

BEAM-BASED ALIGNMENT AND BETA FUNCTION MEASUREMENTS IN PEP-II*

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Abstract

Careful optics studies and stringent lattice control have been identified as two key components to increasing PEP-II luminosity. An accurate, trusted BPM system is required for both of these strategies. To validate the existing BPM system and to better understand some optical anomalies in the PEP-II rings, an aggressive program of beam-based alignment (BBA) has been initiated. Using a quad-shunt BBA procedure in which a quadrupole's field strength is varied over a range of beam positions, relative offsets are determined by the BPM readings at which quadrupole field changes no longer induce a closed orbit shift. This procedure was verified in the HER and is well underway in the LER IR. We have found several surprisingly large BPM offsets, one over one centimeter, as well as a number of locations where the current nominal orbit is several millimeters from the design. Tune versus quadrupole field data were taken during the BBA process in the LER IR, and the non-linear response in each case is compared to simulation to infer local beta functions.

INTRODUCTION

The PEP-II collider has an interaction region (IR) that is unique in its use of strong sextupole magnets, a solenoid compensation scheme using skew quadrupoles, and a nonzero design orbit [1]. For these reasons, it is essential for the beams to traverse the quadrupoles and sextupoles with the proper offset in this region in order to maintain the desired IR optical functions.

To better control the trajectory of the beams in the IR and better understand the optics and potential luminosity degradation factors in this region, a program of BBA was undertaken in both the Low Energy Ring (LER) IR and the High Energy Ring (HER) IR.

The BBA program used the technique developed for the Accelerator Test Facility (ATF) at KEK [2]. The strength of a quadrupole whose offset is to be measured is varied (typically five excitation currents are measured, with a maximum quadrupole strength change of 5%). At each magnet excitation, a closed local orbit bump at the quadrupole is varied, typically to six different bump amplitudes. Figure 1 shows the BPM reading at PR02 3042 (the BPM adjacent to the quadrupole being studied) in the LER while making closed orbit bumps of up to four millimeters at each quad excitation current.

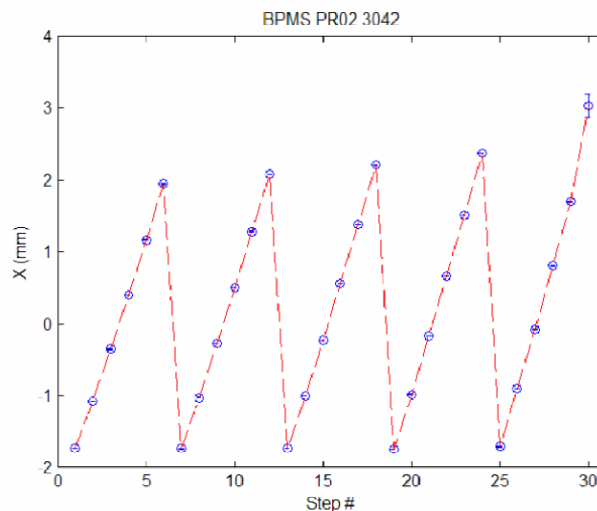


Fig. 1: Variation of the magnet and knob.

The closed orbit change generated by the change in quadrupole strength with an off-center beam trajectory through the quadrupole is then fitted offline to a model and the offset calculated.

Figure 2 shows the fitted X offset at QFCX1R1X with respect to the center of the BPM at 3042. As seen by the green dotted line intercept, the fit returns a value of -1.89 mm in BPM 3042 where the beam goes through the center of the quadrupole. Figure 3 shows an example of an orbit fit to the model.

HIGH ENERGY RING

The BBA procedure was applied first to the IR in the HER, partly due to a better understanding of the HER model in the near IR at the time. The program was successful in determining BPM-quadrupole offsets which were used to steer the ring flat with good results. Additionally, an online modeling system that takes into account the currently configured magnets and actual orbit through the machine returns more reliable results.

