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TIME RESOLVED MEASUREMENTS OF DARHT-II MULTI-PULSE BEAM*

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Abstract

Using a calibrated permanent magnet spectrometer and a streak camera, a time resolved measurement is made for a multi-pulse beam. These measurements are cross calibrated with cell voltage monitors to have a reliable online energy measurement. The Dual Axis Radiographic Hydrodynamic Test Facility (DARHT) Axis-II produces a 16 MeV, 1.65 kA electron beam. Timing on the cell voltages is changed such that the beam has a varying kinetic energy spread. Multi-pulses are produced by a kicker at varying pulse lengths and selecting out different energies from the beam. This paper reports the results of these measurements.

INTRODUCTION

The Dual Axis Radiographic Hydrodynamic Test Facility (DARHT) Axis-II has numerous instrumentation and diagnostic systems [1, 2]. Particularly, for online beam energy measurements are the 74 cell voltage monitors (CVM) throughout the accelerator and the diode voltage monitor at A-K gap potential in the injector. Each cell is driven by a tunable pulse forming network (PFN) [3] that applies a voltage pulse to the beam. The CVM is a resistive-divider measuring the PFN voltage pulse for each cell. These CVM's are summed and added to the diode voltage to estimate the accelerated beam energy [4]. Over time drifts and other changes in CVM signals occur, and periodic cross calibration measurements needs to be done. Measurements of the beam energy with a calibrated permanent magnet spectrometer at the end of the accelerator are used to cross calibrate the summed CVMs and diode voltage signals. The magnet spectrometer is an invasive measurement, and is removed for radiographic operations, whereas the voltage monitors are noninvasive and are used to monitor the beam kinetic energy. Previous cross-calibration measurements were performed with an electromagnet spectrometer that relied on a power supply whereas using a permanent magnet spectrometer eliminates variables such as hysteresis cycle, power supply ripples, and temperature variation [5, 6].

EXPERIMENTAL ARRANGEMENT

The permanent magnet spectrometer setup is placed at the end of the downstream transport of Axis-II. The entrance of the spectrometer consists of two collimators that are made from 100 mm thick graphite with a 2 mm diameter aperture, followed by a 30 mm thick tungsten with a 1 mm diameter aperture. A 60°, with a pole gap of 22 mm, sector permanent magnet, made of Samarium Cobalt (SmCo) magnets and yoke made of C1006 steel is used. The detector region of the spectrometer accommodates 100×10 mm^2 scintillating or phosphor imaging plates [5]. The polyvinyltoluene scintillator light is focused by a camera lens onto a linear coherent fiber optic array. A self-developing dosimetry film was placed in situ with the scintillator as well. The other end of the array is coupled to a streak camera. An optical comb generator that can produce time markers from 10 ns to 50 µs is coupled to the end fibers of the array. A diagram of the experimental setup is shown in Fig. 1.

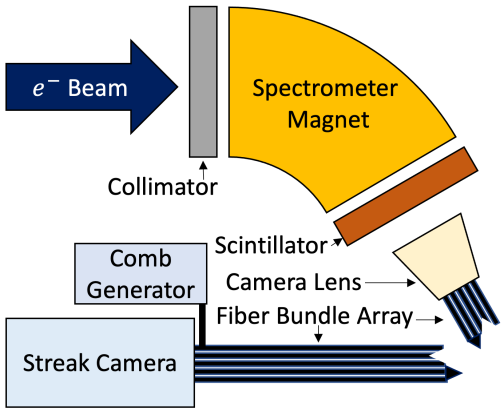

Figure 1: Diagram of experimental setup.

Permanent Magnet Calibration

The compact permanent magnet spectrometer was calibrated using H^- and OH^- anions at the Special Technologies Laboratory in Santa Barbara, California, USA. The measurable range of electron kinetic energies is between 14.1 MeV-21.1 MeV. The calculated beam kinetic energy, in MeV, is given by the quadratic polynomial from the calibrated permanent magnet spectrometer by [5]:

$$T_e = 1.92 \times 10^{-4} x^2 + 5.73 \times 10^{-2} \times 1.022^{t/5} x + 16.5 \times 1.022^{t/5}, \quad (1)$$

where x is the horizontal position on the detector in millimeters and t is the translation distance in millimeters. The combined uncertainty from mechanical tolerance, resolution, and temperature swing is 51 keV [5].

