ELECTRON BEAM 3.5MV, 2KA INJECTOR DIODE DIAGNOSTICS FOR THE DARHT FACILITY*

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Abstract

The injector for the second axis of the dual-axis Radiographic Hydrotest Facility (DARHT) is being designed and manufactured in LBNL. The injector consists of a single gap diode, extracting at 2 microseconds, 2kA (can be extended to 4kA), up to 3.5MV electrons from a dispenser cathode. The diode is powered through a high voltage insulating column by a Marx generator. We shall present an overview of the 3.5MV diode diagnostics, including: the A-K gap voltage measurement using a capacitive voltage divider (dE/dt) probe[1], cathode (source) current using 12 low inductance stainless steel foil current viewing resistors (CVRs) located on the cathode base plate[1], and anode dark current collected on the anode shroud using CVRs. A rise in the dark current, can indicate a buildup of an A-K breakdown, and is used to trigger the injector crowbar switch, thus limiting breakdown damage. Beam spillage, generating X-rays around the anode tube and shroud, is monitored using solid state PIN diodes positioned around the anode tube. Furthermore, we shall present the diode diagnostic system conceptual design, development tests, manufacturing and the results of some acceptance tests.

1 INTRODUCTION

A high voltage, high current, long pulse and high quality electron beam injector for a linear induction accelerator for flash-radiography applications is being developed at LBNL for the second axis of the Dual-Axis Radiographic Hydrotest Facility (DARHT). The injector conceptual design is based on LBNL Heavy Ion Fusion Injector technology [1], and beam dynamics simulations. The injector is driven by a Marx pulse generator. The Marx output pulse is fed through a 3.2MV insulating graded (ceramic) column into the beam diode.

The electron beam is generated in a 3.5 MV diode. It consists of a thermionic source surrounded by a Pierce electrode and focused by three solenoids located at the anode. A bucking coil is placed close to the source to zero the axial magnetic field in order to minimize the initial canonical angular momentum of the beam, which would be transformed into beam emittance.

We shall present an overview of the 3.5 MV diode diagnostics, including: the A-K gap voltage measurement using a capacitive voltage divider (dE/dt) probe; cathode (source) current using 12 low inductance stainless steel foil current viewing resistors (CVRs) located on the cathode base plate; and anode dark current collected on the anode shroud using CVRs.
A rise in the dark current, can indicate a buildup of an A-K breakdown, and is used to trigger the injector crowbar switch, thus limiting breakdown damage. Beam spillage, generating X-rays around the anode tube and shroud, is monitored using solid state PIN diodes positioned around the anode tube.

2 INJECTOR DIODE DIAGNOSTICS

2.1 A-K gap voltage measurement

The A-K gap voltage, up to 3.5 MV, measurement is performed using a capacitive divider, dV_d/dt monitor. The monitor which consists of a 7.5 inch diameter charge collecting plate is positioned on the vacuum tank wall facing the diode dome. The monitor plate is integrated with in a standard 8 inch vacuum tank port. The plate output voltage V_s can be estimated using:

$$V_s=C_cZ_o dV_d / dt=0.13\text{pF } 50\Omega \text{ } 3.2\text{MV}/0.4\mu\text{s}=52\text{V}$$

Where C_c is the coupling capacitance (Dome to plate), Z_o cable impedance and dt is the V_d rise time. V_s is integrated into V A-K at the scope input. The V_s response (frequency band width) is determined by Z_oC_s time constant T_s where C_s is the monitor plate stray capacitance < 15pF leading to T_s < 0.75ns, i.e., B.W < 250MHz.

Fig. 1 Shows the DARHT Marx injector 3.2MV output pulse. This wave form was measured at the Marx exit (dome), using a capacitive divider with a similar design facing the Marx dome.

