

# FURTHER ANALYSIS OF REAL BEAM LINE OPTICS FROM A SYNTHETIC BEAM\*

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## Abstract

Standard closed-orbit techniques for Twiss parameter measurement are not applicable to the open-ended Continuous Electron Beam Accelerator Facility (CEBAF) at Jefferson Lab. The evolution of selected sets of real orbits in the accelerator models the behavior of a “synthetic” beam. This process will be validated against beam profile-based Twiss parameter measurements and should provide the distributed optical information needed to optimize beamline tuning for an open-ended system. This work will discuss the current and future states of this technique, as well as an example of its use in the CEBAF machine.

## INTRODUCTION

The CEBAF accelerator at Jefferson Lab, composed of two superconducting LINACs connected by independent bending arcs, 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, and are used by up to three experimental halls simultaneously. Each hall has its own requirements for beam energy, current, and quality which include specifications for beam size at multiple locations, including the physics target.

We are developing a procedure to characterize the optical properties of the beam which measures beam optics parameters simultaneously at multiple locations. The goal is to identify not only point errors, but also distributed errors along the beamline. Optical parameters in transfer lines are commonly measured by performing a quadrupole scan with beam profile monitors, measuring the variation in beam size as the strength of a set of lenses is varied by a known amount. This provides local information but does not give distributed understanding of the optics of the rest of the machine.

The RMS beam Twiss parameters are fundamentally the covariances of a particle distribution:

$$\epsilon_{rms}^2 = \langle x^2 \rangle \langle x'^2 \rangle - \langle xx' \rangle^2 \quad (1)$$

$$\beta_{rms} = \frac{\langle x^2 \rangle}{\epsilon_{rms}} \quad (2)$$

$$\alpha_{rms} = \frac{-\langle xx' \rangle}{\epsilon_{rms}} \quad (3)$$

Modeling particle orbits in the actual beamline by a set of differential beam trajectories, the Twiss parameters at all points may be read directly from the trajectory

distribution (see Figure 1). For example, for a dense set of injected trajectories populating an elliptical curve in phase space, the half-span of the beam positions at any point downstream will be equal to  $\sqrt{\beta\epsilon}$ . This model-independent measure of  $\beta$  is available at every BPM. A short-range model can provide the trajectory angles for closely spaced BPMs, enabling measurements of  $\epsilon$  and  $\alpha$  (see Figure 2). For low-current systems such as CEBAF, this zero self-field model is adequate to model beam transport. However, even in systems for which self-fields are essential, there is a bare lattice for which the design parameters may be validated.

## PROCEDURE

Two correctors in each plane are varied simultaneously so that the beam centroid is steered successively to a series of points along phase space ellipse at a point chosen along the beamline. The number of points is chosen by the user, as is the number of times the phase ellipse is traced. Every BPM in the machine simultaneously reads the beam position in the plane being studied, and this data is logged for analysis.

## ANALYSIS

### Initial analysis with fitphase

The initial analysis of the data is performed by a program called fitphase, written by Yves Roblin. This program uses the position data from the BPMs, as well as local, short-range optical models to calculate the angular terms,  $X'$  and  $Y'$ . It then plots the position and angular information for each plane at each BPM on a phase space plot, and fits an ellipse over this plot using an image processing algorithm that identifies ellipses. It also plots the model phase ellipse at each location for easy comparison. This quick, visually-oriented description of the optics of the machine allows one to distinguish between point errors and distributed errors. However, the BPM noise is sufficiently large that one cannot obtain adequately accurate Twiss values for deterministic rematching. Singular value decomposition is useful in reducing noise contribution.

### Singular Value Decomposition

In order to reduce the effective noise level in some BPMs, singular value decomposition (SVD) was useful. Performing SVD analysis on differential orbit data, one can find the dominant singular values and the corresponding temporal and spatial basis vectors. By cutting off the singular values that correspond to the uncorrelated responses, and reconstructing the BPM position data, one can greatly decrease the noise, and the

