LA-UR-20-23236

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Intended for: Report

Issued: 2020-08-13 (rev.2)

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Optimization of DARHT Axis 1 Injector Voltage

D. C. Moir, T. J. Burris-Mog, N. Kallas, M. A. Jaworski, B. T. McCuistian

I. Introduction

The Dual-Axis Radiographic Hydrodynamic Test (DARHT) facility provides flash radiography capabilities using two electron Linear Induction Accelerators (LIA's). Axis-1 of DARHT produces a 20-MeV, 2-kA, 80-ns-FWHM electron beam. The strict requirements for flash radiography require a detailed understanding of the LIA's performance, including precision measurements of the injector electron beam energy. The technique for time resolved measurement of the electron beam energy using electron Permanent Magnet Spectrometer (ePMSpec) has been developed.¹ The electron energy then is used to infer the voltage produced by the injector pulsed power.

The injector pulsed power of DARHT I consists of a 1.5-MV, glycol-insulated Blumlein that is pulse-charged by a step-up transformer and switched by four, laser-triggered spark gaps. A series of increasing impedance transmission lines are used to transform the output voltage of the Blumlein to a maximum of 3.8MV at the diode. Figure 1a shows a graphic of the Axis-1 prime power tank, Blumlein and downstream transmission lines. The injector pulse power is designed to produce voltage on a velvet cathode located in the vacuum vessel. The specifications of the voltage-pulse flat-top over 60ns is $\pm 1\%$. A key element in the high-voltage circuit is the ethylene glycol Blumlein shown in Figure 1b.

Figure 1. Layout of DARHT Axis 1 injector pulsed power and vacuum diode

¹ D. C. Moir, T.J Burris-Mog, M. A. Jaworski, B. T. McCuistian, "DARHT Axis-1 Time-Resolved Injector Energy Measurement," LA-UR-20-20575.

The outer volume, adjacent to the laser triggered switches of the Blumlein, is a peaking capacitor shown in Figure 2. This is an independent volume that contains a mixture of ethylene glycol and water to make it an adjustable capacitor of 380 to 750 pF.²

Figure 2 Glycol Blumlein schematic showing the peaking capacitor.

II. The New Glycol Experiment

The glycol dielectric used in the Axis 1 injector Blumlein was originally obtained from Pulse Sciences Incorporated (PSI) when the injector was delivered in 1991. Over the years it was observed that the injector output pulse width had increased. Glycol which is hygroscopic had increased its percentage of water and as a consequence the dielectric constant had increased. The pulse lengthening had also

affected the performance of the time-isolating transmission lines downstream of the Blumlein. To examine this problem the Electron Permanent Magnet Spectrometer (ePMSpec) was installed on the injector¹ prior to replacing the water contaminated glycol with pure glycol. The waveforms shown in Figure 3 are the resultant energy for both pure ($\epsilon=44$) and contaminated glycol ($\epsilon=48$). The red dashed lines are the 60-ns flat-tops. The pulse widths are significantly different (6ns). The before and after IBPM2 current waveforms are shown in Figure 4. The parameters for both pulses are shown in Table 1. The value of the peaking capacitor is the same for both data sets. The percent RMS energy spread for the new (pure glycol) versus the old glycol with water contamination is not large, but the peaking capacitor has not been optimized for the new glycol. This result will be shown later.

Figure 1. Spectrometer waveforms for pure and contaminated glycol. Red dashed line is 60 ns.

² J. Fockler, B. Bowen, V Carboni, P. Cochoran, J. Kishi, R. Kuenning, "A 4-MeV +/- 1% Flat-top Electron Diode Driver," <https://ieeexplore.ieee.org/stamp/stamp.jsp?tp=&number=733261>

Figure 4. Overlay of beam current measurements at BPM2 location.

