ISBN: 978-3-95450-254-7 ISSN: 2226-0358 doi:10.18429/JACoW-ICALEPCS1991-S12FC05

PLS Beam Position Measurement and Feedback System†

J.Y. Huang, Jinwon Lee, M.K. Park, J.H. Kim and S.C. Won
Pohang Accelerator Laboratory,
POSTECH, P.O.Box 125,
Pohang 790-600, Korea

Abstract

A real-time orbit correction system is proposed for the stabilization of beam orbit and photon beam positions in Pohang Light Source. PLS beam position monitoring system is designed to be VMEbus compatible to fit the real-time digital orbit feedback system. A VMEbus based subsystem control computer, Mil-1553B communication network and 12 BPM/PS machine interface units constitute digital part of the feedback system. With the super-stable PLS correction magnet power supply, powerline frequency noise is almost filtered out and the dominant spectra of beam obtit fluctuations are expected to appear below $15Hz$. Using DSP board in SCC for the computation and using an appropriate compensation circuit for the phase delay by the vacuum chamber, PLS real-time orbit correction system is realizable without changing the basic structure of PLS computer control system[1].

I. Introduction

In an electron storage ring various kind of beam orbit disturbing sources exist, e.g., power line drift and ripple in magnet power supply, magnet and girder deformation by temperature changes, low frequency vibrations from mechanical vibrations of compressors, etc. When these sources are coupled with strong focusing magnets, beam orbit stability is severely deteriorated. Measurement on the spectra of beam position fluctuation shows that the dominant beam position fluctuation appear in the range $0 \sim 100Hz$[1]. In the third generation synchrotron radiation source, stability of the beam orbit is very sensitive to the noise sources. Many beamline users also require very stable photon beam source, i.e., stable within a small fraction of the beam size. Considering the photon beam sizes from Insertion Devices(ID), beam orbit should be controlled within a few μm.

Pohang Light Source(PLS) is designed as the low-emittance synchrotron radiation source[2]. The magnet lattice is $280m$ long, 12-period Triple Band Achromat(TBA) structure. Results of beam dynamics simulations show that dynamic aperture of the circulating beam is much reduced by the closed orbit distortion[3]. Without correction of the orbit distortion, even a single turn orbit may not be closed, i.e., the beam may have no dynamic aperture. In the PLS, effect of all position errors should enter within $150\mu mrms$. For these reasons, a real-time orbit correction system and local beam steering system for each ID beamlines are forseen for the Pohang Light Source.

PLS computer control system has a four-layer hierarchical structure with distributed control computers and communication networks; a host computer for the large scale computation and central database, console computers for the user interface to the control system, subsystem control computers(SCC) and machine interface units(MIU)[4]. Console computers and SCC are connected by Ethernet. SCC and MIU are connected by Mil-1553B data communication network.

PLS Beam Position Monitor(BPM) is designed as VXIbus modules to fit to the digital closed orbit correction system. All the 9 BPM detector electronics and 6 H/V correction magnet power supply(PS) control modules in a lattice period are designed to be VMEbus-compatible and are housed in a single VXIbus crate. Utilizing those VMEbus based BPM system and high performance PLS computer control system, a fully digital orbit feedback system is under development. A dedicated SCC and 12 BPM/PS MIU's constitutes the real-time closed orbit correction system.

There are some practical limitations in realizing the real-time orbit feedback system. Time delays for digital data communication and computation, and phase delay by eddy current effect of the thick aluminum vacuum chamber limit the feedback frequency range below $15Hz$. One of the biggest noise sources from power line ripples is almost filtered out in the design of PLS correction magnet power supply. Therefore, major orbit noises are expected to appear below $15Hz$ in the PLS storage ring.

