LA-UR-20-25852
Approved for public release; distribution is unlimited.

Title: DARHT Axis 1 Performance Results with and without a Blumlein Charge Unit

Author(s): Moir, David C.
Balzer, Stephen James

Intended for: Report

Issued: 2020-08-03

DARHT Axis 1 Performance Results with and without a Blumlein Charge Unit

David C Moir and Steve Balzer

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. As DARHT Axis 1 enters its twentieth year of operation, the probability of Blumlein Charge Unit (BCU) failure has increased and the risk of a failure on the day of an explosive experiment has become more likely. Replacement time for a BCU is four to six hours. This report examines the radiographic and beam transport effect of operating the accelerator with a missing or reduced charge voltage BCU. The results are compared with normal, full machine operation. A prescription for alternate operation with missing or reduced charge voltage on BCU22 is given.

II. Analysis

The IDL code xtr is used to calculate the accelerator envelope from 167cm downstream of the cathode to the final focus at the target. The initial conditions (r0, r0p and emittance) were obtained from emittance scans with the anode magnet. The injector energy input to the code was measured by calibrated capacitive monitors in the vacuum diode. The charge voltage on the BCU's was 27kV which corresponds to a beam-loaded cell voltage of 250kV. The magnet tune was optimized to obtain a smooth envelope. The final energy was obtained from the sum of electronic injector voltage and current viewing resistors that monitor cell voltage.

Figure 1 is the xtr plot of the beam envelope through the accelerator, shown in red. The vertical axis is the beam radius and the horizontal axis is the distance from the cathode along the accelerator. The green lines correspond to the on-axis magnetic field in the accelerator and in the downstream drift region. The location of BCU22 is indicated on Figure 1. BCU22 was turned off. Consequently, cells 43 and 44 gaps were set to -25kV in the code to compensate for beam loading. The envelope for this configuration is shown in blue. It begins to deviate slightly from the full machine after cells 43 and 44, but at the entrance to the final focus there is a significant deviation. Not shown is the calculation of the envelope for reduced voltage on the gap (225kV vs 250kV). The beam envelope for this condition was not discernible from the standard full machine calculation.