Axis-II Arrangement

The last four induction cell timing is offset to create a global 3% energy variation of the beam. This energy variation would correspond to a ±10 mm horizontal position range on the permanent magnet spectrometer detector plane

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according to Eq. (1). Figure 2 overlays the cell voltage monitor signals for each of the 74 cells, and the diode voltage monitor signal at the A-K gap. The last four cells, 71-74, are labeled on Fig. 2, whereas the remaining cells have the same corresponding timing offset and similar voltage signal. Each cell flattop adds an average of 200 keV to the beam energy, and 2 MeV from the injector. Nominally Axis-II produces a 16 MeV to 17 MeV beam with a flat-top pulse length of 1.6 µs at 1.65 kA out of the accelerator. At the downstream transport, the beam is kicked [7] into four varying pulse lengths of 35 ns, 42 ns, 60 ns, and 73 ns, and head to head pulse spacing of 500 ns.

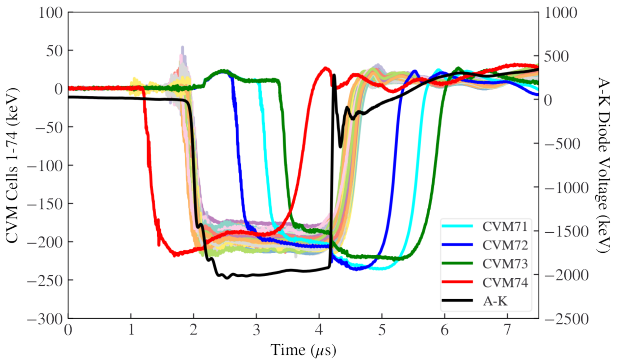

Figure 2: On the left axis is the overlay of Cells 1-74 voltage signals, where cells 71 through 74 are labeled, whereas the right axis is the diode voltage signal.

The accelerator beam and spectrometer are aligned with a combination of steering coils and mechanical motion. The spectrometer magnet is removed from the assembly and the beam position is measured with a self-developing x-ray film. Adjustments to steering and mechanical alignment are accomplished to place the resulting beamlet position within 1mm of the detector-plane center as was done during absolute calibration.

The accelerator and downstream tuning were set to provide sufficient signal for time-resolved imaging. A solenoid scan was conducted to determine the beam radius, convergence, and emittance at the entrance to the spectrometer. Applying a mechanical scraping model to the beam, we estimate 4 A of current is transmitted to the detector plane out of the total of 1.65 kA. This allowed measurements down to 200 ps/pixel in individual pulse measurements.

RESULTS

Figure 3 is the image from the streak camera set at a sweep of 2 µs and the optical comb generator spacing is 500 ns. The zeroth position and magnification was determined by fiducial markers on a 1 s exposure static image. For each column along time in Fig. 3, the mode of the intensity distribution is determined. Using Eq. (1), the kinetic energy is calculated from the mode of each column distribution. The kinetic energy of each pulse is plotted along time in Fig. 4, with uncertainty from the spectrometer magnet of 51 keV. The

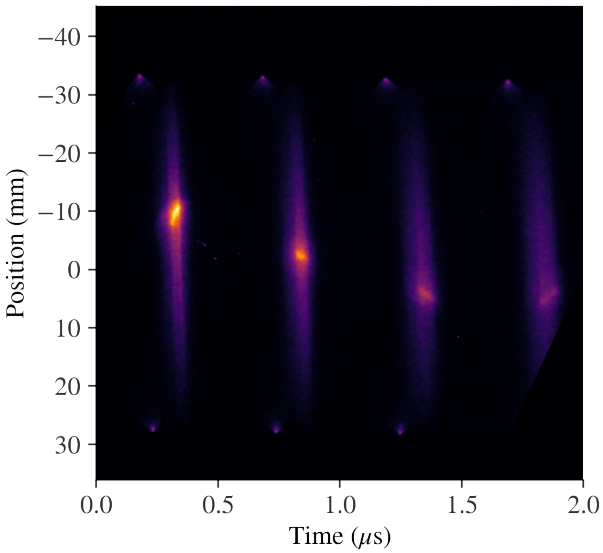

Figure 3: Measured streak camera image with four pulses and optical comb generator timing fiducial. Fiducial spacing is 500 ns.