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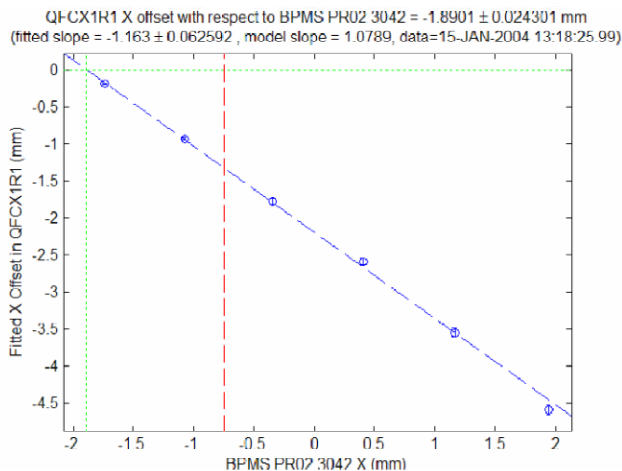


Fig. 2: Result of orbit fit model.

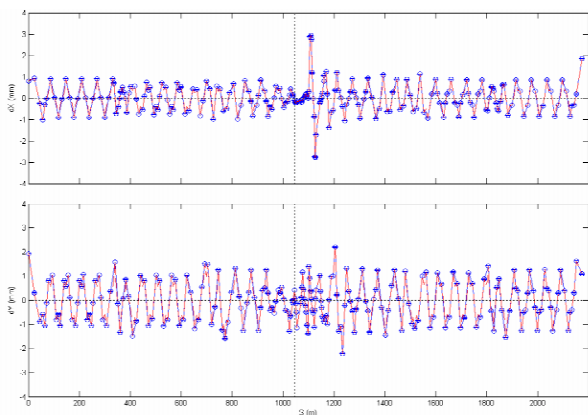


Fig 3: Kick orbit fit to model.

LOW ENERGY RING

Following the success in the HER, the LER IR was approached using the same method. Several IR quadrupoles could not be measured due to the fact that they are connected in series to one power supply. Only IR quadrupoles with independent power supplies were measured in PEP-II Run 4. An initial analysis of the LER was undertaken using an uncoupled approach that yielded unphysical offsets. Due to the highly coupled nature of the LER design lattice, it was necessary to take a fully coupled approach as expressed in Wolski and Zimmermann's fully coupled equation [3]:

$$\begin{pmatrix} \Delta x_{co} \\ \Delta y_{co} \end{pmatrix}_s = [Q^{(1)}\bar{C}^{(1)}(s_q : s) - Q^{(0)}\bar{C}^{(0)}(s_q : s)] \cdot \dots [1 + Q^{(0)}\bar{C}^{(0)}(s_q : s)]^{-1} \cdot \begin{pmatrix} x_{bq} \\ y_{bq} \end{pmatrix},$$

where $\bar{C} \equiv \begin{pmatrix} -C_{12} & C_{14} \\ -C_{32} & C_{34} \end{pmatrix}$. (1)

This coupled formula was in good agreement with the PEP-II LER data and allowed for greater understanding of the offsets seen.

Table 1 shows the values of the offsets found in the LER IR.

Table 1: Offsets in the LER.

Quad Designation	BPM Nearest	Horizontal Offset (mm)	Vertical Offset (mm)
QFBM5	3184	-0.813	-2.008
QFBM4	3182	-10.145	+6.931
QFBM3	3172	-1.576	+0.043
QFBM2	3162	-0.250	-0.607
QFBM1	3149	-0.639	-1.017
QFCX1R2	3082	+1.804	-0.427
QFCX1R1	3042	-1.831	-3.193
QF2R	3024	+6.019	+7.326
QF2L	2203	-5.737	-3.893
QFCX1L1	2182	+1.078	-1.400
QFCX1L2	2142	+0.130	+0.829
QFBM1L	2062	-0.077	+0.259
QFBM2L	2056	+0.642	+1.136
QFBM3L	2052	+0.026	-0.079
QFBM4L	2032	-1.067	-0.729
QFBM5L	3022	-0.217	-2.469

Large Offsets in the LER

Many large offsets were found in the LER, including several magnets with an apparent 1 cm offset. Tests were performed in an attempt to determine whether these offsets were mechanical, electrical, or otherwise.

The first such test to be performed was a re-arrangement of cabling in the tunnel at the BPM to test the BPM's electronic offset. Positive terminals were swapped for negative, and conversely negative for positive. The magnet was then re-measured and analyzed using the same tools. If the BPM electronics performed as understood, the result from the cable swap should return the negative of the original offset. The one magnet/BPM combination for which this test was performed did indeed return the negative of the initial observed offset.

Other tests performed in the tunnel included measuring fringe fields near adjacent, high steel content magnets in anticipation of field distortions, measuring voltage drops across coils in expectation of turn-to-turn shorts influencing the field profile, monitoring the pole-tip field using a Hall probe, and physically inspecting the bore of the magnet for metallic detritus. None of these tests revealed any anomalies in or around the quadrupole and brought no contradiction to the measured large offset.