Table 1. Parameter summary for pure and contaminated glycol

Date	Shot Number	Charge Voltage (kV)	Anode Magnet (A)	Peaking Capacitor Dielectric Constant	IBPM2 (kA)	60ns Mean Energy (MeV)	RMS dE (MeV) for 60ns	RMS % Energy Spread
12/20/2018	30385	98	198	73	1.465	3.213	0.0266	0.83
02/20/2019	30456	98	210	73	1.57	3.391	0.0209	0.62

III. Peaking Capacitor Optimization

The Blumlein contains a short section in oil with a diaphragm (see Figure 2). This section of the Blumlein contains the laser switches. The stored energy in this short oil section is lower

than the rest of Blumlein that is filled with glycol. To compensate for this oil/diaphragm section, a capacitor with a dielectric constant that is higher than that of the glycol is located just downstream of it. This is called the peaking capacitor and it is designed to boost the initial output voltage pulse of the Blumlein. Any increase in rise time caused by the peaking capacitor is eliminated by the filter plates.²

Figure 5 shows the electron beam energy out of the injector as a function of time for three different peaking capacitor effective dielectric constants. For a high dielectric constant (73) in the peaking capacitor, the front of the pulse is over-peaked. With a low dielectric constant that is closer to glycol (53), the energy waveform is under-peaked. Finally, with the dielectric constant adjusted to 66, the peaking is optimized.

Figure 5. Overlay of energy vs time of the injector using for various values of peaking capacitor.

Table 2 is a summary of the peaking capacitor data. Columns six through nine are data which has been time integrated over 60 ns.

Table 2 Summary of time integrated (60ns) data for various peaking capacitor configurations

Date	Shot Number	Charge Voltage (kV)	Anode Magnet (A)	Peaking Capacitor Dielectric Constant	IBPM2 (kA)	60ns Mean Energy (MeV)	RMS dE (MeV) for 60ns	RMS % Energy Spread
2/20/2019	30456	98	210	73	1.57	3.391	0.0209	0.62
2/21/2019	30488	98	200	57	1.57	3.363	0.0310	0.92
2/25/2019	30517	98	200	66	1.56	3.378	0.0154	0.46
2/26/2019	30551	98	200	66	1.56	3.373	0.0150	0.45

Figure 6 is a plot of RMS % Energy Spread (column 9 in Table 2) vs Peaking Capacitor Dielectric Constant (column 5). The two shots at a dielectric constant of 66 overlay. Clearly there is a minimum in the energy spread indicating the importance of optimization.

Figure 6. Percent energy spread vs peaking capacitor dielectric constant showing optimization of energy spread.

IV. Voltage Peaking as a Function of Charge Voltage

For a fixed value of peaking capacitance, measurements were made of the time-resolved electron beam energy for a series of prime power tank charge voltages. Figure 7 is a plot of these waveforms. Analysis of this data over averaged over 60ns, produces the results in columns 7 to 9 of Table 3. There is an increase in the percent RMS value as a function of charge voltage. This change is also shown in Figure 8.

Time Resolved Electron Energy Spectra for 91, 98, 105 and 112kV Injector Charge

Figure 7. Overlay of energy vs time for various prime power tank charge voltages

Table 2. Summary of data for a fixed peaking capacitance

Date	Shot Number	Charge Voltage (kV)	Anode Magnet (A)	Peaking Capacitor Dielectric Constant	IBPM2 (kA)	60ns Mean Energy (MeV)	RMS dE (MeV) for 60ns	RMS % Energy Spread
2/27/2019	30575	91	165	66	1.41	3.135	0.0115	0.37
2/27/2019	30580	98	200	66	1.56	3.365	0.0144	0.43
2/27/2019	30590	105	188	66	1.72	3.622	0.0174	0.48
2/27/2019	30591	112	201	66	1.87	3.843	0.0222	0.58

Figure 8. Increase in % RMS energy spread vs electron energy averaged over 60ns.

To examine the temporal variation of the energy spread, the wave forms of Figure 8 are normalized at 120ns in time and overlaid in Figure 9. Here, the assumption is made that late in time, the shape of the waveforms is the same. The overlay confirms this fact to within a few percent. Clearly, the peaking is a function of charge voltage and should be optimized for the operating voltage.

Figure 9. Normalized overlay of injector waveforms as a function of charge voltage. Colors correspond to those used in Figure 7

V. Conclusion

The time-resolved electron beam energy is directly proportional to the injector pulsed power output voltage. The peaking capacitance produces a voltage-dependent correction for the injector pulsed power. Each operating charge voltage should have a unique peaking capacitance dielectric constant. The glycol dielectric constant should be measured annually to verify that it has not drifted upwards more than 1-2% due to water absorption.