COMMISSIONING THE DARHT-II SCALED ACCELERATOR DOWNSTREAM TRANSPORT*

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Abstract

The DARHT-II accelerator [1] will produce a 2-kA, 17-MeV beam in a 1600-ns pulse when completed this summer. 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 tests of the kicker, septum, transport, and multi-pulse converter target using a short accelerator assembled from the first available refurbished cells. This scaled accelerator was operated at ~8 MeV and ~1 kA, providing a beam with approximately the same ν/γ as the final 18-MeV, 2-kA beam, and therefore the same beam dynamics in the downstream transport. The results of beam measurements made during the commissioning of this scaled accelerator downstream transport are described.

INTRODUCTION

The DARHT–II scaled accelerator beam parameters were 8-MeV and 1.1 kA with a flattop of 1.6 microseconds. The purpose of the scaled accelerator was to test the performance of the refurbished accelerator cells [2], commission the downstream transport and kicker with a long pulse and demonstrate the target performance. The energy and current were adjusted to match the beam dynamics at full energy.

The downstream transport system for the DARHT-II accelerator [3] 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.

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. 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 beam profiles the downstream transport region are shown in Figure 2. The purpose of the remaining solenoids is to transport the beam to the final focus solenoid which delivers a tightly focused beam to the target.

Beam position and current measuring diagnostics are located throughout the downstream transport. Imaging stations were located just before the 2nd solenoid, between the 1st and 2nd Collins quadrupole magnets, and after the 4th solenoid. Beam profiles were measured at each location and magnet scans were performed. The beam emittance, spot size and divergence were inferred from the magnet scans using beam transport codes. The beam parameters at the exit of the accelerator were determined as part of the accelerator commissioning [4] and are given in Table 1. The transverse beam parameters are for the beam envelope.

Table 1: Beam parameters at accelerator exit

Parameter	Value
Energy	8.0 MeV
Current	0.9 to 1.1 kA
Size	0.8 cm
Divergence	3.2 mrad
Normalized emittance	617 π(mm-mrad)

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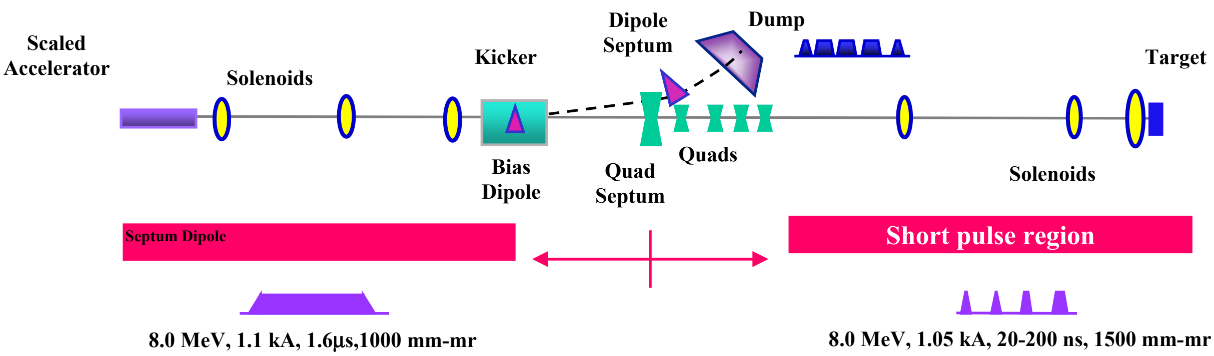

Figure 1: Schematic layout of DARHT 2nd Axis scaled accelerator downstream transport.

COMMISSIONING PLAN

Beamline tunes were developed based on the measured beam parameters at the accelerator exit. 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. A relatively large beam envelope variation is introduced to minimize sensitivity to ion hose instabilities in this long pulse region of the downstream transport. The beam is then focused to a small waist at the entrance to the septum quad as shown in Figure 2.