head of the first pulse is correlated with the kicker read back signal, and each pulse thereafter is separated by 500 ns center to center spacing. Also in Fig. 4 is the timing read-back signal from the kicker (vertical lines), labeled as KMON, and sum signal of the CVM's and injector diode voltage. The zeroth energy variation is determined by the mid-range, mean of the lowest and highest value, of the the cross calibrated summed voltage signals. In Fig 4 this corresponds to a kinetic energy value of 16.4 MeV.

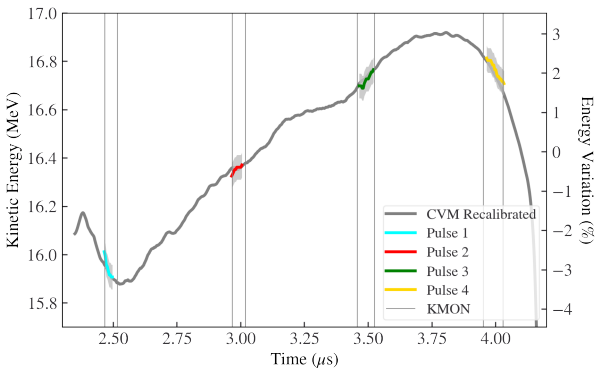

Figure 4: Measured kinetic energy of the four pulses overlay with the cross calibrated voltage sum signal. Vertical lines are timing signal from the kicker. Zeroth energy variation is at 16.4 MeV.

The summed voltage signal is cross calibrated against the measured pulse kinetic energies, the kinetic energy can be expressed as:

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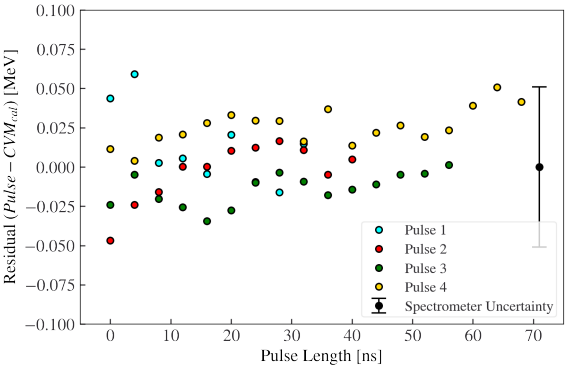

Figure 5: Residual values of four measured pulse kinetic energy from the voltage summed signal.

$$KE = V_{A-K} + K_{cell} \sum_{1}^{74} V_{cell}, \tag{2}$$

where V_{A-K} and V_{cell} is the diode voltage signal and cell voltage signal, respectfully. K_{cell} is the average correction factor for the cell voltages. The correction factor is adjusted such that the residuals from the pulses and cross calibrated signal is minimized. The result for this paper is $K_{cell} = 1.000$, whereas the previous reported value of $K_{cell} = 0.979$ [6]. This corresponds to a 2.1% change in the average correction factor. The residuals for each of the four pulses is shown in Fig. 5. The cross calibrated signal is within the uncertainties of the measurements of 51 keV.

CONCLUSION

Invasive measurements with a permanent magnet spectrometer with a streak camera was performed to accurately measure the beam kinetic energy. Cross calibrating the CVM signals and the diode voltage monitor with a well calibrated permanent magnet spectrometer enables a reliable, online, noninvasive measurement of the beam energy. The average correction factor to the CVM signals is corrected to the updated value, and the readback sum voltages is within the uncertainties of the measurements.

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