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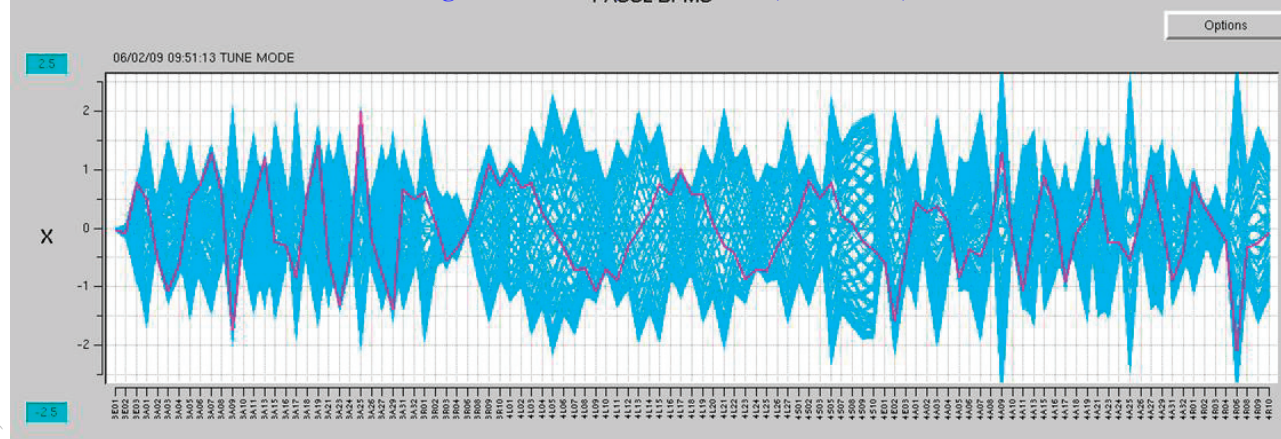


Figure 1: Overlaid, detrended X-plane orbits of 2nd pass tune-mode beam during characterization procedure. This beam is launched in East Arc, passes through the South Linac, and terminates at the end of the West Arc.

data can then be reanalysed using fitphase or any other analysis technique (see Figures 2 and 3).

Isolated noisy BPMs can be identified in the plot of the spatial basis vectors. If the dominant signal of one of these basis vectors occurs primarily in one location, this is evidence of a bad BPM. Further evidence is seen in the corresponding temporal basis vector plot and its FFT (Figure 4). If these show that the reading of that BPM is not periodic, then the BPM may be malfunctioning and should be investigated.

The first two columns in Figure 4 show the spatial and temporal basis vectors which correspond to the largest three singular values. The third column shows the FFT of the temporal basis vector. In the third row, one can see that a single BPM is responsible for nearly all of the response in the spatial basis. The temporal basis vector in the same row shows that this response is noise, and this is confirmed in the FFT of this basis vector. For further information on the use of SVD in beamline characterization, the authors would point the reader to the work of C.X. Wang [1, 2].

## FURTHER WORK

The use of SVD analysis to obtain information on phase advance and other Twiss parameters is being investigated. These values will be compared to those found using the fitphase analysis of the noise-reduced data, providing a method to enhance our data analysis.

Further noise reduction will be investigated with these data by fitting transfer matrices along sections of the beamline. The transfer function projected Twiss parameters should then be useable for deterministic rematching.