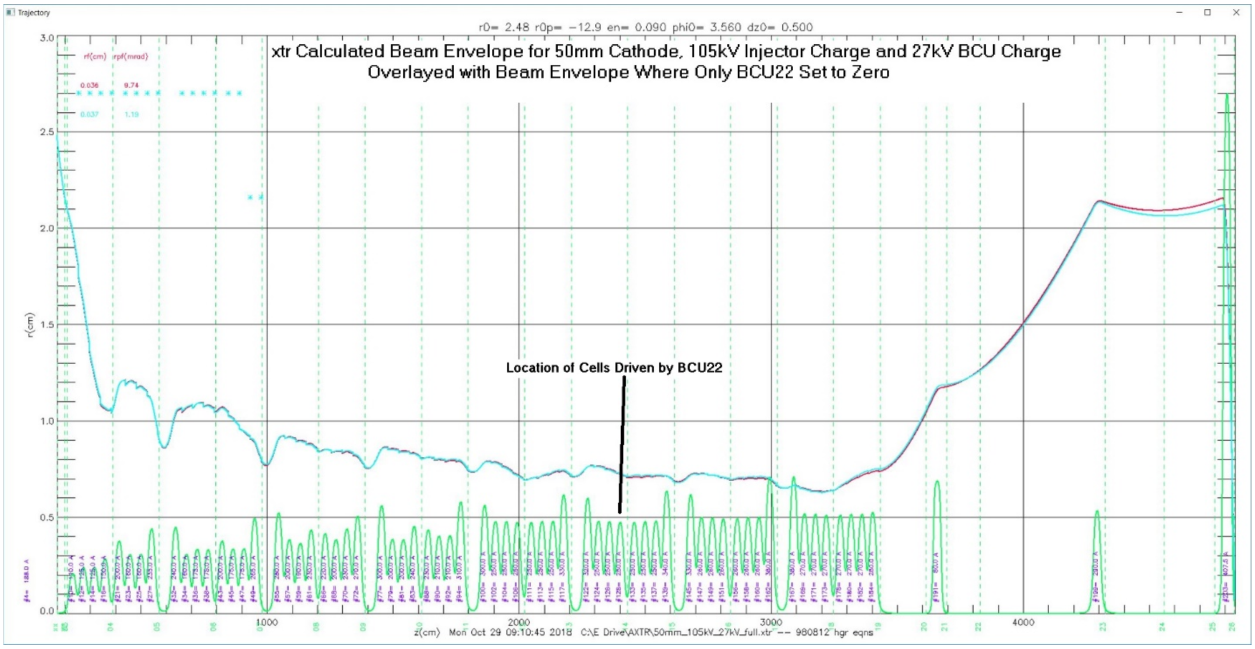

Figure 1. xtr beam envelope calculation for with and without BCU22

Figure 2 shows the downstream drift of the accelerator. The distinction between with (red) and without (blue) BCU22 is much clearer. The 2-rms spot radii are in the upper left corner. In both cases the final focus beam radius was optimized for a minimum. The calculated final focus magnet current was 406.4A for full machine. Without BCU22, the current was 396.0A. This amounts to a 10A difference.

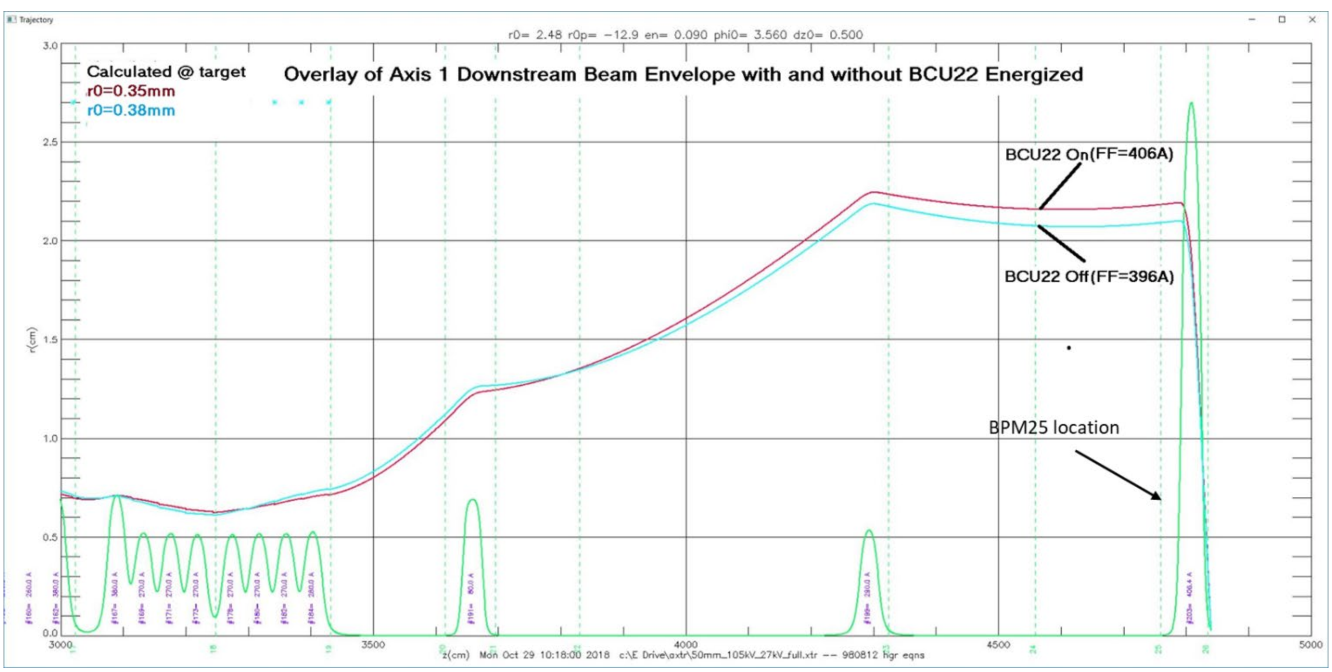

Figure 2. xtr downstream beam envelope calculation.

III. Measurements

A summary of the beam properties and experimental results are presented in Table 1. Column 1 is the reference shot number. The second column is the charge on the BCU22 for each shot. Columns 3 and 4 are the beam parameters associated with each shot. Note the energy difference with and without BCU22 in column 4 is larger than the expected 500kV because beam loading in the cell extracts additional energy from the beam. The beam current was measured at BPM25 whose location is just in front of the final focus (shown in Figure 2). Column 5 contains the final focus settings. There was no change for 25 kV versus 27kV (Full) but for 27kV compared with no BCU voltage the focusing current changed by 10A. This is what was calculated by xtr. Results of the pinhole-measured spot size for the three focus shots are in column 6. From a radiographic standpoint, all three are adequate. Using a dose scaling of energy to the 2.8 power the expected decrease in dose is 46R. However, it only fell 21R. A better comparison would be of the flat-field peak intensities, which are not available.