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. These magnets are set solely by the beam energy and the desired deflection in the bias dipole.

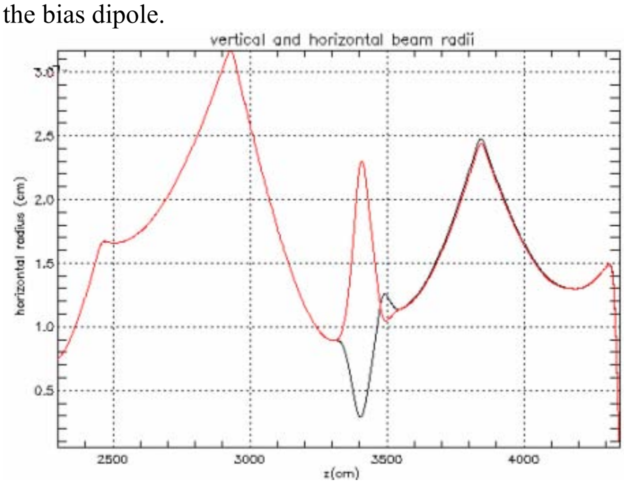

Figure 2: Beam envelope in the downstream transport.

The third region includes the four Collins quadrupoles that are used to return the beam back to round. Although only two quadrupoles are required to return the beam to round, different tunes using three quadrupoles were investigated to find tunes in which a point-to-point focus was achieved between the kicker and the target. In this manner, the partially kicked beam that is transported to the target will intersect on axis with the fully kicked beam and not contribute significantly to the beam size on target. Settings of the second and third Collins quadrupoles were determined as a function of the first Collins quadrupole. The forth Collins quadrupole was not used.

The forth region consists of two transport solenoids and a final focus solenoid to produce a small beam size on target. The tune of these three solenoids was studied for each tune of the small quadrupoles to minimize the spot size dilution from the partially kicked beam.

RESULTS

We will report results on the first short pulse beam transported 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.

First Kicked Beam

Figure 3 shows beam profiles of the first beam transported through the kicker and quadrupole regions at different values of the S4 magnet current. The roundness of the beam as measured by the difference in the FWHM in the two transverse planes is better than 10%. The measured spot sizes agreed with the model predictions transporting the beam from the accelerator exit using the parameters in Table 1 to better than 10%. The beam transmission was approximately 95%. The grid pattern on the images is due to screens on the viewing ports

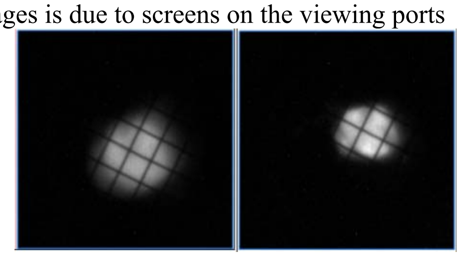

Figure 3: Beam profile of the first kicked beam for different S4 currents.

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 200 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 60, 60, 60, and 120 nsec respectively. The beam current is about 1.1 kA.

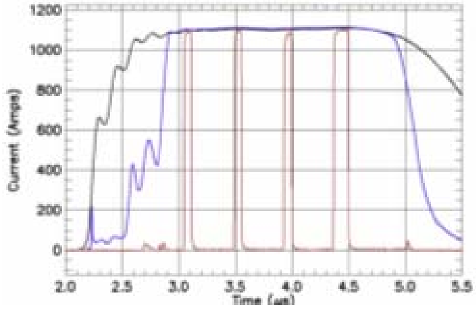

Figure 4: Beam current profile at injector, accelerator exit and target showing four kicked pulses.