2.2 Cathode current measurement

The cathode (source) electron current I_c of 2kA flow is symmetrically distributed through 12 parallel current viewing resistors (CVRs). Each100mΩ, resistor consists of a 304 (non magnetic) stainless steel 2mil foil strip. The strip is folded around a 5mil insulating Keptan foil. The resistor is “sandwiched” between the source flange and the water cooled cathode support plate, Fig. 1. The CVR response time is determined mainly by CVR skin effect resistance and inductance. For the 2mil CVR foil and a B.W. of 250 MHz, the calculated skin depth is 16 mils >> 2 mils foil. The calculated CVR inductance is 0.057 nH leading to a L/R time constant of about 0.5 ns, i.e., B.W. > 300MHz.

Four output current signals V^s (about 15V at I_c of 2KA) across 4 CVRs are measured and displayed. The current signals (through vacuum coaxial cable along the diode dome and the high voltage insulting column) are digitized and stored using 4 fast digitizers in the Marx dome. During injector operation the cathode, the Marx dome, and column go to 3.2MV. The current signals from the digitizers are converted into optical signals and transferred through fiber optics lines to ground potential to be displayed in the control room.

Fig. 2 shows the cathode (source) current measured on the LBNL Relatevistic Klystron Test Accelerator (RTA). The RTA cathode current monitor uses a design similar to the above. Furthermore, the monitor was successfully tested using fast (2ns rise time) pulses. The 12 CVRs cathode assembly was tested and calibrated showing a less than 2% spread in the measured output (current).

2.3 Anode dark current (I^d) measurement

A rise in anode dark current I_d, can lead to a non symmetric magnetic field offsetting the beam into the accelerator wall. Furthermore, it can be an indication of the buildup of an A-K voltage breakdown.

The dark current is collected in an open ended anode shroud (Fig. 1). The other end of the shroud is connected to the accelerator structure (ground) through a 1.1Ω dark current viewing resistor (DCVR). The DCVR consists of 24x27Ω resistors connected in parallel around the shroud end. Each resistor is by-passed by a 300V MOV to limit energy in the DCVR during an A-K breakdown. The accelerator return current flows through the accelerator structure (inner shroud Fig. 1).

I_d of about 100A is used as a threshold indicator to a build up of an A-K breakdown, or, a beam offset. Injector circuits simulations anticipate the dissipation of high damaging energy (kJs) in the diode electrodes. To limit the damage , I_d above 100A is used to turn on the Marx crow bar, thus limiting pulse duration, i.e., damaging energy. This fast gating system can be used in other cases of beam spillage (bumping) into the accelerator tube walls.

Within the physics design of the monitor, we checked the following physics issues:

- Displacement current (I_d) During the injector A-K pulse rise, within 0.4μs to a VA-K of 3.2MV, I_d of about 75A will flow into the anode shroud through the A-K stray capacitance.

- Induced voltage The magnetic field generated by the accelerator return current along the inner shroud and the induced current around the anode shroud leads to an induced voltage of V_{ind} < 2kV. V_{ind} appears across the 1cm gap formed between the anode shroud and accelerator tube. V_{ind} is well below the breakdown voltage for this gap.

- Generation of RF cavity transverse dipole modes. RF dipole modes can interact with the beam leading to transverse beam oscillations. The oscillating beam can interact coherently with the beam accelerating cavities, thus amplifying beam oscillation leading to a beam breakup. RF mode simulations of the monitor identify 2 dipole cavity modes below the accelerator tube 600MHz cutoff frequency, at 287MHz and 428MHz. To identify and evaluate the RF modes we have “RF” tested the anode assembly using high frequency network analyzers with in the LBNL RF Laboratory. The measurements results are summarized in Table 1:

Table 1. Dark current cavity dipole modes .

f^1, MHz	Q	damping ferrites
540	54	No
	<5	Yes
330	15	No
317	8	Yes

A high Q (~50) dipole mode at about 540MHz, was considered too close the accelerator cut off frequency. Introducing damping ferrite tiles in the cavity around the inner shroud led to a reduction in the 540 MHz dipole Q to <5, which is acceptable.

