BEAM BASED ALIGNMENT AT THE POHANG LIGHT SOURCE*

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Abstract

A beam based alignment method was adopted to recalibrate the Beam Position Monitors (BPM) to the center of quadrupole magnets at the Pohang Light Source (PLS). We added a shunt circuit to each quadrupole magnet to control the current independently. This alignment method involves BPM readings and shunt impedance controls at the quadurpole magnets. This paper presents the beam based alignment control mechanism, the process, and the results.

1 INTRODUCTION

In the modern synchrotron light sources, the beam offsets at the quadrupole magnets can give significant effects on accelerator performance because of the high field strengths. These offsets cannot be eliminated with the geometric alignment methods and many accelerator facilities are applying beam based alignment method to their machines. Beam based alignment means driving the particle beam so that it passes through the magnetic field centers of quadrupoles. To achieve this alignment, we should find out the beam offsets at quadrupoles and then recalibrate BPMs. For offset measurements, we added shunt circuits to all the quadrupoles so that we can control each quadrupole strength independently down to about 10%.

For the shunt control, we set up separate control system not to interfere with the main control system. We chose personal computer (PC) with Microsoft Windows as the main system. The high level software was developed based on serial communication and OLE for Process Control (OPC) system. By using the standard and proved methods we could develop the reliable control system fast and easily. We applied this shunt system to sample quadrupoles and obtained the offset data. It was also direct and easy to measure the beta functions at the quadrupole positions.

2 SHUNT SYSTEM

2.1 Quadrupole Magnets

The PLS consists of 12 cells and each cell has 12 quadrupoles. The cell has mirror symmetry and there are 6 kinds of quadrupoles. If we call them as Q1,..,Q6, all Q1, Q2, Q3's are serially connected and Q4, Q5, Q6's have independent power supplies for each cell. This makes the total number of quadrupole families be 39 while the total number of quadrupoles are 144.

2.2 Shunt System Design

The currents for the quadrupole range from 35.5A to 415.7A and we cannot expect one kind of shunt system would work for all quraduploe families. Also, it is very inefficient to design all different shunt systems for all quadrupole families. So, we designed two kinds of shunt system which shunt off up to 15A and 50A. The first one is applied to Q1, Q2, Q3, and Q6 power supplies whose main currents are 35.5A, 83.4A, 95.85A, and 186.0A respectively. The second one is applied to Q4 and Q5 whose main currents are 339.7A and 415.7A. The system is equipped with closed circuit control to maintain the current stability within $\pm 0.005\%$ and the ripple within $\pm 0.05\%$ which are the design requirements for the magnet power supplies. The shunt controller is capable of making the current rising and falling be processed slowly to prevent the excessive current changes which could bring the beam loss.

3 CONTROL SYSTEM

The main control system of the PLS consists of VME and workstations. Usually there are a lot of data communications between them as well as many their own background processes. We could not get the desired performance when we used the existing control system. Furthermore, it was also possible that the added loads could degrade the perfomance of the main control system. From these reasons, we decided to set up independent control system dedicated to the beam based alignment. The new system is based on PC with Microsoft Windows and RS232 serial communications.

All BPM ADC boards and shunt systems are equipped with RS232 serial ports and all the serial connections are converted to the ethernet through conversion devices. We use the ENET-232 of National Instrument for the conversion. Through the ethernet, all connections are recognized by the PC(s) as if they are input to the local serial ports. The shunt system controller is equipped with MODBus protocol which is one of the industrial open protocols. This protocol is managed by OPC server which is installed at the console PC where the application program is running or another one. The application program is developed using serial communications and OPC system. The systematic diagram of the BBA control system is shown in Figure 1.

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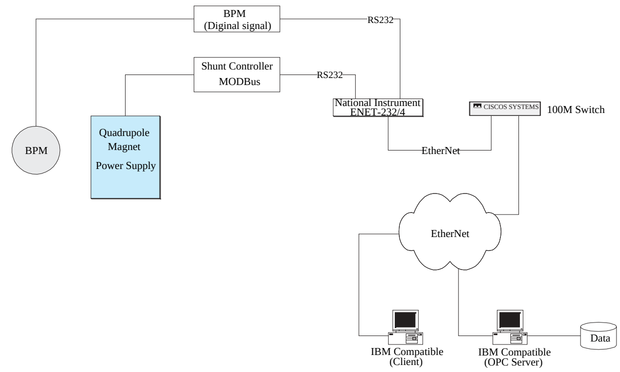

Figure 1: Layout of the BBA control system.