Table 1. Beam properties and experimental results.

2018/10/28 Shot #	BCU22 Charge Voltage (kV)	BPM25 Electron Beam Current (A)	Final Electron Beam Energy (MeV)	Final Focus Magnet Current (A)	50% MTF Spot Size (mm)	Diamond Diode Dose (R)
29696	27	1.59	19.47	404.9	0.96	561
29698	25	1.58	19.39	404.9	1.06[1]	557
29699[2]	0	1.59	18.87	100	N/A	N/A
29704[3]	0	1.59	18.88	395	1.00[1]	540

[1]Spot size was not minimized with a magnet sweep due to time constraint.

[2]Steering the same as for 29696 to measure beam deviation at BPM25.

[3] Beam centered before focusing (see Figure 3).

Figure 3 is an x-y plot of the beam centroid at BPM25 for the shots in Table 1. The diameter of the circle is the measured beam 2-rms radial corkscrew amplitude at BPM25. The largest increase in corkscrew amplitude occurred for shot 2698 where the BCU22 charge voltage was lowered by only 2 kV. This result is surprising since the centroid shift at BPM25 was less than 1mm. With BCU22 off (shot 29699), the centroid shifted radially 4.3mm. The beam was re-centered for the focus shot 29704. The corkscrew amplitude remained unchanged after re-steering.

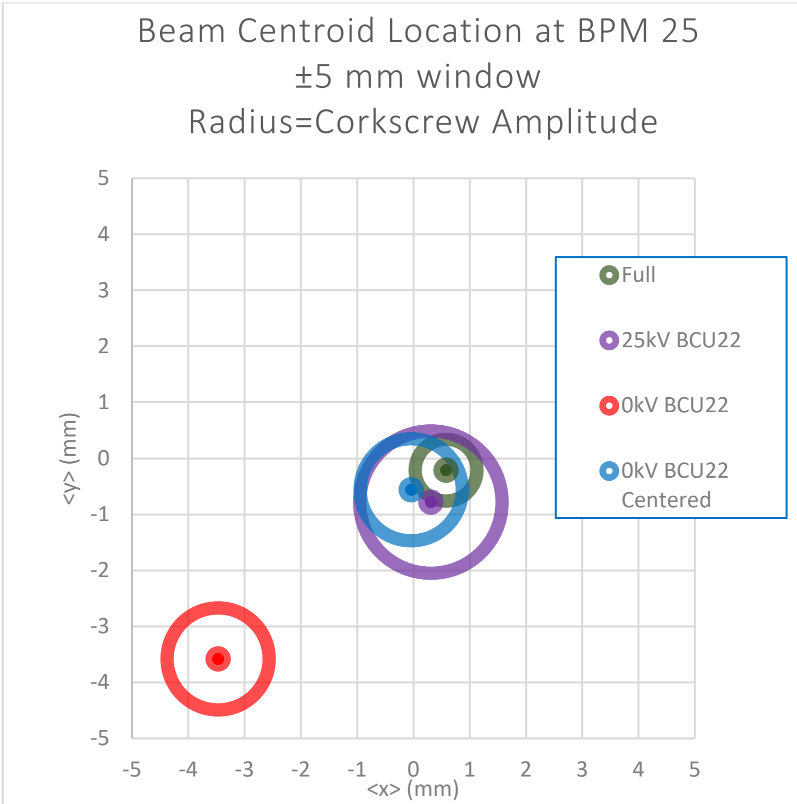

Figure 3. Centroid (dots) at BPM25 showing the RMS radial corkscrew amplitude as bubble radius.

IV. Conclusion

It is possible to mitigate the risk for a single BCU failure (BCU22) on the day of an explosive experiment. The accelerator can be re-tuned to produce an equivalent spot size and reduced dose (4 to 8% lower). Unfortunately, due to time constraints of this experiment, many other avenues were not pursued. Could the final spot size be reduced by tuning the final focus? Are these conclusions valid for any of the 1-32 BCU's turned off? What would the spot size and dose be for a BCU which failed during an explosive experiment? What would be the difference in spot size be if the beam was not re-steered for BCU off?