PERFORMANCE OF PLS BEAM POSITION MONITOR SYSTEM

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Abstract

Since its commissioning in 1994, many beamlines including high-brightness undulators have been constructed and operated in the PLS (Pohang Light Source). For high-quality experiments, the positions of electron and photon beams should be maintained very stable. The stability of the beams are measured by Beam Position Monitors (BPM's), and they should provide accurate and reliable beam-position information. Recently, we have started to examine and upgrade the performance of the electron BPM's. This is to obtain required resolution and reliability for achieving stable beam position. In this article, we discuss the performance of the PLS BPM's and their application to the improvement of beam stability.

1 INTRODUCTION

Generally, electron beam current in a storage ring is composed of harmonics of RF and revolution frequencies. For the PLS case, these are ~500 MHz and ~1 MHz respectively. The measurement of the beam position starts with picking up the beam current by the 4 PUE's (Pick-Up Electrodes). Through wide-band coaxial cables, picked-up beam signals are transmitted to RF processing unit whose front end consists of a combination of low-pass and band-pass filters (LPF's and BPF's). The BPF's are tuned to the RF frequency. After passing through the BPF, the beam signals are converted to RF bursts, which are heterodyned to IF (Intermediate Frequency), and their envelopes are detected by the following circuits. Beam position information is obtained from these base-band signals utilizing proper algorithms, such as the "difference-over-sum" method. Modern precision BPM circuit employ single heterodyne receiver combined with multiplexing circuit at its front end. This scheme has greatly improved the accuracy and reliability of the BPM, since the channel-to-channel gain differences of multi-channel receivers are avoided. Specification of the PLS BPM system is summarized as follows:

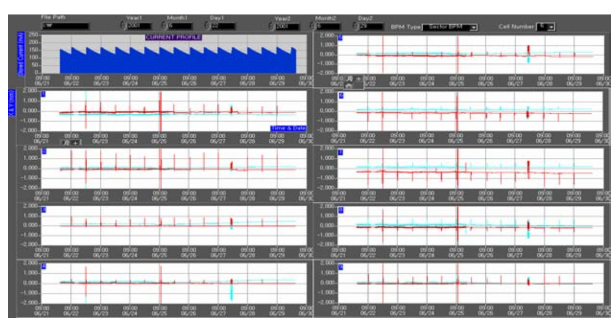
1. Total Number : 112 (108 arcBPM's + 4 IDBPM's)
2. PUE Type : 4 Buttons (10-mm diameter) with SMA feedthroughs
3. Cables : 1/4-inch Coaxial
4. RF Processing Boards:
   - MUX type with Single Tuned Receiver
   - GaAs RF Switch
   - Procured from BERGOZ
   - X & Y Signals are in Analogue Voltages (± 10 V)
5. Analog-to-Digital Conversion Board:
   - 12-bit Resolution
   - On-board Data Averaging Function
6. System Resolution: 5 μm @ 1 S/s (w/ averaging)
   ~40 μm @ 2 kS/s

The RF processing boards generate X and Y position data in the form of analogue voltages which are digitised by ADC boards with 12-bit resolution. The bandwidth of X & Y signals is 2 – 2.5 kHz depending on the clock frequency driving the multiplexer. They fluctuate by ~50 mV which translates into the resolution of ~40 μm. This has been improved down to 5 μm by enabling the data-averaging capability in the ADC board. It could be further improved if we adopt low-pass filters and ADC's with higher resolution. Currently, beam position data update once per second which is sufficient for orbit monitoring.

2 PERFORMANCE

Fig. 1 is the BPM data plot of a machine cell (there are 9 BPM's per one machine cell) during typical user service period. The BPM data come up from the ADC boards in the VME crates, displayed on a console in the machine control room, and saved in a dedicated data server. Also shown in the left top part of Fig. 1 is the plot of stored current and beam energy. Spikes in the BPM data plot are due to beam injections performed twice per day.

Fig. 1. Plot of BPM data during typical user service period.



BPM data plot is useful for monitoring and maintaining the orbit stability. Fig. 2 shows 24-hour orbit drift of BPM66-Y (vertical beam position at BPM#6 at machine cell 6) We can clearly recognise that there was about 20-μm drift excluding two spikes due to beam injections.

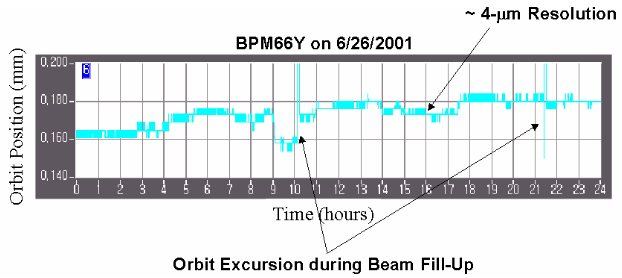


Fig. 2. Measurement of 24-hour orbit drift using BPM.