4 BEAM BASED ALIGNMENT

4.1 Theory

In storage ring, if there is a kick variation $\Delta\theta$ at the position s the position variation at s' can be expressed as

$$\Delta z(s') = \frac{\sqrt{\beta(s)\beta(s')}}{2\sin\pi\nu}\Delta\theta\cos(|\psi(s)-\psi(s')|-\pi\nu), \quad (1)$$

where z denotes the horizontal or vertical position and β, ψ, and ν are corresponding beta function, phase, and tune. If the beam passes a quadrupole with an offset, the kick to the beam is changed when the quadrupole current is changed. If we denote the offset by ξ the kick variation at the quadrupole can be expressed as

$$\Delta\theta = \xi\Delta kL \quad (2)$$

Here, Δk and L are the field gradient change and the length of the quadrupole. Different from the case when the field strength of a corrector magnet is changed, when we change that of the quadrupole the twiss parameters also change and the Equation 1 does not hold exactly. However, if we reasonably assume that the offsets are small enough, we can combine Equations 1 and 2 to get

$$\Delta z_j = \left[\frac{\sqrt{\beta_i\beta_j}\Delta k_i L_i}{2\sin\pi\nu}\cos(|\psi_i-\psi_j|-\pi\nu)\right]\xi_i. \quad (3)$$

Here we use the subscripts i and j instead of s and s'. The i represents the ith quadrupole and j represents the jth BPM.

4.2 Measurements

If we express Equation 3 as

$$\Delta z_j = M_{ji}\xi_i, \quad (4)$$

we can find the offsets, ξ's, by measuring the position changes Δz's and matrix M_{ij}, and using a non-square matrix inversion algorithm. However, this process will give the reliable result only under the assumption that all BPMs are working equally well. Even though we carefully eliminated a number of unbelievable BPMs in the measuring process, still there is a possibility that some BPMs could work abnormally at some specific measurements. So, we obtained the offsets by directly comparing the measured orbit distortions with the simulated ones using the assumed offsets. The measured orbit distortions are direct BPM reading variations due to the quadrupole field strength variations. The measurements were made using 8 quadrupoles located at cell 9 and 10. And the shunt currents were chosen to be about 1% of the original current.

Unfortunately, the PLS is not equipped with dedicated devices to measure the twiss parameters and we should rely on the response matrices. We adopted Singular Value Decomposition (SVD) method[1] to obtain them from the response matrices.

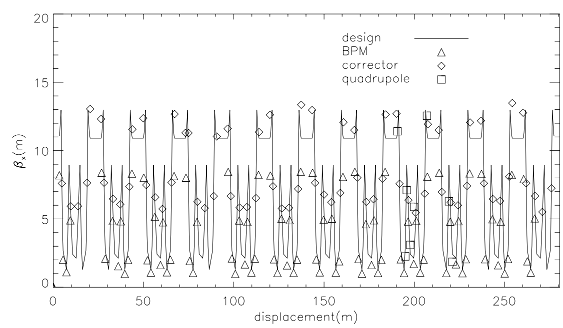

Figure 2: Beta values at horizontal plane.

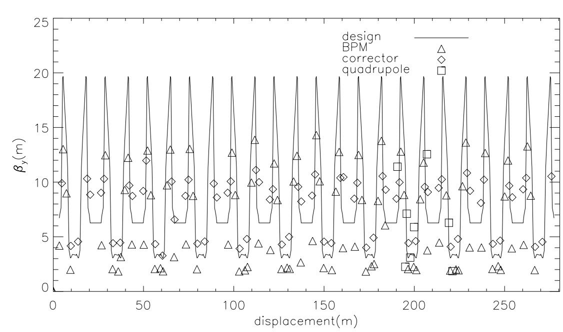

Figure 3: Beta values at vertical plane.

This method gives the beta and phase values at the BPMs and the correctors. However, the response matrices themselves can be influenced by the unidentified malfunctions of some BPMs and SVD method itself gives only the approximate solution with a certain arbitrariness. For the beta functions at quadrupoles, we can directly measure them by observing the tune shifts when the currents are shunt off. That is, applying the relation $\Delta\nu = -\frac{1}{4\pi}\beta\Delta kL$, we can obtain the beta values. We found that theses values are closer to the designed values than those measured using SVD method. Figure 2 and 3 show the theory and measured beta functions. Figure 4 and 5 show the theory and measured phases.

