UNFOLDING ELECTRON BEAM PARAMETERS USING SPOT SIZE MEASUREMENT FROM MAGNET SCAN

Yuan Hui Wu†, Yu-Jiuan Chen and Jennifer Ellsworth
Lawrence Livermore National Laboratory, CA, USA

Abstract

The Flash X-ray Radiography (FXR) [1] linear induction accelerator at Lawrence Livermore National Laboratory produces x-ray bursts for radiographs. The machine is able to produce x-ray spot sizes less than 2mm. The beam parameters are unfolded from electron beam radii measured during magnet scan by modelling the FXR LINAC with the simulation code AMBER [2] and the envelope code XENV [3]. These unfolded beam parameters are then used as the initial condition for forward simulations of the beam transport through the drift region to the target. Using x-ray spot size data from a scan of final focus magnet, a good agreement between data and simulation is found for the back streaming ions' neutralization factor f = 0.3.

INTRODUCTION

The beam accelerated by the FXR linac is transported through a drift region to the x-ray conversion target (See Fig. 1). This downstream transport system consists of five magnetic solenoids (DR1, DR2, DR3, DR4 and DR5) and a final focusing solenoid (FF4). A diagnostics station is located between the DR2 and DR3 magnets. For the experiments described in this paper, the time resolved electron beam size was measured by inserting a 1mm thick aluminium coated quartz disk into the beam line at 45 degree angle and imaging the disk with a gated scientific imaging camera. The Cherenkov light captured by CCD camera in the diagnostic cross is calibrated to measure the electron beam radius.

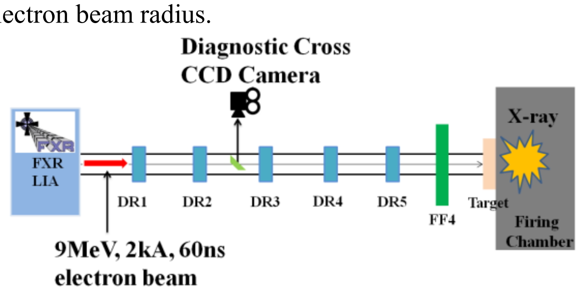

Figure 1: Schematic of FXR downstream section

UNFOLDING ELECTRON BEAM PARAMTERS

To unfold the beam parameters at a given position of the accelerator, the electron beam transport from that position to the diagnostic cross is simulated with AMBER PIC code. A global optimization algorithm [4] (Genetic Algorithm) was used to search beam parameters to match the experimental spot sizes from DR1 scan. The unfolded Lapostolle normalized emittance is 1230 mm-mrad, rms radius r is 9.4 mm, rms envelope slope r' is 15.5 mrad, beam energy E is 8.85 MeV and peak current I is 1.83 kA. Using these beam parameters as initial condition, the simulated electron beam radii for the DR1 magnet scan are shown in Fig. 2. The same beam parameters then used to simulate the beam radii for a magnet scan from DR2, the comparison between the simulated beam radii and the measured beam radii for the DR2 magnet scan are shown in Fig.3. These are a good agreement. The unfolded emittance is consistent with the previously measured value [5].

As discussed in Ref. 1, FXR can produce two electron pulses with different acceleration scheme by sequentially energizing alternate cells. Each of the two pulses gains half of the full machine energy. Minimum beam envelope oscillation is important to reduce emittance growth [6]. Using the unfolded beam parameters as the initial condition for simulations, a magnetic tune is developed for two electron pulses (see Fig. 4). For this simulation, it is assumed that the injector produces two identical electron pulses. The optimized magnetic tune offers a similar final emittance for two pulses.

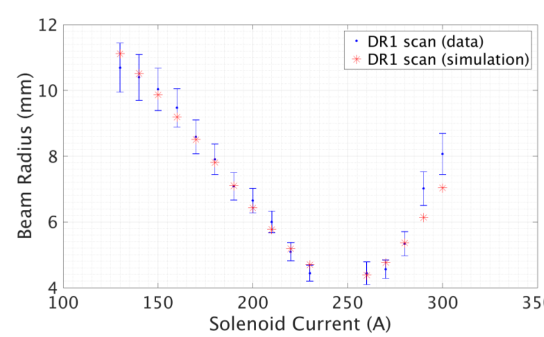

Figure 2: DR1 scan, comparison of measured and simulated beam radius.

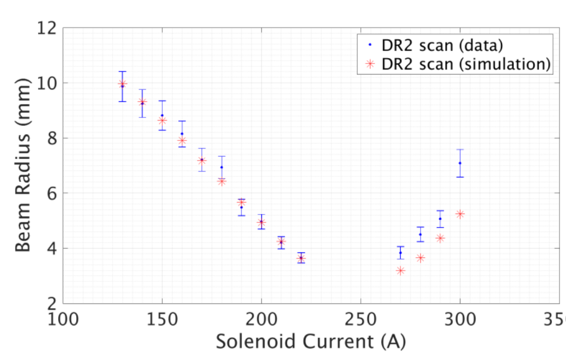

Figure 3: DR2 magnet scan, comparison of measured and simulated beam radius.

† wu39@llnl.gov

Table 1: Unfolded electron beam parameters at the accelerator exit.