Quantum jumps in orbit data shown in Fig. 2 represent the ultimate resolution of the BPM.

The resolution limit was further investigated in a test-lab experiment whose set-up is shown in Fig. 3.

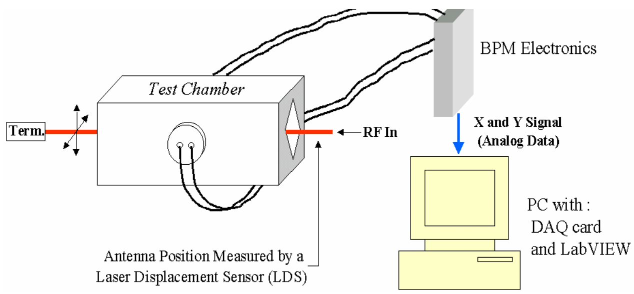


Fig. 3. Schematics of BPM test set-up.

We have prepared a test chamber with 4 PUE's of the same cross section and dimensions to the real machine. An antenna runs through the test chamber and swept across the cross section of the test chamber by stepping motors. 500-MHz RF is fed from one end of the antenna that is terminated at the other end. 4 wide-band coaxial cables deliver signals picked up from the PUE's to a RF processing board. In order to acquire and process the output signals from the RF processing board, we have prepared a PC equipped with a National Instrument DAQ board (12-bit resolution) and LabVIEW. We have measured the position of the antenna using the BPM. For reference, a Laser Displacement Sensor (LDS) with 0.4-μm resolution was used to monitor the antenna position. Fig. 4 is the plot of BPM and LDS signal, in which the resolution of the BPM is clearly seen. The BPM data was averaged to improve the resolution.

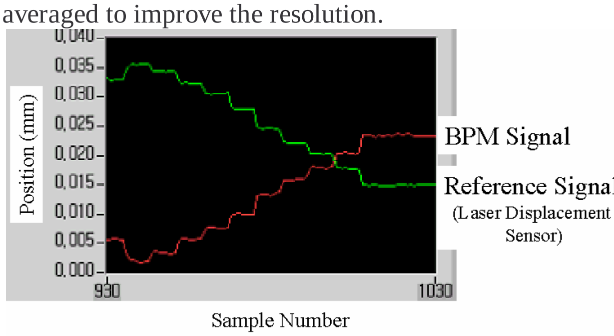


Fig. 4. Demonstration of 5-μm resolution in test lab.

Long-term stability of the BPM signal was also tested in the test lab whose result is shown in Fig. 5.

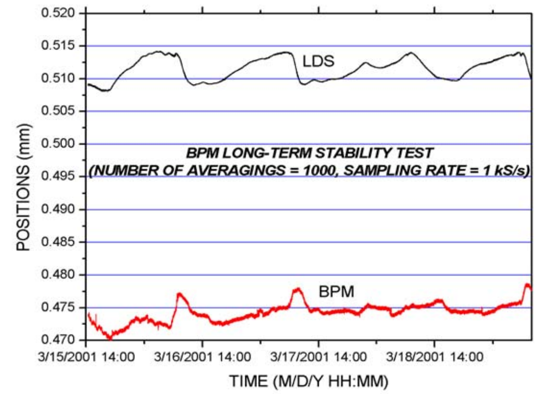


Fig. 5. Test of long-term stability of BPM signal.

Upper trace in Fig. 5 is the 4-day variation of the antenna position that was measured by the LDS. There was about 5-μm drift in antenna position that was supposed to be caused by the thermal effects due to the daily temperature changes. Lower trace is the variation in BPM signals (averaged after digitising). Its drift is about 10 μm which is the total value including the drift of the antenna position and that of the BPM itself. Therefore, we can say that the drift in BPM itself is roughly 5 μm.

3 IMPROVEMENT OF ORBIT STABILITY

The orbit stability is the basic and critical requirement for high-quality experiments in photon beamlines of the 3rd generation light sources. There are many factors that influence the orbit stability. Furthermore they might be correlated each other, and it would be almost impossible to identify a single "cause-and-effect" relation. However we could assume typical operation conditions of the machine, and figure out the most probable factors for investigating the existence of the correlation.

The work has started from the BPM. Since it is the direct measure for evaluating the orbit stability, one should establish good resolution, stability, and reliability of the BPM system. Since the PUE's of the BPM system are integrated in the vacuum chambers of the storage ring, the BPM data might reflect the thermal drifts of them. We have tried to measure the amount of the chamber drift with varying operation conditions of the machine. As the result, it was found that the vertical position of the vacuum chamber changes ~10 μm per 1 ^{o}C change of its temperature. This is clearly seen when machine start-up. Fig. 6 is variations of the vertical position and temperatures of the vacuum chamber shown with the ambient temperature of machine tunnel. Note that spikes in the red trace are noises caused by beam injections (kicker).

