UNFOLDING ELECTRON BEAM PARAMETERS USING SPOT SIZE MEASUREMENT FROM MAGNET SCAN

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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. Using the spot sizes measured from the magnet scanning, the beam parameters are unfolded by modelling the FXR LINAC with the PIC slice code AMBER [2] and the envelope code XENV [3]. In this study, the most recent measured spot size measurement results and technique used to extract the beam parameters are described. Using the unfolded beam parameters as the initial condition, the backstreaming ions' neutralization factor f = 0.3 is found by comparing the calculated spot sizes with measured spot sizes at the target.

Introduction

The FXR downstream system (See Figure 1)

- five magnetic solenoids (DR1, DR2, DR3, DR4 and DR5)
- A final focusing solenoid (FF4).
- A diagnostic cross camera is located after DR2 magnet to measured time resolved electron beam radius image
- a 1mm thick aluminium coated quartz disk is inserted into the beam line at 45 degree to intercepts the electron beam.
- The Cherenkov light captured by CCD camera in the diagnostic cross is calibrated to measure the electron beam radius.

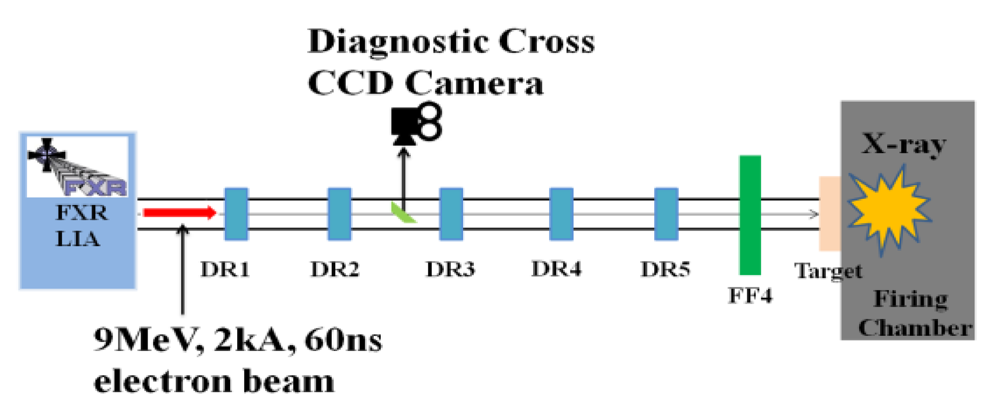

Figure 1: Schematic of FXR final focusing drift section

Beam Envelope Equation

$$r''(z) + \frac{(\gamma\beta)'}{\gamma\beta} r' + \frac{\gamma''}{2\gamma\beta^2} r + \left(\frac{eB_o}{2\gamma\beta mc}\right)^2 r - \frac{2I}{\gamma^3\beta^3 I_0 R} - \left(\frac{p_\theta}{\gamma\beta mc}\right)^2 \frac{1}{r^3} - \frac{\varepsilon_n{}^2}{\gamma^2\beta^2}\frac{1}{r^3} = 0$$

Inertia; Acceleration damping; Field gradient Focus/defocus; Solenoidal focusing; Self-field $E_r{}^{self} - v_z B_r{}^{self}$; Centrifugal term; thermal expansion

- (r, r', ε_n, I, γ) are the beam parameters we are trying to unfold.

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Magnet Scan and Beam Parameters

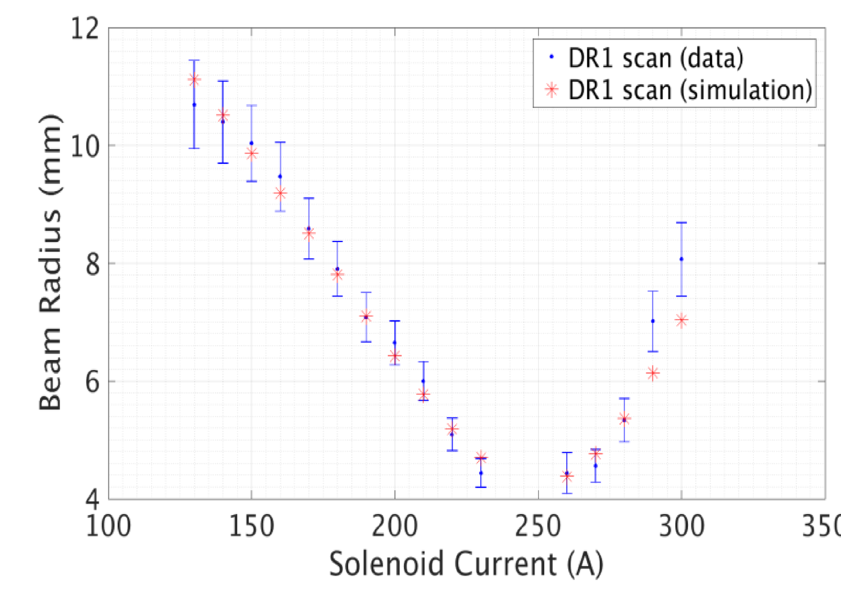


Figure 2: DR1 scan, comparison of measured and simulated beam radius.