II. Beam Position Monitoring System

The most important role of the PLS beam diagnostics will be the accurate and fast measurement of beam position for the stabilization of the beam orbit to meet the stringent low emittance lattice design and experimental user requirements. For this purpose, the state of the art beam position monitoring system, featuring measurement

[1]† Work supported by MOST and POSCO

ISBN: 978-3-95450-254-7 ISSN: 2226-0358 doi:10.18429/JACoW-ICALEPCS1991-S12FC05

accuracy less than 30 μm, wide dynamic range, long time stability, is under development. There are 9 beam position monitors(BPM) in each period which totals 108 BPM's around the 12-period storage ring chamber. Each BPM consists of four button pickup electrodes and signal processing electronics. We designed two types of processing electronics. One of 9 BPM's per period is a wide band detector which has $2M$ position measurement rate to be able to trace the electron orbit turn by turn in the single bunch operation mode. This novel BPM system can be used for the machine study and development as well as for the commissioning of the storage ring. Other BPM's are narrow band processors tuned to $500MHz$ rf frequency for the accurate measurement and correction of the closed orbit.

PLS BPM system should satisfy the following requirements. For the closed orbit measurement; $20\mu m$ resolution in the whole range of operation, $150\mu m$ absolute accuracy including mechanical and thermal errors, life-time orbit stability within the small fraction of beam size at ID chamber and the capability of $15Hz$ real-time closed orbit feedback. Wide band detector electronics should have over $2M$ position measurement rate for the first single turn measurement during the commissioning or turn by turn position measurement in the single bunch operation. This system should also meet the same operational requirement for the closed orbit measurement. During the commissioning, however, $500\mu m$ accuracy would be enough.

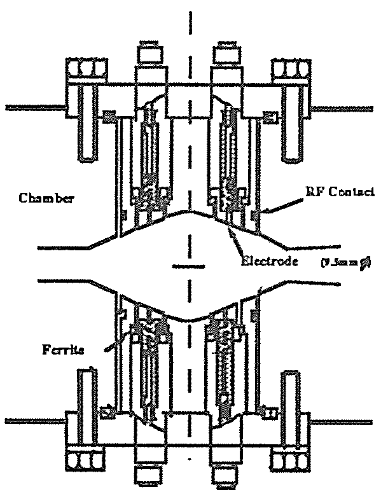

Figure 1: Schematic of the PLS Beam Position Monitor

Since the PLS vacuum chamber is machined from thick aluminum plates, and top and bottom plates are welded together to form the vacuum chamber[5], PLS BPM electrodes are assembled as modular units and mounted on the vacuum chamber with Helicoflex vacuum seals as shown in Figure 1. This modular electrode units have advantage in testing and calibration of BPM modules before installation. In each BPM modules, two electrodes are tightly positioned with ferrite bushings in precisely machined holes. These ferrite bushings damp out various kind of rf resonances as well. Kyocera-SMA feedthrus are welded to be vacuum tight in pairs to the BPM flanges and connected to the electrodes by means of rf spring contacts. In this way, the position of the electrodes will not be affected by the position offset of feedthroughs. The diameter of an electrode is $9.5mm$ which is comparable to the bunch length. The maximum sensitivity in the linear region is about $10\%/mm$. Within the $10mm$ circle, it has shown good linearity. The short bunch signals are picked up by four electrodes and delivered to the electronic detector via coaxial cables. The beam spectrum extends flat to very high frequency with the $3dB$ corner at $9GHz$ and has the high-pass shoulder at $160MHz$, well below the $500MHz$ working frequency. Signal voltage at $500MHz$ is about $22mV$[6].