Beta Function Measurements

During the LER BBA quadrupole scans, the tunes were measured at each step using the tune spectrum analyzer to get a plot of tune versus quadrupole excitation. These measurements don't offer easily calculated beta functions due to the magnets measured being in the highly coupled region near the BABAR detector. The angles of rotation of eigenplanes are variable due to the regular "tuning" of skew quadrupoles, however estimates of beta functions can be made using comparison to simulation (Figure 3) of the actual measurements done (Figure 4). Where

measurements are qualitatively similar to simulation, fits of like order can be used in scaling to determine the beta functions in highly coupled areas.

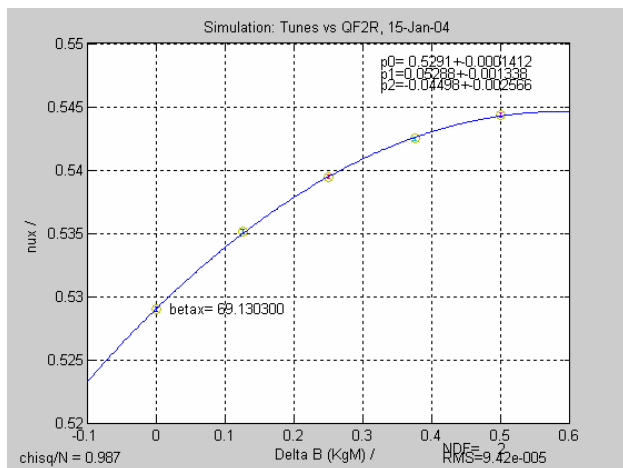


Figure 3. Simulation of tune change versus deltaB at QF2R.

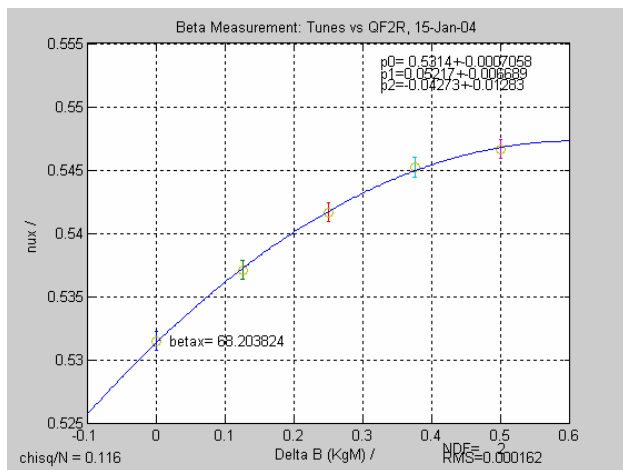


Figure 4. Beta measurement at QF2R

OBSERVATIONS IN HER AND LER

Typical data acquisition required 15 minutes per magnet per plane. The nature of the PEP-II control system prevented faster acquisition of BPM data. In fact a special variant of the SLAC Control Program (SCP) was compiled to deal with the large number of BPMs and other variables needed for the acquisition.

Data acquisition was hampered initially by the present PEP-II operating point, with the x-tune very close to the half-integer. Any orbit excursion in a sextupole or large variation in quadrupole excitation would cause tune shifts that either pushed the tune down onto the half-integer resonance or up into one of the multiples of the synchrotron tune resonances. After adjusting the tune farther away from the half-integer, acquisition was smoother, but other resonances still limited either the bump amplitude through the sextupoles, or the amplitude of the quadrupole excitation current.

SUMMARY

PEP-II has benefited from the time taken both on the machine for acquisition and offline in the analysis of the data in improved luminosity performance and better understanding of the model. The BPM offsets entered into the HER database have resulted in a more consistent model and a machine that is operationally more stable. The LER IR offsets have been entered into the database and do not contradict modeling results. No attempt to steer the LER IR has been made for PEP-II in Run 4 despite the BBA results, due to other operational issues involving the BPM system stability. Further BBA is required throughout the ring, in both the IR and near the injection point. A program is under way to install shunts on those PEP-II quadrupoles that lack independent control.

The BBA data acquisition process offered a natural opportunity to measure the tune response to changing quadrupole fields in the IR. The beta functions at these quads has provided another check for the model.

REFERENCES

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