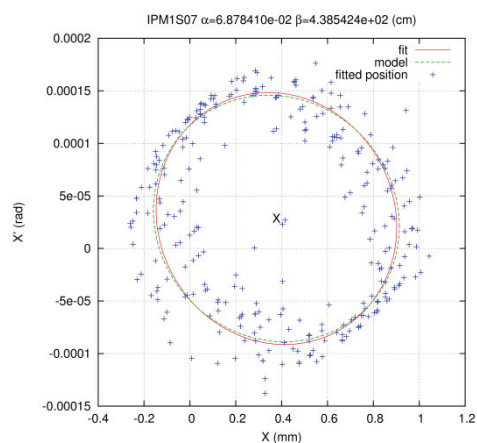


Figure 2: fitphase analysis with raw data

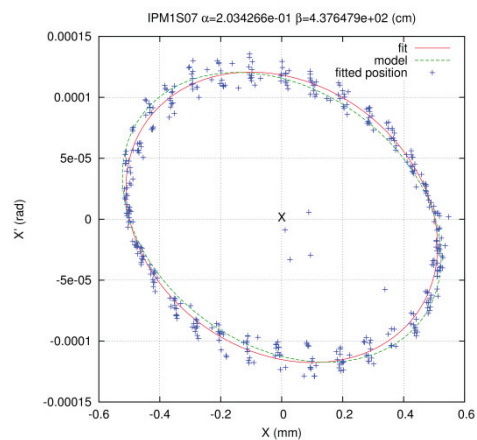


Figure 3: fitphase analysis after SVD clean-up

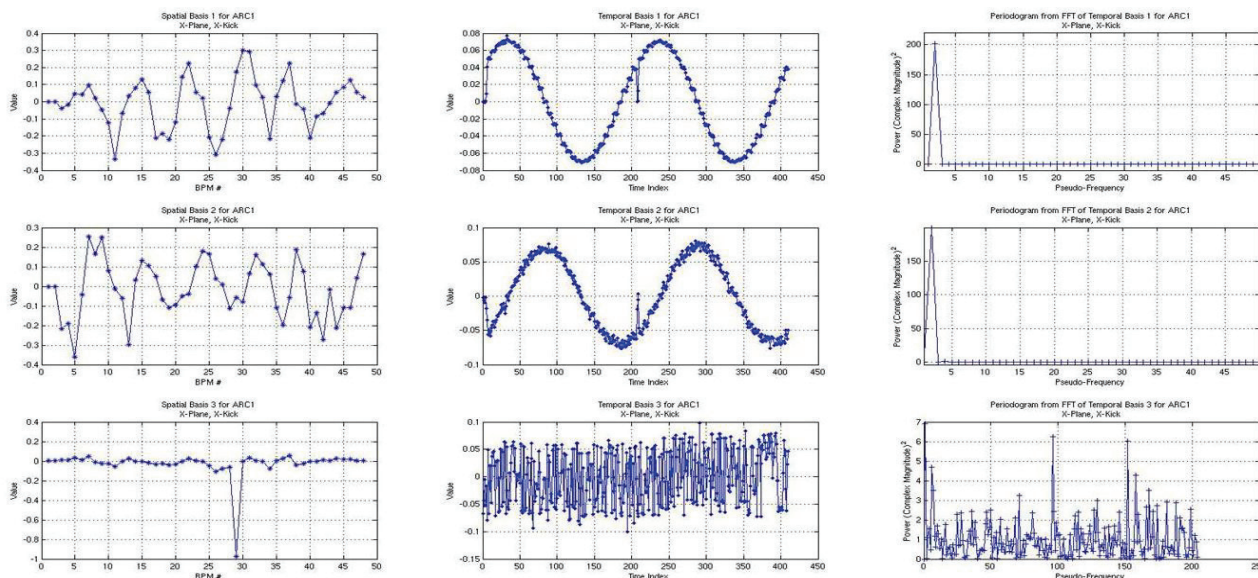


Figure 4: First column contains spatial basis vectors. Second column contains temporal basis vectors. Third column contains FFTs of temporal basis vectors. Notice the third row identifies a noisy BPM.

Future work for this project shall include the investigation of cross-plane coupling. The CEBAF machine actively compensates for coupling, but this procedure should be able to characterize the nature of the coupling that is uncompensated. The transfer matrix fitting that is currently being investigated will be used to ensure the beam is behaving in the expected symplectic manner. The determination of fully coupled transfer functions should be done using symplectic fits for appropriate hyper-ellipsoidal families of orbits.

## CONCLUSION

As an open-ended beamline, the Twiss parameters of the CEBAF machine at Jefferson Lab cannot be found in the same manner as in closed-orbit machines. The procedure that we are developing injects a family of rays, selected to paint the boundary of a phase ellipse at a given location, into a region of the accelerator. The response of this synthetic beam envelope is traced through the real CEBAF machine by measuring the beam positions at all downstream BPMs. This position data, combined local model optics, is used to calculate the Twiss parameters at

each BPM in the accelerator. In an effort to reduce system noise, SVD analysis has been performed on the BPM data. This analysis has reduced the error of the current method, but is also providing a model-independent method for calculating the Twiss parameters. The Twiss parameters will then be used in tuning the CEBAF machine to the required parameters during operation.

## ACKNOWLEDGMENT

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## REFERENCES

- [1] Chun-xi Wang, "Model Independent Analysis of Beam Centroid Dynamics in Accelerators," PhD Dissertation, SLAC, September 1999, Issued as SLAC-R-547, April 2003.
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