Fermilab Contributions to the FFTB

V. Bharadwaj, A. Braun, M. Halling, J. A. Holt, D. Still
Fermi National Accelerator Laboratory
P. O. Box 500, Batavia, IL 60510, USA

Abstract

The Final Focus Test Beam (FFTB) project at SLAC is a demonstration of the feasibility of making the extremely small spot sizes needed for future e^+e^- linear colliders. Fermilab joined the FFTB collaboration in late 1993. This paper describes the Fermilab contributions to FFTB, emphasizing the work on lattice diagnostics.

I. Introduction

There has been an ongoing involvement by Fermilab in work on high energy e^+e^- linear colliders [1]. In 1993 Fermilab joined the Final Focus Test Beam Collaboration. The FFTB [2] is an experiment to demonstrate the feasibility of making the small beam spot sizes that are required for the success any future linear collider project. The experiment has already yielded impressive results [3] and has shown that the demagnifications needed for the NLC design are feasible. Fermilab joined the collaboration after almost all of the hardware was already installed. However an earlier engineering run indicated the need for an additional $x-y$ halo collimator, which Fermilab built and helped commission in the FFTB beamline. The FFTB beamline requires very careful alignment and the magnet strengths have to be correct [4] for the beam to focused down to its design value at the final focus. Fermilab was responsible for checking the magnet strengths (i.e. lattice diagnostics) and developed two independant methods for this project. This paper deals mostly with these lattice diagnostic methods.

II. Offline Analysis

One method of measuring the FFTB lattice is to fit beam data from a large number of 3 and 4 bumps. There are 12 precision trim magnets in the beamline that are used to create trajectory bumps. There are not however, enough trims to make bumps over a short region in the lattice. Typical 3-bumps with the correctors include about 10 quads. Almost every quad in the beamline is mounted on a movable stand that can be positioned to about 1 micron accuracy. Trajectory bumps were also made using these quad movers. The advantage of using bumps created by the movers is two-fold; the movers do not suffer from hysteresis, and there are movers on each quad allowing us to make a wide variety of very short bumps. This gives many more combinations of bumps than can be made using the limited number of precision dipole trim elements.

The BPMs have demonstrated accuracy in many cases better than 1 um for small displacements. For large displacements the non-linear nature of their response limits their accuracy to about 30 microns absolute accuracy. An overall scale factor error of 10%, and channel to channel non-linear errors of a few percent are two other effects that limited the absolute precision of the BPM system at large displacements.

The most precise test that the BPM's can make is to require that a bump be closed so that there is zero deflection downstream. The BPMs used in the FFTB are capable of measuring small changes in the trajectory from one pulse to the next with a precision of 1 μm or better. In order to measure the lattice properties to 0.1% or better accuracy closed 3 and 4 bumps are used to test the lattice. Small imperfections in the lattice appear as small movements of the beam downstream of the bump.

The complication of using closed bumps for the measurement is that each measurement includes the effect of several quads. In order to separate out the trajectory errors from each quad without any correlation with its neighbors we made many overlapping orthogonal closed bumps. We used over 100 different closed bumps to measure the individual strengths of about 30 quads. The large amount of redundancy in the measurements allow the measurement of each quad strength with little ambiguity. The lattice properties were then extracted by the simultaneous fitting of all the experimental data

Each closed bump was tried with 5-10 steps of different strengths. Each of these steps in bump strength was repeated 5-10 times. For each bump the trajectories of between 50 and 100 different linac cycles were taken. A correction is made for each linac beam pulse to correct for the pulse to pulse variation of the SLAC linac.

The lattice properties were measured by fitting the processed BPM measurements for all of the different 3 and 4 bumps simultaneously. Each bump trajectory was compared to a model prediction based on a tracking simulation originating from the SLAC control system online model. The fitting was performed using the MINUIT optimization program, using a χ^2 that based on the measured errors determined by the reproducibility of the measurements. The quantity used for the minimization is the χ^2/dof of all BPMs for all bump measurements.

By far, the most important parameter needed to fit the data is an overall BPM scale factor. In one sub-sample of our data the overall χ^2/dof is reduced from 50 to 25 by including a 13% scale factor change. In addition the beam energy may also be fit to all the data.

Table I shows the strength of each quad in our test region relative to the online model, obtained by fitting each quad separately. In most cases the precision is of order 10^{-3}.

The two most critical sections of the FFTB lattice are the $-I$ transformers in the chromatic correction sections. Each of these sections contains five quads. Table II shows the results of a simultaneous fit to four of the five quads in each of these sections. If the measured errors had been large enough to cause

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Table I
Quadrupole strengths in the test region relative to the model.