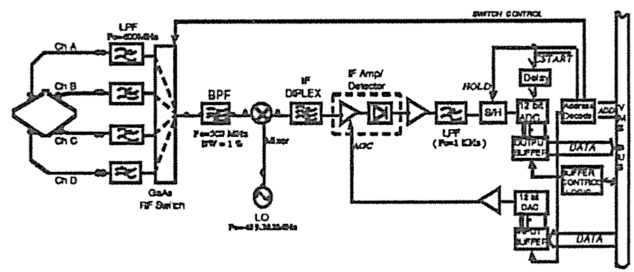

Figure 2: PLS BPM Detector Electronics

A schematic block diagram of BPM detector electronics is shown in Figure 2. Narrow band detector will be used mainly for closed orbit measurement. However this BPM can also be used as the beam-finding tool during the commissioning: by watching whether the beam signal is induced or not on a certain pickup electrode, e.g., button A, we can conclude whether the beam has passed or not. This can also be applied as the first-turn beam position measurement system by four injection beams. By detecting four button signals alternatively induced by four sequentially injected beams, we can measure the first turn beam orbit. There are several narrow band detector systems recently developed, e.g., NSLS[7], ALS[8] and ELETTRA[9] BPM systems. PLS BPM electronics consists of four channel rf switch and a single channel detector. Four pickup signals are scanned via a fast four channel switch and detected in a common processor. After scanning four switches, the fifth clock is used for the detection of the system offset, which is then subtracted from the electrode signals. To avoid the transient periods at both the rising and falling edges of the switching and sampling signal, ADC gate will be set well within the rf switch-on period. Total scanning time is about $100\mu sec$. Fast GaAs rf switch, e.g., SW-254, has low insertion loss, good linearity up to $33dBm$ and good thermal stability; $<3\%$ absolute and $<0.4\%$ relative drift in the temperature range of $10\sim50°C$. To protect rf switch from the high-power high-frequency components, SLP-600 low pass filter is used before the input to the rf

ISBN: 978-3-95450-254-7 ISSN: 2226-0358 doi:10.18429/JACoW-ICALEPCS1991-S12FC05

switch. Button signal is again filtered by the band pass filter and mixed down to $10.7MHz$ with a Vectron CO-233 local oscillator and a SRA-1W mixer. Finally detected signal is digitized by 12bit ADC and interfaced to VMEbus.

A wide band detector will be installed on each period of the lattice and used for both the single turn measurement and the closed orbit measurement. After the first-turn commissioning, most of the fluorescent screens innstalled on ID chambers will be removed when the insertion devices are installed. Wide band detectors are then particularly useful for the trouble-shooting and the recommissionings. A commercially available hybrid junction device, Omni-Spectra Monopulse Comparator Network, will be used as the signal processor. It outputs difference and sum signals from four electrode signals. For the fast turn-by-turn measurement, a 1024-byte FIFO is used to store each sum and difference signals.

With the VMEbus based design of BPM detector boards we have great flexibility in the beam position measurement and feedback operation. One of the novel feature is the capability of broadening the measurement dynamic range by using digitally controllable attenuator in front of the mixer.

III. Closed Orbit Correction System

There are several kinds of closed orbit correction and local beam steering methods: harmonic correction method, least-squared minimization method, the eigenvector method, local bump method, etc[10]. In the Pohang Light Source there are 108 BPM's and 72 horizontal and vertical corrector magnets as the lumped coil windings. Slow drift of closed orbit can be corrected very accurately with these all BPM's and correctors. However real-time correction with those many BPM's and correctors are impossible without using extraordinary hardwares dedicated to the orbit correction system. In the PLS, we want to utilize high-performance PLS computer control system, without changing the basic control system structure, for the real time orbit correction system. Test results show that only a few number of correction magnets and BPM's can suppress the closed orbit distortion to about one-tenth by applying harmonic correction method[11]. Since the harmonic contents of the orbit distortion is dominant near the machine tune value, we can damp out orbit distortion efficiently by using small number of BPM's and correctors.

There are 9 BPM's and 6 H/V corrector magnets in a period of PLS magnet lattice. One section is shown in Figure 3. Two BPM's and a correction magnet in the center of the achromat will be used for the real time orbit correction system, and four H/V correctors and two BPM's at both sides of the ID chamber will be used for the local beam steering system. In ELETTRA, much has been progressed in this kind of real-time orbit correction system[12].

