ELIMINATING THE SPOT DILUTION DUE TO KICKER SWITCHING IN DARHT-II*

Yu-Jiuan Chen, Frank W. Chambers, Arthur C. Paul, James A. Watson and John T. Weir
Lawrence Livermore National Laboratory, Livermore, Livermore, CA 94550, USA

Abstract

To produce four short x-ray pulses for radiography, the second-axis of the Dual Axis Radiographic Hydrodynamic Test facility (DARHT-II) will use a fast kicker to select current pulses out of the 2-μs duration beam provided by the accelerator. Beam motion during the kicker voltage switching could lead to dilution of the time integrated beam spot and make the spot elliptical. A large elliptical x-ray source produced by those beams would degrade the resolution and make radiographic analysis difficult. We have developed a tuning strategy to eliminate the spot size dilution, and tested the strategy successfully on ETA-II with the DARHT-II kicker hardware.

1 INTRODUCTION

The second-axis of the Dual Axis Radiographic Hydrodynamic Test facility (DARHT-II) will perform multiple-pulse (1 - 4 pulses) x-ray flash radiography [1]. The downstream [2] consists of a high-speed, high-precision kicker system [3] and an x-ray converter target assemble [4]. The kicker will be used to select four short current pulses out of the 2-μs duration beam provided by the accelerator. In general, the beam motion introduced by the kicker voltage switching could lead to a large smeared elliptical time integrated beam spot even though each beam slice is focused to a small round spot [5]. To achieve good x-ray resolution, we can simply focus every beam slice to a spot tighter than the design specifications to accommodate beam motion during switching. However, the DARHT-II facility uses a static x-ray converter target to preserve the radiographic axis, and having enough target material for all four beam pulses to generate the required X-ray doses provides a big challenge. A tighter beam will put the multi-pulse, static target's confinement at risk. Furthermore, an elliptical x-ray source would make radiographic analysis difficult. We have explored a tuning strategy to eliminate the spot size dilution, and tested the strategy successfully on ETA-II with the DARHT-II kicker hardware.

This paper presents the ETA-II kicker experimental results for minimizing the spot dilution in Sec. 2. The beam transport for the kicked beam with elimination of spot size dilution during kicker switching is discussed in Sec. 3. Finally, conclusions are given in Sec. 4.

2 BEAM TRANSPORT

The DARHT-II kicker ensemble consists of the kicker with a DC bias dipole, a large quadrupole magnet serving as a septum, four Collins quadrupole magnets, a septum dipole and a beam dump. When the kicker is off, the DC bias dipole deflects the beam, and the magnetic field of the quadrupole septum, set by the beam energy, sends the unkicked portion of the 2-μs beam to the beam dump. When the kicker is on, the net deflecting field is reduced to zero. The beam transports through three Collins quadrupoles, which are needed to re-establish the beam to round, onto the straight target line. The fourth Collins quadrupole incorporated into the design was originally included to provide flexibility in the tuning if needed. The nominal beam envelope without using the 4th quadrupole in the target line is shown in Fig. 1. For an 18-MeV beam, the net dipole field from the kicker and the DC bias dipole during the kicker switching varies from 8 to zero Gauss. The beam centroids corresponding to the net field of zero to 2 Gauss (with a 0.2-Gauss increment) during the kicker switching are also shown in Fig. 1 (dashed curves). Although the nominal net deflecting field during the kicker switching varies from zero to 8 Gauss, only the slice with a deflecting field no greater than 2 Gauss would reach the target. Figure 1 indicates that the beam arriving the target will have a few nanoseconds of rise and fall. The beam phase space at the converter target is presented in Fig. 2. For simplicity, we have ignored the coupling in the x-y plane due to the beam rotation in solenoid field. Hence, the beam motion during the kicker switching only appears in the x direction. Therefore, the y-y' phase space plots are the same for all the beam slices during the kicker switching. The x-y plot clearly shows the beam spot moves with the net deflecting field during the switching. The time integrated spot would be a large elongated spot. The x-x' plot also indicates that there is large beam motion during the switching.

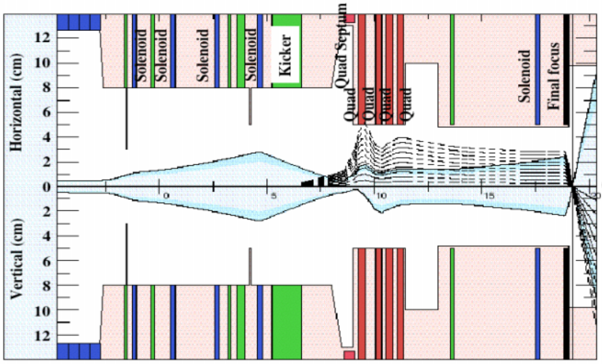

Figure 1. The nominal beam envelope and the beam centroid during the kicker switching in the DARHT-II transport line from the accelerator exit to the target.