Current (Ampere)	1830
Energy (MeV)	8.85
Radius (mm)	9.39
Rprime (mrad)	15.5
Normalized Lapostolle emittance (mm-mrad)	1230

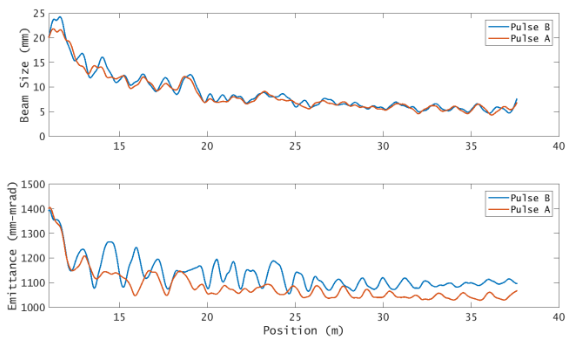

Figure 4: The rms beam envelope and Lapostolle normalized emittance from the accelerator entrance to the diagnostic cross, with an optimized magnetic tune for two electron pulses with different acceleration scheme.

BACK-STREAMING ION EFFECT

Flash radiography imaging requires a small beam spot size at the target to produce x-ray through bremsstrahlung radiation. As shown in [7], the focusing effect of the target is insignificant. Ions accelerated backward from the surface of x-ray converter target by the electron beam's space charge forces form an ion channel, which can have adverse effects on the final beam spot size. Reference [8] shows that the maximum ion speed in a 'beer can' model is given by

$$v_{max} = 2.48 \times 10^8 \sqrt{I[kA]\frac{Z}{A}} \quad (cm/sec) \quad . (1)$$

Z and A are the charge state and atomic number of ions extracted from the surface of the target. The ion channel extracted from the target will propagate upstream with a velocity corresponding to the different ions as shown in equation (2).

The beam envelope equation, taking into account of the charge neutralization from the ions is

$$r''(z) = -\left(\frac{eB_o}{2\gamma\beta mc}\right)^2 r + \frac{2I}{\gamma\beta^3 I_0 R}\left(\frac{1}{\gamma^2} - f\right) + \frac{{\varepsilon_n}^2}{\gamma^2\beta^2 r^3} \quad (2)$$

r is beam edge radius, B_o is solenoid magnetic field, I_0 is Alfven current (17 kA), ε_n is normalized edge emittance, and f is the charge neutralization factor. Since the ion channel grows upstream in time, the ions' charge neutralization factor f(z) is different for different beam slices. For a 2kA, 60 ns electron beam, a hydrogen ion H^+ can travel about 21 cm.

The time varying charge neutralization effect leads to different pinching effects for different slices along the electron beam (Figure 6). Each slice radius r(z) can be calculated by solving equation (2) with the initial electron beam parameters unfolded from the magnet scan. The final full width, half max (FWHM) spot size is obtained by time integrating the distribution of all the 20 slices, then fitting the result with a Gaussian profile. As shown in Figure 7, there is a good agreement between the simulation results and measured spot sizes when neutralization factor is 0.3.

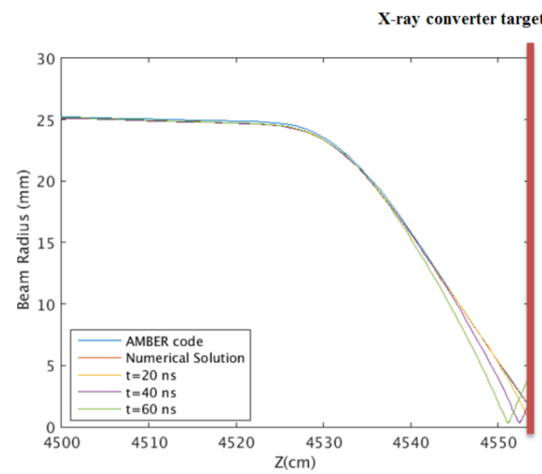

Figure 6: The time varying beam radius on a target with back streaming ions (protons).

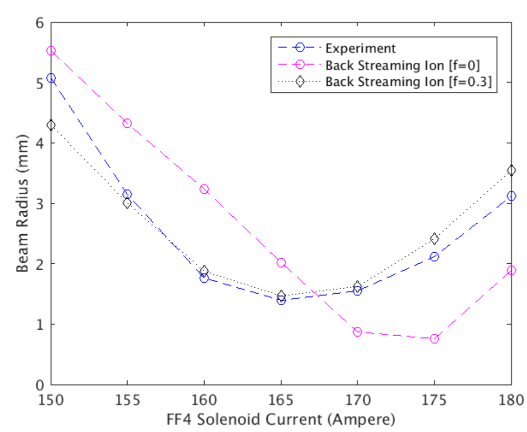

Figure 7: Comparison of x-ray spot size data with spot size form numerical solution, both have good agreement when neutralization factor f=0.3.

SUMMARY

An optimization technique has been developed to unfold the beam parameters for linear accelerators. The unfolded beam parameters are used as the initial condition to optimize a magnetic tune for minimum envelope oscillation for two electron pulses with different acceleration scheme with by sequentially energizing alternate cells. Solving the beam envelope equation with various neutralization factor f, we found that f=0.3 shows good agreement between measured and simulated spot size at the target. This technique of matching the simulated and measured spot size using the optimization algorithm has demonstrated as an efficient way to unfold the beam parameters at a given position of accelerator. These unfolded beam parameters can be used to optimize the electron beam transport tune. For future accelerator operation, magnetic tune of the final drift section can also be optimized by solving a multi-slices' envelope equations and including the neutralization effect of the ions.

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