2.4 Anode beam spillage

Beam spillage on anode and accelerator tube is measured by monitoring the spillage generated X rays. Four fast X ray detectors were placed around the beam tube near the anode beam entrance to the accelerator. The detectors consists of fast PIN silicon diodes . The diodes are backward biased 1kV. One cable is used for applying the bias and extracting the X-ray signal. The spillage signal is separated in a “coupling box” outside the accelerator and shipped to the control room.

The X ray detector was tested on the LBNL RTA. The detector was positioned outside of the accelerator tube at a distance from the cathode near a diagnostic cross. The accelerator was tuned to allow some spillage during the beam rise and fall times. Fig. 3a shows the accelerator cathode current, Fig. 3b shows the beam current at the accelerator end and Fig. 3c shows the X-ray monitor output showing beam spillage as expected during the beam rise and fall times.

REFERENCES

[1] E. Henestroza, “Injectors For Heavy Ion Fusion”,11th International Workshop on Laser Interaction and related Plasma Phenomena, Monterey, CA, October 25-29, 1993 AIP Conf. proc. 318, Ed Miley, pp 577-582.

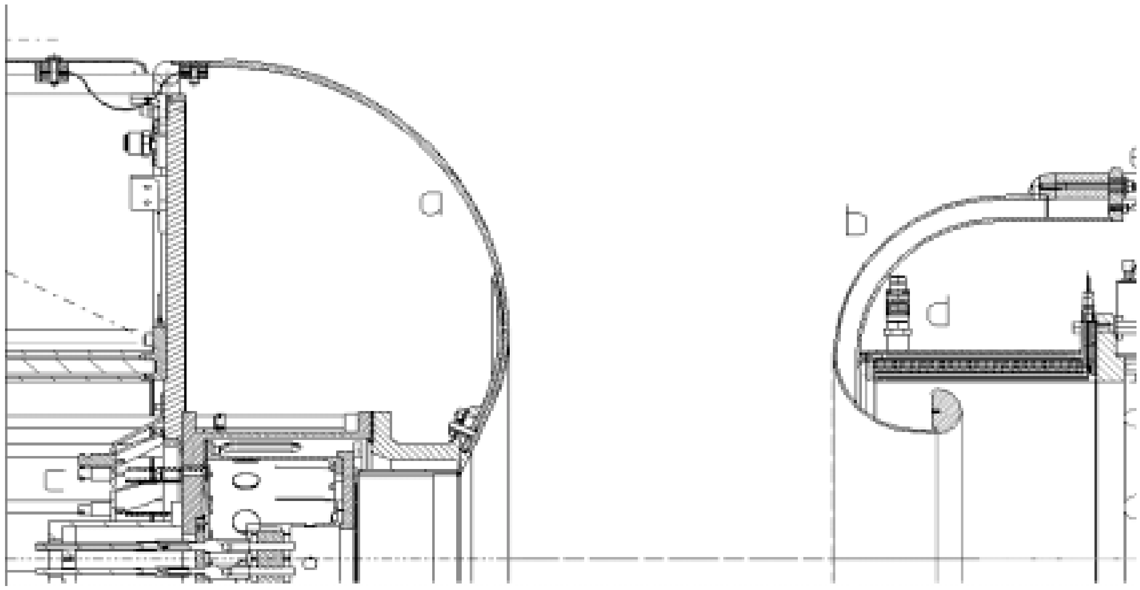

Figure 1: Diode schmatics (upper half)
a. Cathode shroud. b. Anode shroud. c. Cathode current monitor. d. Spillage detector. e. Dark current monitor