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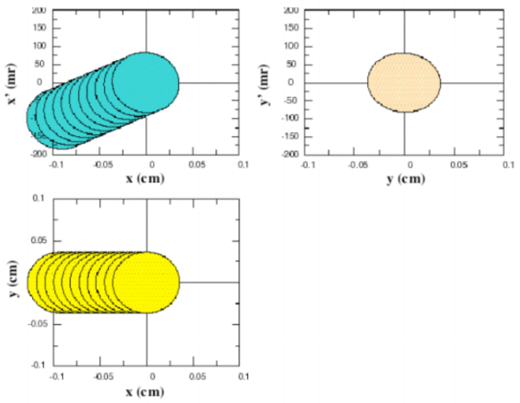

Figure 2. Phase space of the nominal beam at the converter target with the net deflecting field at the kicker varying from 0 to 2 Gauss

To fix the beam motion of an individual beam slice during the kicker switching, we need to apply a set of dipole fields linearly proportional to its residual deflecting field from the kicker and the bias dipole. We have noticed that a beam slice during the kicker pulser's rise and fall will experience a dipole field linearly proportional to its transverse displacement in a quadrupole, and its beam displacement is linearly proportional to the residual field strength. Therefore, we can eliminate the transverse beam displacement on the converter target by using the additional fourth Collins quadrupole with a proper magnetic tune. There are several ways to tune the quadrupoles. We have explored a tuning strategy, which uses four constraints; x = y (round beam), x' = y' = 0 and $x_c = 0$ at the converter to set the field strength of those four quadpoles. By letting the beam round and focused at the target, we have found that scanning the beam radius at the view port downstream from the quadrupoles effectively rotates the kicker sweep in the x-x' phase space (Fig. 3). Double values at the small radii for both curves in Fig. 3 are due to the fact that two different envelopes can give the same beam radius at the view port. There is a wide operation range, which can provide $x_c/a < 10\%$. We have found three quadrupoles tunes with 1.05-cm, 2.19-cm and 2.76-cm beam radii at the view port, which can eliminate spot dilution while the beam angle sweeps either down or up. The beam x-x' phase spaces at the converter target for these tunes are presented in Fig. 4. The x-y plots indicate that there is no spot dilution during the kicker switching.

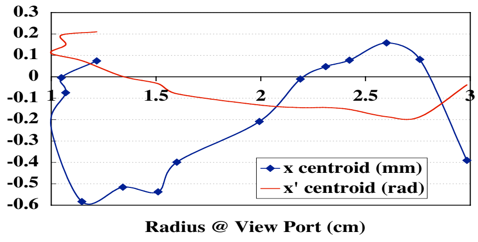

Figure 3. Beam motion at the target of a beam slice with a 1-Gauss residual dipole field during the kicker switching

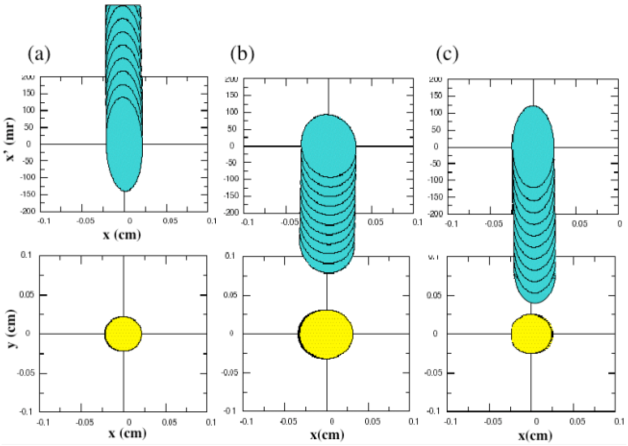

Figure 4. Beam phase spaces at the target for the three optimal tunes that minimize spot dilution. The beam radii at the view port are (a) 1.05 cm, (b) 2.19 cm and (c) 2.76 cm. The net kicker field varies from 0 to 2 Gauss.