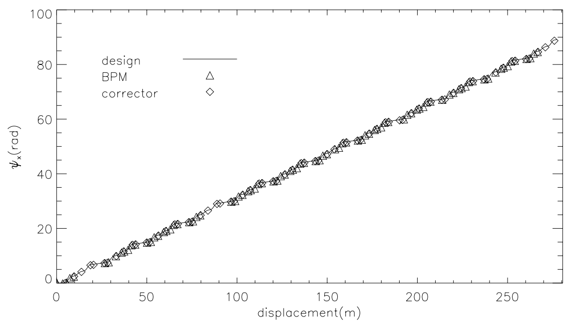

Figure 4: Phase values at horizontal plane.

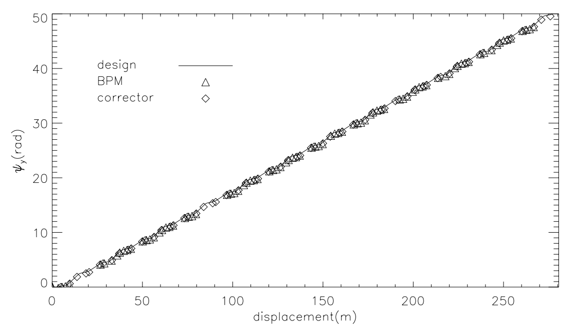

Figure 5: Phase values at vertical plane.

Using these measured values we made a graphic user interace (GUI) which shows the simulated orbit distortion for the assumed offset together with the directly measured orbit distortion. In the GUI, there is a slide bar by which we can vary the assumed offset, and we can manually find the offset by directly comparing the measured and simulated reading changes at BPMs. The GUI is shown in Figure 6. Using the GUI, we also could identify malfunctioning BPMs.

5 RESULT AND DISCUSSION

We installed independent shunt systems and control system for the beam based alignment. By adjusting the slide bar of the GUI shown in Figure 6, we manually found the offset for each quadrupole. The resolution of the slide bar is $30\mu m$. We used measured values for the twiss parameters. However, from the Figures 2∼5 and considering the arbitrariness involved in SVD method, we expect that using the design vlues for the twiss parameters will give as much reliable results. For the sample quadrupoles, we found the offsets as Table 1. These offset values should be used to recalibrate the BPMs. For the usual case where the

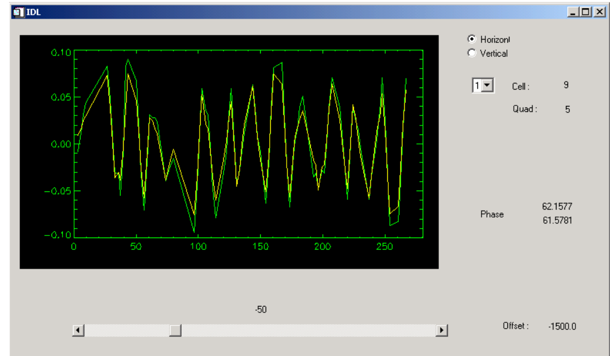

Figure 6: Graphic user interface for the quadrupole offset measurements.

Table 1: Measured offsets.

Cell No.	Quad.	Hor. Offset()	Ver. Offset (mum)
09	01	480 μm	-1050 μm
09	04	1200 μm	360 μm
09	05	-1710 μm	-210 μm
09	06	900 μm	960 μm
09	07	960 μm	1980 μm
09	12	270 μm	300 μm
10	05	-810 μm	-1380 μm
10	06	450 μm	1110 μm

BPM is closely attached to a quadrupole, the calibration is straightforward. At the PLS, however, many BPMs are located not close to any quadrupole and the calibrations need some additional manipulations. Even for these cases, if there is no corrector magnet between the BPM and the surrounding two quadrupoles, the simple linear interpolation method[2] can be used to calibrate the BPM. On the other hand, if corrector magnets are involved, this simple method will not work any more. Consequently, we should reclalibrate each BPM with appropriate method suitable for its own situation, taking into consideration beam offsets at quadrupoles, BPM readings, and corrector magnet field strengths as well as geometric alignment data.

6 REFERENCES

[1] Y. Chung, “Beam Stabilization and Optimization in Synchrotron Light Sources”, presented at PAL Seminar, 1998

[2] K.H. Kim, J.Y. Huang and I.S. Ko, “The Beam Based Alignment Techinique for the Measurements of Beam Position Monitors Offsets and Beam Offsets from Quadrupoles in the Pohang Light Source”, Jpn. J. Appl. Phys. Vol. 38 (1999) 6926