REAL BEAM LINE OPTICS FROM A SYNTHETIC BEAM*

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Abstract

The Continuous Electron Beam Accelerator Facility (CEBAF) at Jefferson Lab can be described as a series of concatenated beamlines. Methods used to measure the Twiss parameters in closed orbit machines are not applicable in such open ended systems. We are using properly selected sets of real orbits in the accelerator, as one would for numerical analysis. The evolution of these trajectories along the beamline models the behavior of a synthetic beam which deterministically supplements beam profile-based Twiss parameter measurements and optimizes the efficiency of beamline tuning. Examples will be presented alongside a description of the process.

INTRODUCTION

The CEBAF accelerator at Jefferson Lab consists of two superconducting LINACs connected by independent bending arcs, and can be viewed as a series of transfer lines. Polarized electrons pass through the racetrack up to five times, reaching a maximum energy of 6 GeV, which can then be used by the three experimental halls. Beam quality requirements include specifications for beam size at multiple locations, including the physics target.

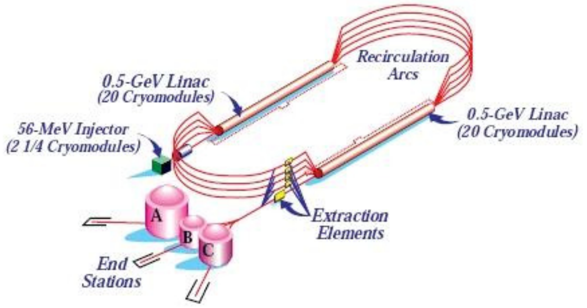

Figure 1: CEBAF.

We are developing a method to characterize the optical properties of the beam which is capable of measuring beam optics parameters simultaneously at multiple locations. The goal is identification not only of large point errors but also small distributed errors along the beamline. Optical parameters in transfer lines are commonly measured by performing a quadrupole scan with a single beam profile monitor (BPM). This involves measuring the variation in beam size as the strength of a quadrupole magnet is varied by a known amount. This provides local information but not a global understanding of the optics of the rest of the machine

Rather than performing a profile scan at one location, a family of rays selected to model the phase space boundary of the design beam can be injected. At every BPM in the accelerator, the X and Y trajectories are measured. For the set of injected rays, the extreme values of these X and Y measurements provide a model-independent measure of the envelope of the "synthetic beam." Using short-range optical modelling, angular information for both planes, X' and Y', can be paired with the position information to provide projected values of the Twiss parameters. Because the bunch charge of the CEBAF beam is small, self-field effects are small, and the transfer properties of the lattice in the zero-current limit are exactly applicable in use.

PROCEDURE

The X and Y transverse planes can be considered separately, as the design optics of CEBAF is uncoupled. Using two correctors and the design transport optics between them, we generate a set of initial trajectories having the design Twiss parameters at some launch point (at or downstream of the second corrector). The central position and angle of the beam are carefully rastered through the set of initial coordinates. These rays are then tracked by reading the BPM positions throughout the rest of the machine.

The trajectory data are used to compute the statistically applicable pseudo-emittance and Twiss parameters α and β at each BPM. We currently use an algorithm developed to identify ellipses in image data, although raw statistical averages can provide the desired information. The analysis program displays the data, phase ellipses of injected rays, and model phase ellipses for each plane. We currently duplicate the beam orbit data and check for reproducibility to guard against drifts of the beam over the few minutes presently required for data gathering. The behavior of the pseudo-emittance of the trajectory family provides another data quality check, as it should show the appropriate amount of acceleration damping. The evolution of Twiss parameters along the beam line can easily be displayed for comparison to design values, and errors with respect to the design optics can be displayed in visually clear ways and fed back into envelope matching programs to provide deterministic optical tuning.

EXAMPLE OF USAGE

The following section is an example of the utilization of this method. Experimental Hall A had high noise levels in their Compton polarimeter and our usual techniques for tuning the optics had failed to identify and correct the problem.

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It was found that the injected beam was mismatched from the designed beam optics in both the horizontal and vertical planes.

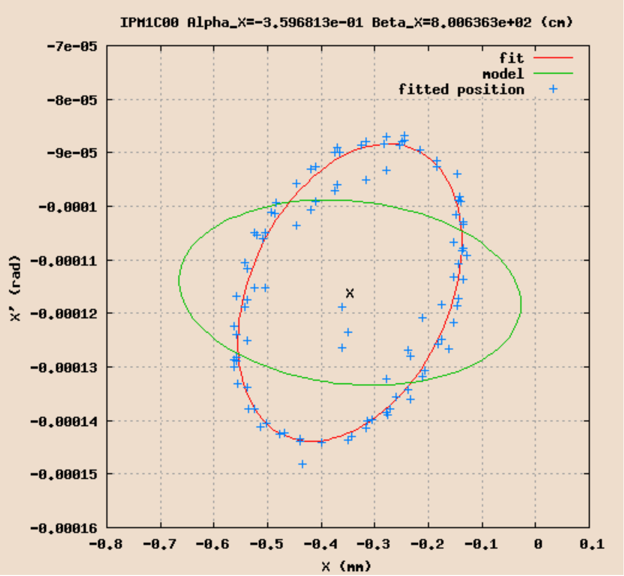

Figure 2a: Horizontal Mismatch.