Photon beam position monitors on an ID beamline may also be used as the position detector. However, in the first phase of the PLS construction there will be no insertion devices.Therefore, only computer control system for the

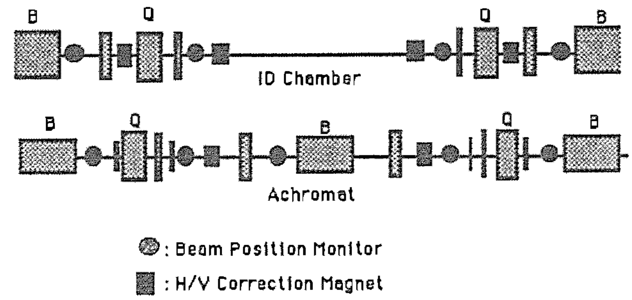

Figure 3: PLS BPM and Corrector Magnet Lattice for Real-Time Orbit Correction

local beam steering will be provided without photon beam position monitors. According to the operation mode, the number and locations of correction magnets and BPM's can be flexibly selected.

Slow closed orbit correction program will be run at the console computer. Instead, an SCC and 12 BPM/PS MIU's based on the VMEbus and Motorola 68030 microprocessor are dedicated for the real-time closed orbit correction system. The overall structure of the real-time orbit correction system is shown in Figure 4. In each lattice period, a BPM/PS MIU is located for the beam position measurement and correction magnet power supply control. Each BPM/PS MIU crate is also equipped with Motorola 68030 CPU. SCC and MIU's are connected by Mil-1553B data communication network.

Each beam position data read by BPM/PS MIU is transferred to SCC through the serial data communication network, Mil-1553B. In the SCC, harmonics of the orbit distortion are analysed and correction magnet strengths are computed. The correction magnet strengths are then transferred back to twelve BPM/PS MIU's to set the correction magnet power supply currents.

The speed of the real time feedback system is limited by time delays in the control system and phase delays in the magnet power supply, correction magnet and vacuum chamber. Dominant portion of the time delay in the control system is attributed to the serial data communication time through the Mil-1553B field network and large size matrix computations in the SCC. For the matrix computation, a VMEbus based DSP board will be used. To achieve $15Hz$ realtime feedback frequency with two BPM's and one corrector magnet in each lattice period, total time delay should enter within $8.33msec$ for the corrections in both horizontal and vertical direction. By analyzing time delays in detail we have got the numbers:

- 100 μsec for the beam position reading
- 110 μsec for the computations in the MIU
- 2400 μsec for the position data transfer from MIU to SCC
- 6600 μsec for the matrix multiplications in SCC
- 1440 μsec for the current data transfer from MIU to SCC
- 4 μsec for the setting of magnet current

ISBN: 978-3-95450-254-7 ISSN: 2226-0358 doi:10.18429/JACoW-ICALEPCS1991-S12FC05

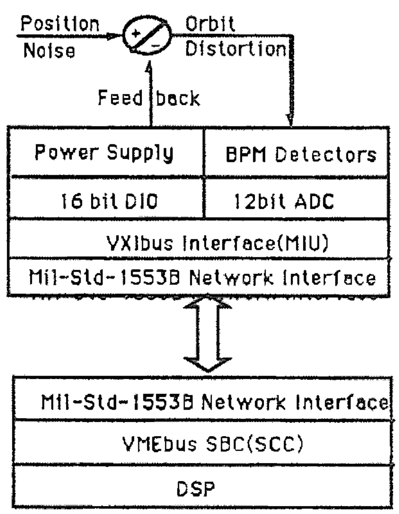

Figure 4: Real-Time Closed Orbit Feedback System

which totals 10.6$msec$. This amount of time delay is too large for the purposed feedback system. With a DSP board, computation time in SCC can be reduced to below 600μsec giving 4.6$msec$ time delay in real time orbit control system.