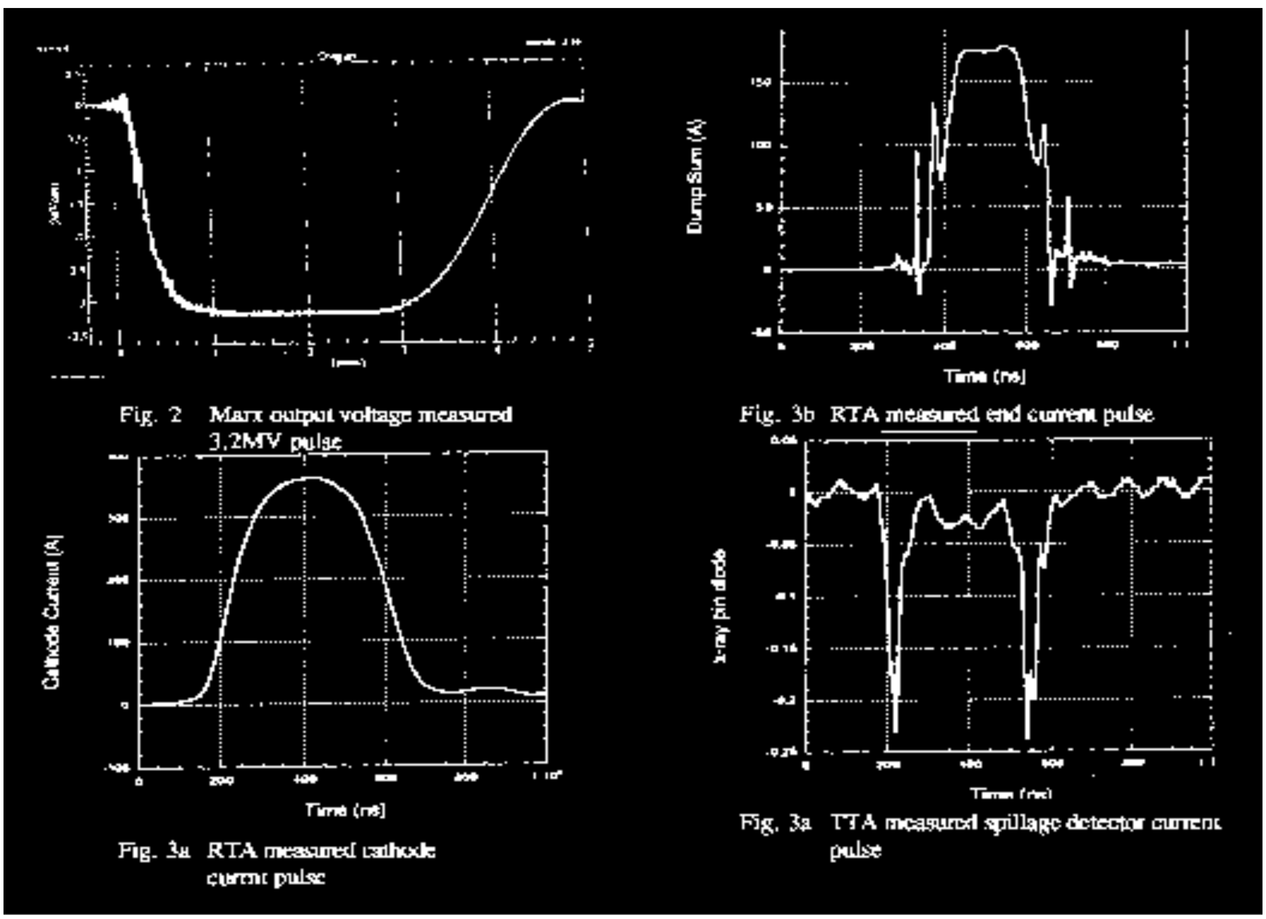

Fig. 2 Marx output voltage measured 3.2MV pulse

Fig. 3b RTA measured end current pulse

Fig. 3a RTA measured cathode current pulse

Fig. 3a TTA measured spillage detector current pulse