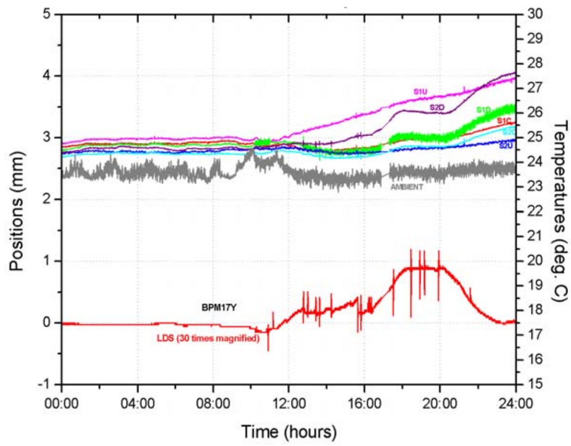


Fig. 6. Variations of vertical position (red line, 30 times magnified) and temperatures of vacuum chamber (machine cell #1). Also shown is the ambient temperature of machine tunnel (grey line).

It takes roughly 12 hours for the chamber temperature equalizes after machine start-up. So we turn on the machine at least 12 hours before regular user service for better orbit stability. But even during regular machine operation, there are temperature variations in the vacuum chambers due to the decay of stored beam current. It was measured ~0.5 ^{o}C between beam injections (12-hour interval). In order to reduce the temperature variations, we have water-cooled some vacuum chambers, eventually achieving temperature drifts of ~0.1 ^{o}C.

From the experiences of light sources around world, one of the most important factors affecting the orbit stability is the air temperature in the machine tunnel[1]. We are trying to improve the stability of the tunnel air temperature within ± 0.1 ^{o}C with affordable budget. We have improved the resolution of temperature sensors in the tunnel to 0.01 ^{o}C, installed precision PID controllers, and optimised the direction of air flows. The ~20-μm (~7-μm rms) orbit drift shown in Fig. 2 is the result of these efforts.

We are now in the stage of investigating the mechanical stability of magnets and girders. For this purpose, we have installed extensive displacement (25 EA) and temperature (41 EA) sensors on the magnets and girders of a selected machine cell. They are intended to measure displacements and rotations of magnets, and girder displacements.

4 FURTHER INVESTIGATIONS

We will need to implement orbit feedback systems in order to achieve the orbit stability of <1 μm. For this, the following efforts are under way or start next year.

1. Improvement of BPM resolution better than 1 μm at >20-Hz measurement bandwidth.
2. Implementation of precision photon BPM's for use as the reference to the electron BPM's.
3. Improvement of the control units for corrector MPS's for better stability and higher access speed.
4. Development of efficient feedback algorithm.
5. Implementation of EPICS-based machine control system.

In addition, we are going to install wide-band BPM's for measuring fast beam oscillations in the storage ring and the beam positions of the linear accelerator. We have procured log-ratio (LR) BPM electronics boards from the Bergoz Instrumentation with the following specification[2],

1. Measurement Bandwidth : 4 MHz
2. Resolution : 200 μm @ Full BW
3. Dynamic Range : 40 dB
4. Operation Frequencies : 500 MHz (for Storage Ring), 357 MHz (for Linac)

Fig. 7 is the test result of a prototype LR-BPM, which was installed at the end of the linac. PUE's for the linac are 4 striplines.

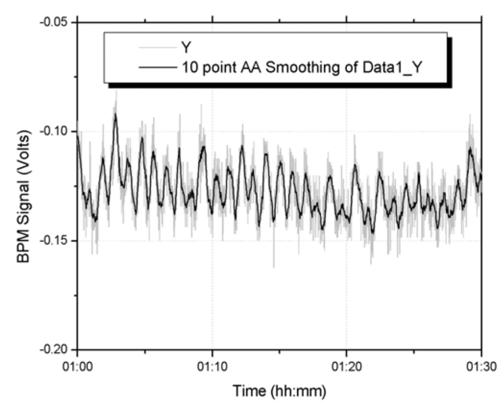


Fig. 7. Short-term variation of vertical beam position at linac endstation that was measured by prototype LR-BPM.

It is seen that there are periodical orbit drift with its period and amplitude of ~10 minutes and ~0.5 mm respectively.

REFERENCES

[1] R. Keller et al., "Orbit Stability of the ALS Storage Ring," Proc. of the 17th Particle Accelerator Conference, Vancouver, Canada, May 12-16, 1997.

[2] *User manual of LR-BPM*, Bergoz Instrumentation.