Time delay budget allocated for the corrector magnet power supply, corrector magnet and vacuum chamber is then 3.73$msec$. Converting this into the equivalent phase value, we get the phase delay $\phi_D = 40.3°$ at the cutoff frequency 30Hz. Since the most phase delay will be taken by aluminum chamber because of its eddy current effect, we will try to make the thickness of the correction magnet chamber as thin as possible. Test result conducted in Advanced Photon Source(APS) shows that with an appropriate phase and amplitude compensation circuit, phase delay in power supply + magnet + aluminum vacuum chamber can be reduced to within 40° at 30Hz[13].

Local beam steering for each ID photon beamline is performed by BPM/PS MIU independent of SCC. Time delays for the beam position reading and computation of the correction magnet current is less than 500μsec. In this case, real-time feedback speed can be extended to the eddy current limited speed of the vacuum chamber. We expect higher than 30Hz local orbit feedback speed.

IV. Summary and Conclusion

96 narrow band BPM detectors and 12 wide band BPM detectors are designed for the closed orbit measurement, real-time orbit correction, commissioning and machine studies. All the BPM's are designed to be VMEbus compatible and are housed in VXIbus crates to fit the fast computer control system.

An SCC and 12 BPM/PS MIU's constitute PLS real-time orbit correction system. To achieve 15Hz real-time feedback speed, we adopted fully programmable DSP board for the computations in SCC. Total time delay for the digital processes in feedback system is significantly reduced with DSP board. With an appropriate phase compensation circuit for the phase delay by the vacuum chamber, we can realize 15Hz global orbit correction system for PLS.

Another sound feature is that the local beam steering system runs in MIU independent of SCC. In this manner, the local beam steering speed depends almost only to vacuum chamber. Higher than 30Hz local orbit feedback speed is expected.

References

[1].T.Katsura, Y.Kamiya, K.Haga and T.Mitsuhashi, *A Beam Position Feedback System for Beam Lines at the Photon Factory*, Proc. 1987 IEEE PAC.

[2].Conceptual Design Report, PLS, 1990.

[3].Moohyun Yoon and Taeyeon Lee, *Closed Orbit Distortion and Correction in a Storage Ring*, PLS TR/BD 91-05.

[4].S.C.Won, S.S.Chang, J.Y.Huang, Jinwon Lee, Jae W.Lee, et al. *Status Report on the PLS Control System Development*, presented in this conference.

[5].C.K.Kim, K.H.Gil, W.C.Choi and S.Y.Park, *PLS Vacuum Chamber Design*, J. Korean Vac. Soc., vol.1, 1991.

[6].J.Y.Huang, M.K.Park, E.R.Kim, S.S.Chang and S.C.Won, *Analysis of the Electrical Signal Induced on a Pickup Electrode in the PLS Beam Position Monitoring System*, Proc. 4th Asia Pacific Phys. Conf.

[7].R.Biscardi and J.W.Bittner, *Switched Detector for Beam Position Monitor*, Proc. 1989 IEEE PAC.

[8].J.Hinkson, J.Johnston and I.Ko, *Advanced Light Source Beam Position Monitor*, LBL-25973, 1989.

[9].J.-C.Denard, A.Carniel, R.Aiello and T.Monaci, *Beam Position Monitoring System for ELETTRA*, Proc. 1989 European Accel. Conf.

[10].Alan Jackson, *Closed Orbit Correction in the SRS Storage Ring*, SRS/NS/76/103.

[11].L.H.Yu, *Orbit Stability and Feedback Control in Synchrotron Radiation Rings*, Proc. 1989 IEEE PAC. also see R.J.Nawrocky et al, *Automatic Beam Steering in the NSLS Storage Ring Using Closed Orbit Feedback*, Nucl. Inst. Meth. Phys. Res., A266, 164(1990).

[12].D.Bulfone, *The Real Time Orbit-Position Feedback System for the ELETTRA Storage Ring*, Nucl. Inst. Meth. Phys. Res., A293, 292(1990).

[13].Y.Chung, *Compensation for the Eddy Current, ANL-APS Note*, 1990.