at full voltage and the ballast resistance increased from the normal 684 Ω to 2325 Ω. Varistor current increased from the normal peak of 80 Amp to 2250 Amp and Marx dome voltage was clamped at 4.2 MV. The varistor stack will have to be reduced to 8/9 the number of units to clamp at 3.7 MV. Fig. 9 is an 8 shot overlay of output voltage at the Marx dome while Fig. 10 demonstrates crowbar switch shortening of the pulse tail.

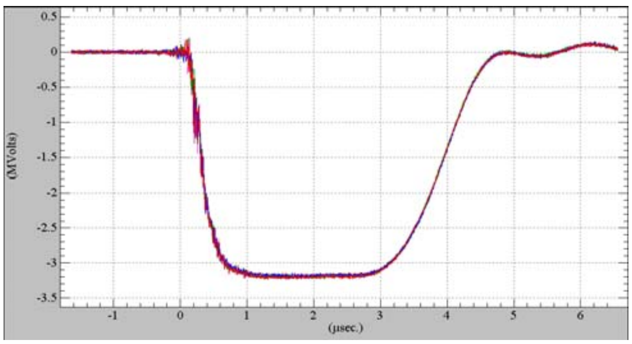

Figure 9.Marx output voltage (8-shot overlay).

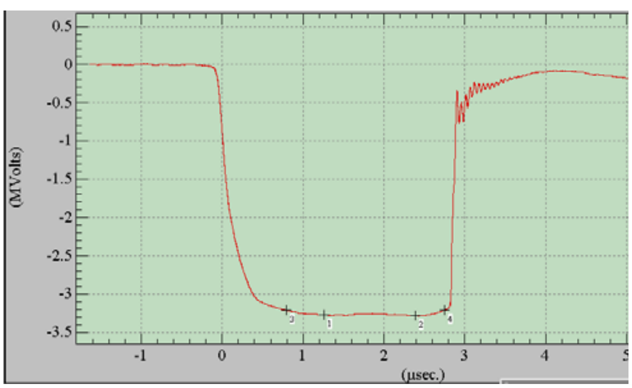

Figure 10. Crowbar switch is used to shorten tail of pulse. The pulse is flat to +/- 1 % for 2 µs.

The injector has now been used at LANL for over 1000 shots in the process of commissioning the second axis accelerator.[4] Operation of the Marx has been without difficulty. For all tests at LANL to date, May 2003, the Marx has been configured in the 400 ns mode to minimize damage to the beamline in the event of beam impingement. Fig. 11 shows an overlay of the 400 ns pulse with pulses from the earlier tests in California. The 100 ns pulse does not get to full voltage and the 2.7 MV was achieved only with +/- 45.5 kV charge and the load increased to 2000 Ω. The one problem that has been experienced regarding the Marx and injector configuration at DARHT II is an 8 MHz oscillation in amplitude of near +/- 1.5 % on voltage at the cathode. This oscillation is a result of the capacitances at the Marx and cathode domes and the stalk inductance between the two. A method to reduce the oscillations has been identified and will be implemented in the event that a 2-kA beam does not damp out the oscillations sufficiently during the rise time of the injector pulse.

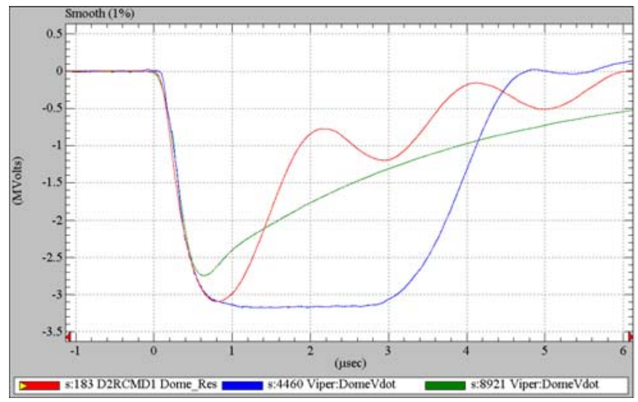

Figure 11. Voltage Waveforms at Marx Dome for 100-, 400- and 2000 ns Marx Configurations.

IV.ACKNOWLEDGEMENTS

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