Emittance Growth and Stability over Flattop

The emittance of the kicked beam was estimated by performing a solenoid using the same approach as described by Ekdahl et al. [4]. Figure 5 shows the measured beam size for three solenoid scans. The yellow points are from early in commissioning. The blue and pink points were taken three months later and correspond to the beginning and end of flattop. Analysis of each of these data sets gives essentially the same results. The estimated emittance suggests an emittance growth of about 60-70% compared to the calculated emittance presented in Table 1. The agreement between the beginning and end of flattop demonstrates beam stability over the full flattop. The consistency of the data taken at the beginning and end of downstream transport commissioning demonstrates the reliability of the DARHT-II scaled accelerator.

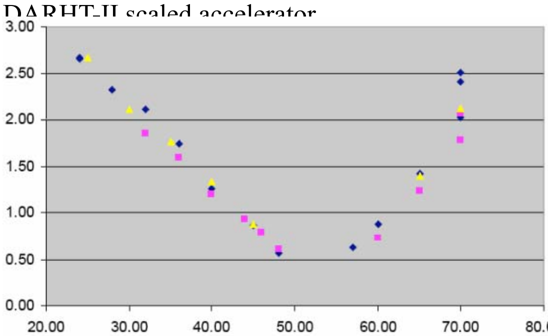

Figure 5: Beam size vs. magnet current for kicked beam.

Beam Induced Septum Desorption

An experiment was performed to determine if beam induced desorption on the septum edge during the kicker rise and fall would affect the beam transport to the target region. The kicker was modified to deliver up to nine beam pulses prior to a tenth test pulse as shown in Figure 6. The beam size, shape and steering of the tenth pulse was studied with and without the initial pulses to observe any differences. Figure 7 show the observed beam images. The first image is without any pre-pulses. The second and third have 6 and 9 pre-pulses respectively. There were no significant differences in the images or the beam positions.

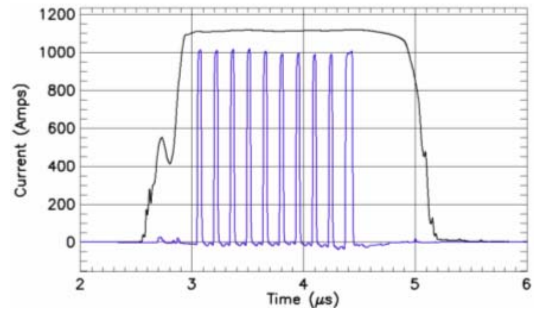

Figure 6: Kicker pulse format for beam desorption study.

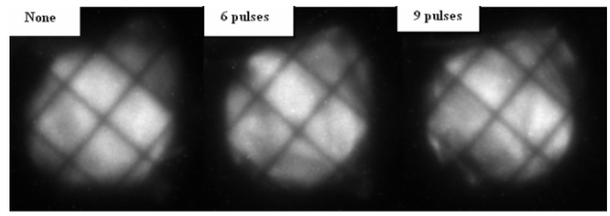

Figure 7: Beam images from desorption study.

Beam Size on Target

X-ray images of a four pulse shot on target corresponding to the pulse format in Figure 4 are presented in Figure 8. These four pulses all have spot sizes of about 1.0 mm FHWM. The DARHT-II project spot size requirement for a Gaussian beam profile is 1.44 mm FWHM. This data clearly indicates that the DARHT-II accelerator will be a valuable tool for radiographic hydrodynamic testing.

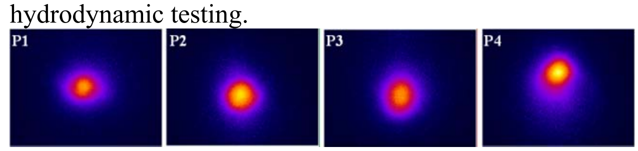

Figure 8: X-ray images of a four pulse target shot.

CONCLUSIONS

The DARHT-II scaled accelerator downstream transport and target systems were successfully commissioned at a beam energy and current for which the relevant beam dynamics scale to the full machine conditions. No evidence of any instability was observed. The successful operation of the downstream transport and kicker is evidenced by the four pulse x-tray beam spot sizes measured at the target.

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