COMMISSIONING THE DARHT-II ACCELERATOR DOWNSTREAM TRANSPORT AND TARGET*

Martin Schulze, SAIC, Los Alamos, NM 87544, USA
E. O. Abeyta,, R. Archuleta, J. Barazza, D. Dalmas, C. Ekdahl, W. Gregory, J. Harrison, J. Johnson, E. Jacquez, P. Marroquin, B. Trent McCuistian, R. Mitchell, N. Montoya, S. Nath, K. Nielson, R. Ortiz, L. Rowton, R. Scarpetti, G. Seitz, M. Schauer,
Los Alamos National Laboratory, Los Alamos, NM 87545, USA
R. Anaya, G Caporaso, F. Chambers, Y.J. Chen, S. Falabella, G. Guethlein, B. Raymond, R. Richardson, J. Watson, J. Weir
Lawrence Livermore National Laboratory, Livermore, CA 94550
H. Bender, W. Broste, C. Carlson, D. Frayer, D. Johnson, and C. Y. Tom,
N.S. Tech, Los Alamos, NM 87544, USA
T. P. Hughes, C. Thoma,
Voss Scientific, Albuquerque, NM 87108, USA

Abstract

The DARHT-II accelerator [1] produces a 2-kA, 17-MeV beam in a 1600-ns pulse. After exiting the accelerator, the pulse is sliced into four short pulses by a kicker and quadrupole septum and then transported for several meters to a tantalum target for conversion to x-rays for radiography. We describe the commissioning of the kicker, septum, transport, and multi-pulse converter target. The results of beam measurements made during the commissioning of the downstream transport are described.

INTRODUCTION

The DARHT–II accelerator beam parameters are 17-MeV and 2.0 kA with a flattop of 1.6 microseconds. The DARHT–II downstream transport was commissioned at reduced energy and current in early 2007 [2]. The beam parameters were 8-MeV and 1.1 kA with a flattop of 1.6 microseconds.

The downstream transport system for the DARHT-II accelerator is designed to extract four short pulses (20-100 nsec) from the 1.6 microsecond beam and deliver these pulses to an x-ray production target for radiography. Figure 1 provides a schematic illustration of the downstream transport beamline.

The high level requirements imposed on the downstream transport are outlined below:

- Deliver four pulses over 1.5-1.6 μsec
- Spot sizes less than 2.3 mm 50% MTF
- Dose format exceeding 100 R, 100 R 100 R and 300 R in each successive pulse

Each of these requirements were met and reproduced over multiple shots. These results will be described. High quality radiographic images with the DARHT-II accelerator impose additional requirements on the beam quality, in particular, the beam motion over flattop. This issue and the methods used to minimize the that have been used to address them are discussed.

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LAYOUT AND OPTICS

The beam from the accelerator is focused using the first and third solenoids to produce a small waist at the entrance to the quad septum. This effectively decouples the accelerator from the remainder of the downstream transport. The beam enters the kicker and is either directed downward to the beam dump with a DC bias dipole magnet or the fast kicker is energized to direct the beam straight ahead. The bias dipole deflects the beam by 1-1.5 degrees. This deflection is magnified with a large aperture septum quadrupole tuned to defocus the beam in the vertical plane resulting in a net deflection of about 15 degrees. This also results in a large beam size on the dump which reduces the power density to acceptable levels. A dipole magnet further deflects the beam into the dump. The kicked beam enters the septum quadrupole on axis and the nominally round beam profile becomes elliptical. The function of the small Collins quadrupoles following the septum quadrupole is to transform this elliptical beam back to a round profile. The purpose of the remaining solenoid is to transport the beam to the final focus solenoid which delivers a tightly focused beam to the target.

There are four semi-independent regions in the downstream transport. The first region is from the accelerator to the septum quadrupole and the settings of the first and third solenoids. The second region is the transport to the septum dump. This defines the required settings of the bias dipole, septum quad and the septum dipole. The third region includes the four Collins quadrupoles that are used to return the beam back to round. The forth region consists of a transport solenoid and a final focus solenoid to produce a small beam size on target. The last transport solenoid was not used.

Beam position and current measuring diagnostics are located throughout the downstream transport. Beam profile imaging stations were located at the accelerator exit, between the 1st and 2nd Collins quadrupole magnets, and after the 4th solenoid.