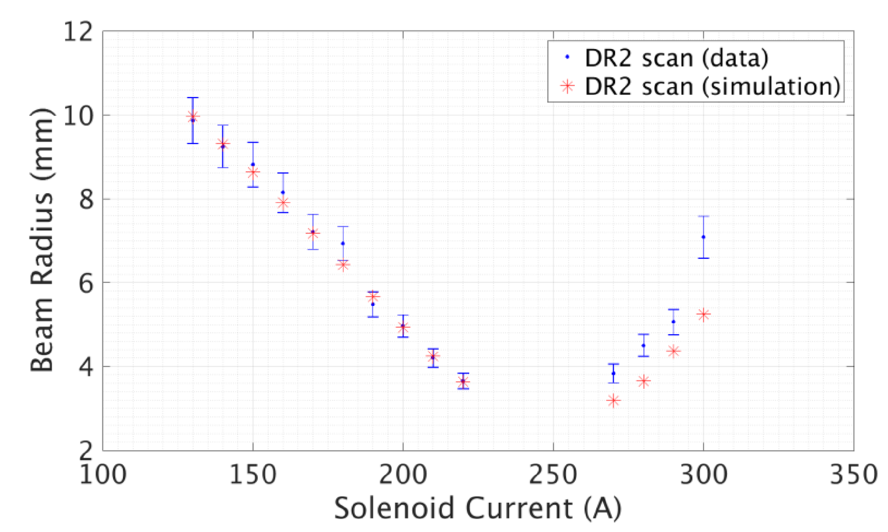


Figure 3: DR2 magnet scan, comparison of measured and simulated beam radius.

- DR1 and DR2 magnet scan were performed by varying the magnet current. The beam spot sizes were measured for each setting.
- To unfold the beam parameters at a given position, global optimization algorithm (Genetic Algorithm) was used to search beam parameters (see Table 1) to match the experimental spot size 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.

Optimized Tune for Two Electron Pulses

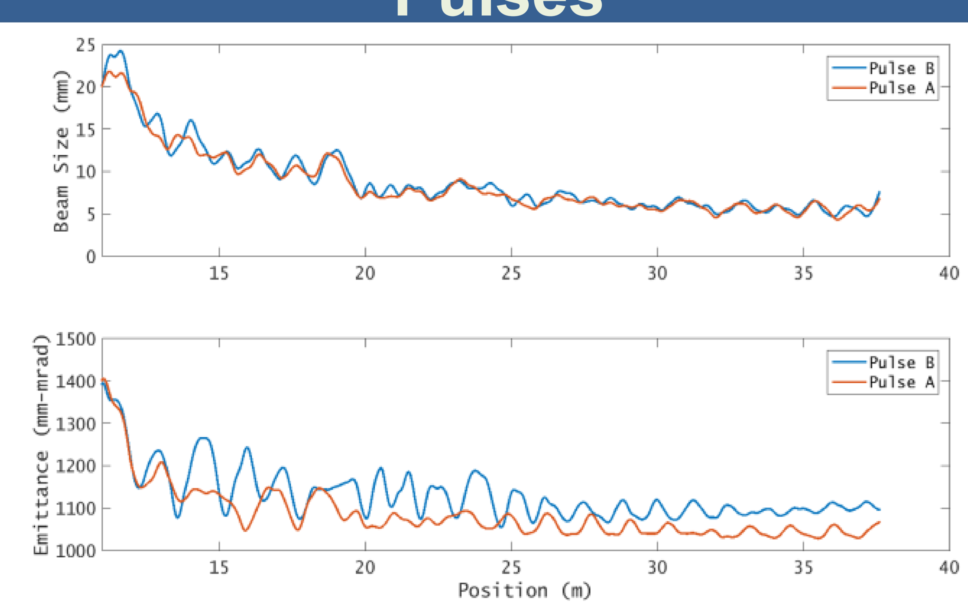
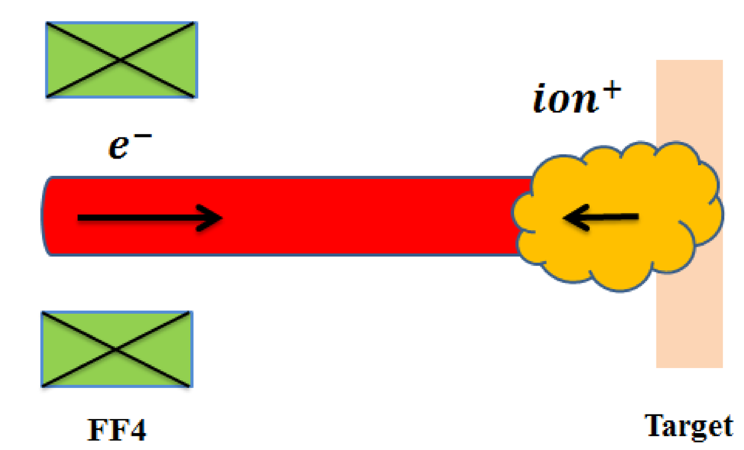


Figure 4: Using the unfolded beam parameters as the initial condition for simulations, a magnetic tune is developed for two electron pulses with different acceleration schemes. The optimized magnetic tune offers a similar final emittance for two pulses.