Name	Value	Error
QN3A	1.0033	0.001239
QN3B	0.99639	0.001677
QN2A	1.0009	0.000602
QN1	1.0006	0.000867
QN2B	1.0007	0.000659
QN3C	1.0021	0.002117
QT1	1.0032	0.002992
QT2A	0.89738	0.045050
QT2B	0.99909	0.002033
QT3	1.0011	0.001594
QT4	1.0027	0.001393
QM3B	1.0022	0.001767
QM1A	0.99437	0.002336
QM2	1.0005	0.001641
QM1B	0.99936	0.003753
QM3C	1.0026	0.002999
QM3D	1.0027	0.002816
QM3D	1.0018	0.006240
QM1C	1.0017	0.004884
QM1C	0.99699	0.001475
QC5	1.0040	0.001516
QC4	0.99958	0.002699
QC3	0.99084	0.006982
QX1	0.97512	0.013512
QC1	0.97981	0.010615
QP1A	0.96081	0.032226

Table II
Results of simultaneous fit to four of the five quads in both of the chromaticity correction sections.

NAME	VALUE	ERROR
QN3B	0.99651	0.0016
QN2A	0.99793	0.0006
QN1	0.99950	0.0009
QN3C	1.00430	0.0021
QM3B	1.0015	0.0007
QM2	1.0005	0.0010
QM1B	0.99756	0.0027
QM3C	1.0012	0.0015

distortion of the spot size at the IP we could have used these measurements as a guide to tune the $-I$ sections to match the perfect $-I$ sections in the model.

In addition to the strengths of the quads, this technique can also be used to measure the alignment and rotation angles of individual quads.

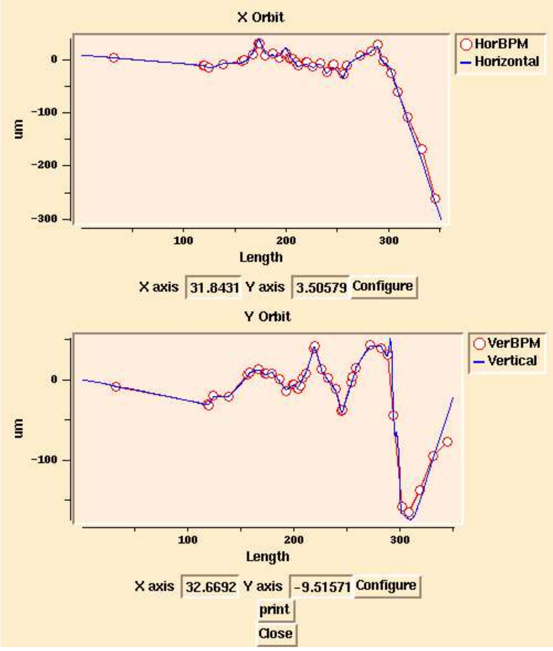
III. Interactive Model

Using the object-oriented beamline class library under development at Fermilab, an interactive model of the FFTB lattice was created to be used as a lattice diagnostic tool, to quickly prototype lattice changes and to calculate various lattice parameters (eg. twiss parameters). The bumps generated for the offline analysis were checked with this model. The program can read data files produced by the SLAC control system.

During one of the FFTB commissioning periods, data from a series of correction dipole bumps and quad displacement bumps were taken and compared to the model. A correlation plot data file was made of all of the magnet currents and read into the model. A correlation plot data file was made for each type of bump. The bump strength was varied over a $\pm 1mm$ range with five to ten data samples taken for each bump value. When the data are read into the model program, the user can select whether or not to average the data points or whether or not the subtract the orbit with zero bump value (the reference orbit). The user can also read in the multi-knob file which produced the bump.

Figure 1 shows the comparison between BPM data and the model for a particular four-bump using the horizontal quadrupole movers. The circles are the BPM data and the solid line is the model. The bump is not closed because of lattice errors and a momentum offset of .03% which was input to the model.

The model was very useful for quickly zeroing in on problem areas in the lattice. For example it was very easy to discover that there was crosstalk in the quadrupole movers; for a 400 μm movement in x there was $\approx 2-3$ μm movement in y.



X axis 31.8431 Y axis 3.50579

X axis 32.6692 Y axis -9.51571

Figure. 1. Comparison of model with BPM data.

References

[1] " The TESLA Test Facility (TTF) Linac - A Status Report", This conference.

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