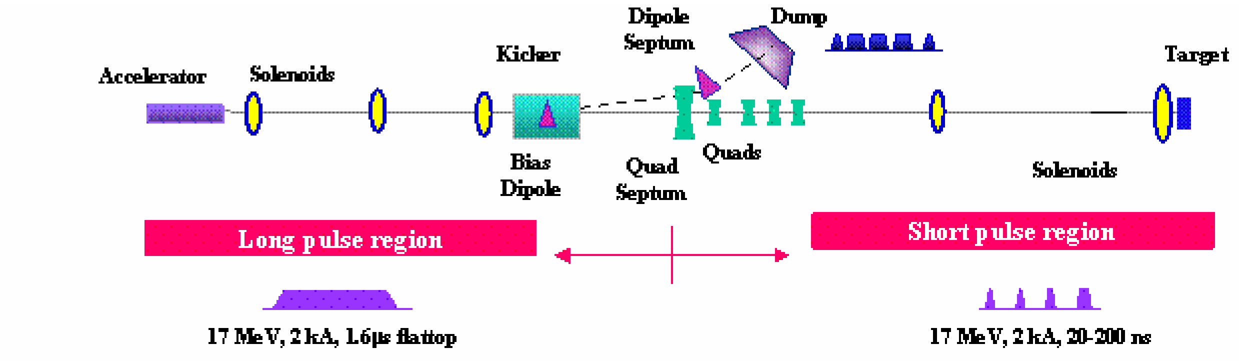

Figure 1: Schematic layout of DARHT 2nd Axis downstream transport.

COMMISSIONING

The beam profile of the beam exiting the accelerator could not be measured due to the high power density of the beam. As a result, it was necessary to tune S1 and S3 based on beam profile measurements at the imaging station between the 1st and 2nd Collins quadrupole magnets. The desired beam profile was an upright ellipse with a vertical to horizontal aspect ratio of about 2:1. This was achieved as shown in the left image in Figure 2. The right image in Figure 2 shows the transverse beam distribution after S4.

The beam envelope and entrance conditions in the downstream were inferred from the magnet settings and images. Figure 3 shows the resulting beam envelope.

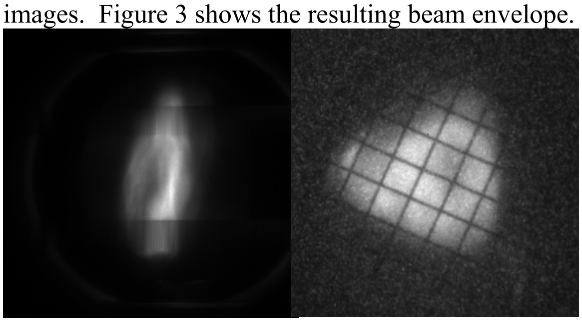

Figure 2: Beam images between the 1st and 2nd Collins quadrupoles (left), and after the 4th solenoid (right).

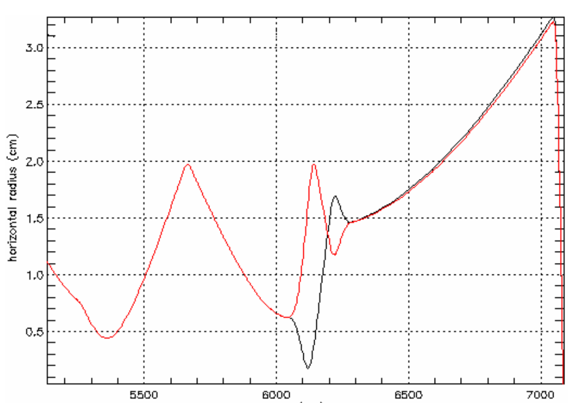

Figure 3: Beam envelope in the downstream transport based on initial conditions inferred from magnet settings and beam profile measurements.

RESULTS

We will report results on the beam transport of four pulses to the target, and spot size and dose measurements of these pulses. through the kicker and quadrupole region, kicker performance, estimates of the emittance growth through the kicker and quadrupole region, stability of the kicked beam parameters at the beginning and end of flattop, studies of beam induced gas desorption at the septum edge, and spot size measurements of the four beam pulses on target.

Kicker Performance

The kicker is nominally programmed to kick up to four pulses spaced over the flattop. The pulse lengths can be adjusted from 20 to 250 nsec. Figure 4 shows a typical beam current profile at the injector (black), accelerator exit (blue) and target (red). The four kicked pulses have lengths of 35, 40, 40, and 100 nsec respectively. The beam current is about 2 kA. The spacing from the beginning of P1 to the end of P4 is 1.5 usec demonstrating the first high level requirement.