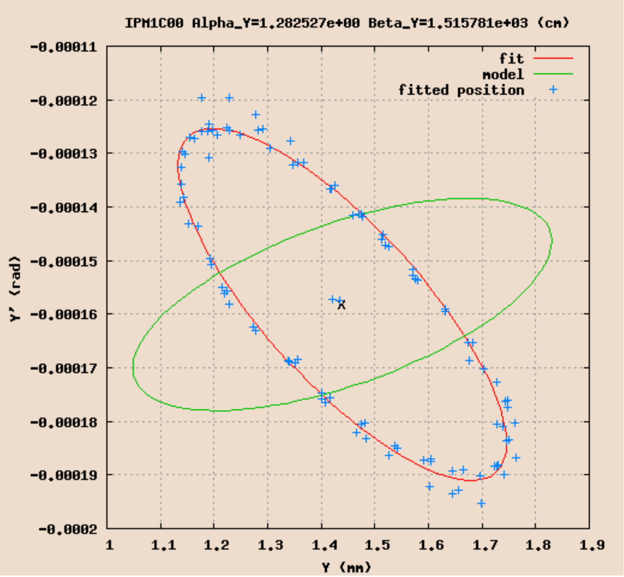

Figure 2b: Vertical Mismatch.

Figures 2a and 2b show the measured phase ellipses for each plane, as well as what is expected from the design model. We used 32 trajectories to trace out each phase ellipse with its design Twiss parameters (α, β) and geometric emittance $5x10^{-8}$ meter-radians. It is clear that upon entry into the Hall A beamline, neither plane was properly matched to the design optics.

In addition to the mismatch at entry to the beamline, the trajectory data showed anomalous behavior beginning at the Compton polarimeter itself. This was traced to partial beam loss during a portion of the vertical phase space scan. This only occurred in the vertical plane and indicated a previously unrecognized aperture limitation. Such violations of beam to first-wall clearance are known to result in the noise which motivated this measurement, but they are normally found and corrected by standard procedures. This region lacks adequate diagnostic tools for the optical characteristics of the beam. However, because BPMs are present, our method is capable of characterizing the beam envelope and allows for the comparison of the optics currently in the machine to the design optics expected in the region.

The partial beam loss was recorded in the machine archiver, as shown in Figure 3. Horizontal measurements began at 11:04AM and ended at 11:11AM. Vertical measurements began at 11:14AM and ended at 11:21AM.

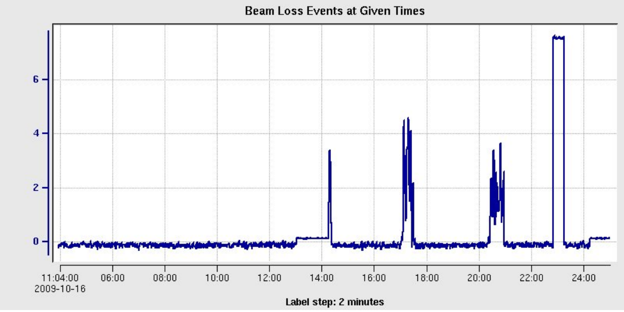

Figure 3: Beam Loss Events.

Figure 4 shows the Compton polarimeter region of the Hall A beamline, where the scraping occurred. As the beam enters the chicane, it is displaced vertically downward, passes through the high-power optical cavity where it scatters photons, and then returns to its original elevation.

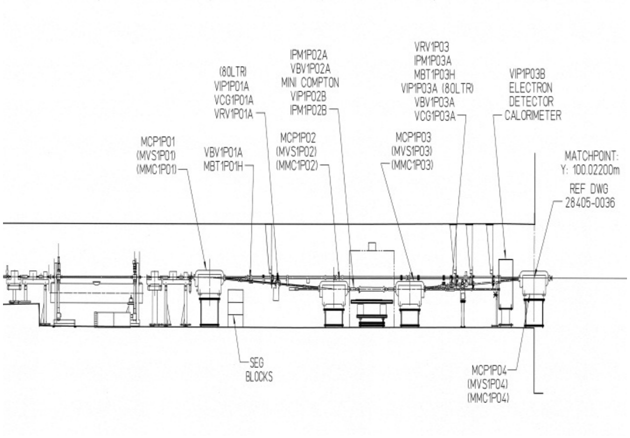

Figure 4: Compton Chicane.

Due to lack of detailed diagnostics in the region, the clearance problem was unrecognized and the transverse Twiss parameters were not well-known. The beam was re-matched in the beamline, the scraping problem was remedied, and the noise problem was reduced.

FURTHER WORK

This technique is being explored for its potential to provide physically transparent optics information along the beamline. The measurement of properties of the "synthetic beam," a collection of sequential trajectory measurements, shows in a meaningful way the evolution of Twiss parameters through a real beamline. The measured Twiss parameters can be used transparently in optics codes to prescribe exactly what setting should be used for each tuning quadrupole to obtain the intended Twiss transformation, including chromatic corrections, if required. The relative merits of invasive techniques compared to parasitic analyses such as the Model Independent Analysis (MIA) developed by Wang [1] will be investigated, but the direct measurement of the transformed Twiss parameters from the actual beamline appears to be best fitted to our local needs and tuning procedures. We are trying to understand the optical deviations of the machine from the model used to describe it, so that changes of configuration can be made more efficiently.

We have found several BPMs which contribute large amounts of noise to these data. This makes clear our need to use systematic, passive data quality checks, such as used by Wang, et al. [1, 2].

CONCLUSION

By properly selecting a family of rays to inject into a region of the accelerator, and tracing the response of this synthetic beam envelope through the real CEBAF machine, we have demonstrated the ability to effectively assess the quality of the beam transport system as well as the matching of the beam parameters to the optics model. This procedure allows for a global understanding of the Twiss parameters throughout an open-ended machine, enabling detailed imaging of the optical transformations which occur in the beamline. This will enable more efficient optical tuning of the beam shape and matching in order to meet the requirements set by the experimental halls.

ACKNOWLEDGEMENTS

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REFERENCES

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