3 KICKER EXPERIMENT

We tested the spot size dilution optimization on the ETA-II accelerator at LLNL with the DARHT-II kicker hardware (Fig. 5). The experimental setup is given in Fig. 6. A removable Cherenkov foil was used to examine beam profile past the last quadrupole. Current and beam position were measured with a beam bug placed upstream of the viewing foil. At the end of the setup, we installed a second viewing foil followed by a permanent magnet dipole and beam dump. A camera set with a wide time gate relative to the ETA-II beam was used to observe the time integrated beam profile at this location.s

Figure 5. The DARHT-II kicker system being tested on the ETA-II accelerator

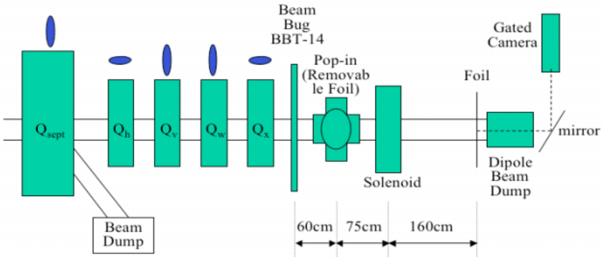

Figure 6. The ETA-II Kicker experimental setup after the kicker

Although the kicker pulser's amplitude modulation and control system can provide precision beam manipulation, such as compensating for transverse beam motion at the kicker input as well as the dynamic response and beam-induced steering effects associated with the kicker structure during the flattop portion of the kicker pulse for high current electron beams [6], the transverse beam motion during the kicker switching will not be compensated. The beam motion during the kicker switching should not be an issue for a long pulse since its time integrated spot size on the target will be mainly determined by the beam flattop instead of by the beam head and tail. However, as demonstrated on the ETA-II (Fig. 7), kicker switching can potentially lead to sever dilution of the time integrated spot size for a short pulse. Fortunately, the spot size dilution can be eliminated with proper tuning of the Collins quadrupoles. The data for kicked beams in Fig. 7 were taken when 20-ns kicker pulses were applied to the center of the 40-ns ETA-II beam. The beam was set to be round at the pop-in foil upstream of the solenoid and at the end of the beam line. Without an optimized tune, the time integrated beam over 100 ns shows the beam being kicked away from and back to its original spot. This beam motion resulted a large elongated time integrated spot size. With an optimized tune to minimize the beam motion during the switching, there was little net beam motion over the entire beam even though the kicker pulser was on, and the 100 ns gated beam image looked similar to the unkicked round beam.

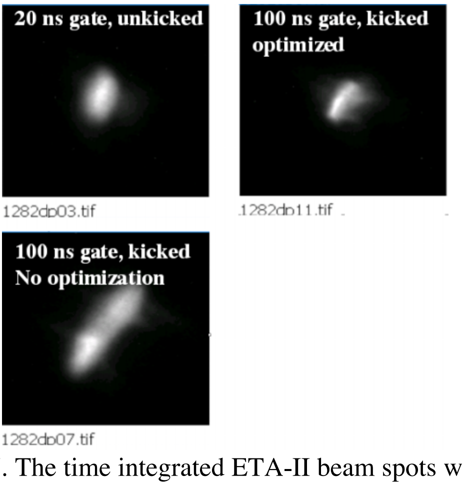

Figure 7. The time integrated ETA-II beam spots without the kicker pulser, and during the entire kicker switching with and without implementing the tuning optimization scheme.

4 CONCLUSIONS

Spot size dilution caused by beam motion during the kicker switching can degrade the DARHT-II radiography facility's performance. We have demonstrated both computationally and experimentally that the beam spot dilution can be removed by tuning the kicker quadrupole system properly. We have noticed that the beam centroid angle at the target during the switching is large for all cases presented in Fig. 4 even though the beam spatial displacement vanishes. Our transport modelling results indicate that only the beam with a 1-Gauss or less net kicker deflecting field will reach the target for those tunes, and that the centroid slope for the beam with a1-Gauss net deflecting field is about ± 200 mr. There are two solenoids after the quadrupoles on the DARHT-II beamline, One serves as the final focus lens, and the other is for the tuning flexibility. The modelling results presented in Sec. 2 were done without using the additional solenoid. Using the extra solenoid would change the steepest centroid angle roughly to ± 100 mr. The nominal beam has a – 65-mr centroid angle (Fig. 2), which indicates that the spot minimization tunes do not trade the beam displacement with the ccentroid angle. A large beam centroid angle during the kicker switching is a concern. The x-rays produced by large angle electrons may smear the x-ray spot while the beam spot is small and round. Some end-to-end particle simulations should be performed to estimate the impact of the large beam angle to the x-ray spot and on-axis dose. If it is needed, adding an additional quadrupole to the beamline may fix the problem. As discussed in Sec. 2, we have used four constraints to tune four Collins quadrupoles. It is possible that the additional quadrupole would allow us to set an additional constraint, i. e., a zero centroid angle.

5 REFERENCES

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