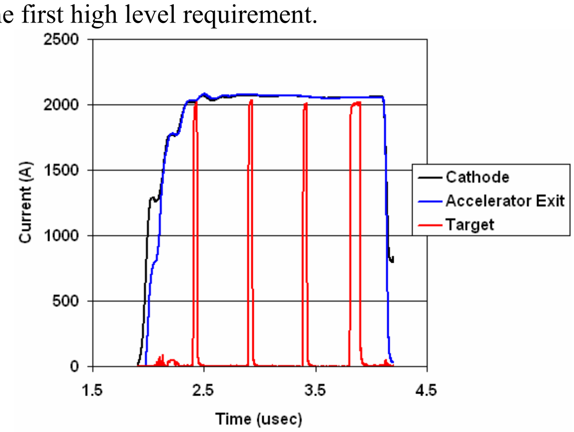

Figure 4: Beam current profile at injector, accelerator exit and target showing four kicked pulses.

Beam Size on Target

The size of the x-ray spot on the target was measured using the Time-Resolved-Spot-Size camera as described by McCuistian et al. [3]. A series of measurements were made using the pulse format shown in Figure 4. The x-ray images and the calculated 50% MTF (Modulation-Transfer-Function) are presented in Figure 5. The values for the 50% MTF of the four pulses are all significantly smaller than the second high level requirement of 2.3 mm and are comparable to or less than the measured beam size for the DARHT 1st axis. The plots on the right side of the images compare the MTF of the single pulse from the first axis (grey) with that calculated for the corresponding second axis pulse (black). The larger high frequency or wave-number structure in the 2nd axis x-ray images translates directly into higher quality radiographic images.

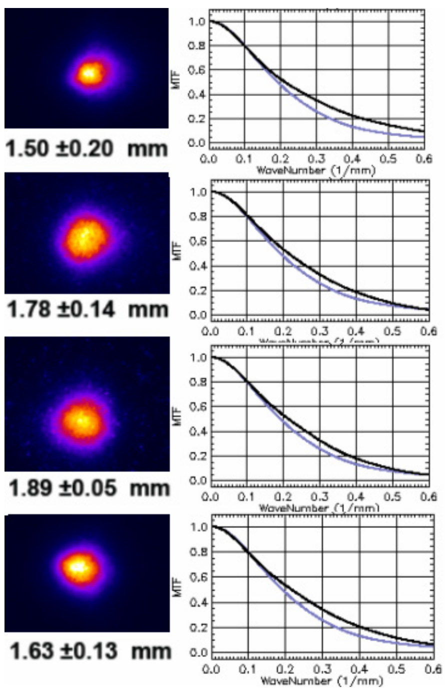

Figure 5: X-ray images of a four pulse target shot with measured 50% MTF and calculated MTF.

Dose Measurement

The dose was measured with a diamond radiation detector (DRD) located approximately 30 cm downstream from the x-ray target. Measurements were made on the DARHT 1st and 2nd axes and the DRD is described by Bender [4]. The dose on the 1st axis was also measured using a calibrated dose calorimeter [5]. This provides a calibration for the DRD measurements. Table 1 presents the pulse length, dose and dose rate for the pulse format presented in Figure 4. The measurements correspond to five beam shots taken under identical conditions. The standard deviation in the dose and dose rate was less than 1%. This result exceeds the third high level requirement.

Table 1: Pulse Format and Dose

Pulse	Pulse length (ns)	Dose at 1 m (R)	Dose Rate (R/ns)
P1	34.4	169	4.92
P2	37.1	186	5.00
P3	36.1	170	4.71
P4	93.9	444	4.73

Beam Motion Over Four Pulses

The beam motion of the four pulses at the x-ray production target must be kept to a very small fraction of the x-ray spot size. Studies of the beam transport from the accelerator exit to the target were performed and resulted in beam motion requirements of less than 2 mm and 2 mrad in both transverse planes at the accelerator exit. This was achieved in accelerator commissioning as described by Ekdahl et al.[6]. The measured beam motion between P1 and P4 was about 0.3 mm in both transverse planes. Subsequent studies have shown that the beam trajectory through the kicker can significantly alter the beam motion over flattop due to the action of image currents and charges on the kicker electrodes. Beam induced kicker steering is described by Caporaso et al [7]. Beam motion in the vertical plane can be minimized by independent controls on the kicker voltage for the four pulses. The horizontal beam motion on the target will be defined by the initial beam motion at the accelerator exit and the beam trajectory through the kicker. Beam studies have demonstrated that the trajectory through the kicker can be adjusted to reduce the horizontal beam motion in target. Further studies are required determine the minimal beam motion on target.

CONCLUSIONS

The DARHT-II scaled accelerator downstream transport and target systems were successfully commissioned. The high level requirements for pulse length, spot size and dose were successfully demonstrated.

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