Back Streaming Ion Effect

- Flash radiography imaging required a small beam spot size at the target to produce x-ray through bremsstrahlung radiation.
- 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 [6], which can have adverse effects on the final beam spot size. Reference [6] shows that the maximum ion speed in a 'beer can' model is given by

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



The beam envelope equation by taking into account of ions' charge neutralization is

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

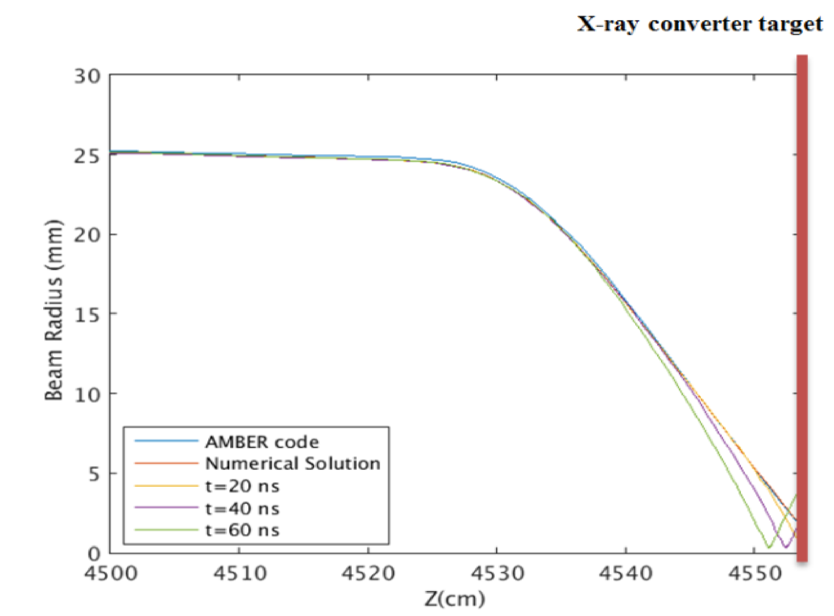


Figure 6: The time varying beam radius on a target with back streaming ions (protons).

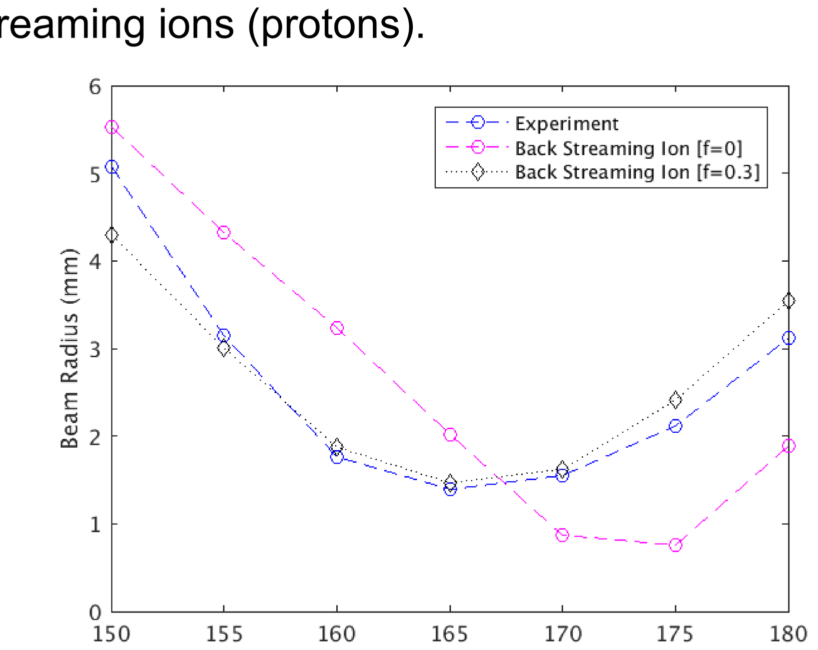


Figure 7: Comparison of x-ray spot size data with spot size form numerical solution, both have good agreement when neutralization factor f=0.3.

Conclusions

- An optimization technique has been developed to unfold the beam parameters for linear accelerators.
  1. 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.
  2. 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.
  3. The technique of matching the simulated and measured spot size through optimization algorithm has demonstrated as an efficient way to unfold the accelerator's beam parameters. Then these unfolded beam parameters can be used to optimize the electron beam transport tune.
  4. For future accelerator operation, magnetic tune of the final drift section can also be optimized by solving multi-slices' envelope equations with back-streaming ions' neutralization effect.

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