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Commissioning Results of the APS Storage Ring RF Beam Position Monitors

Emmanuel Kahana and Youngjoo Chung†

Accelerator Systems Division, Advanced Photon Source,
Argonne National Laboratory, Argonne, IL 60439

Abstract. The commissioning of the 360 rf beam position monitors (BPMs) in the Advanced Photon Source (APS) storage ring (SR) is nearing completion. After using the single-turn capability of the BPM electronics in the early ring commissioning phase, resolution measurements versus current and bandwidth were successfully performed. In the standard SR vacuum chamber geometry, the resolution was measured with beam as $0.16 \mu\text{mA}/\sqrt{\text{Hz}}$. For the insertion device vacuum chamber geometry, the resolution was measured to be $0.1 \mu\text{mA}/\sqrt{\text{Hz}}$.

Since the photon beam stability requirement for the users is only 4.5 microns rms in the vertical direction, investigations of rf BPM offset versus current and bunch pattern have also been initiated. Both single bunch and multibunch beam patterns with varying intensity were used to determine offset stability for both the global and the local orbit feedback applications.

INTRODUCTION

The stability of the X-ray beam is an essential requirement of the APS. The current requirement is 4.5 microns rms. In order to achieve this stability, we need a BPM system with a very good resolution that serves as a sensor for local and global feedback systems. The BPM resolution is inversely proportional to the beam current and directly proportional to the square root of the processing bandwidth (1)(2). Another consideration is the beam stability dependence upon bunch pattern and current. This paper presents the results of BPM resolution measurements, their relation to beam current and bandwidth, and beam stability as a function of current and bunch pattern.

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† Present address: Kwangju Institute of Science and Technology, South Korea.

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RESOLUTION MEASUREMENTS

The BPM samples the beam position N consecutive times, with the time interval Δt , using a 12-bit A/D converter. The revolution time is 3.68 microseconds, and, since in the normal mode we alternate between x and y , the sampling is at half this rate (3). The rms beam position error Δx has two components: one due to real beam motion and one due to electronic noise. Since the two components are assumed to be uncorrelated, the rms beam position error is given by:

$$\Delta x^2 \leq \Delta x_b^2 + \Delta x_e^2, \quad (1)$$

where Δx_b is the rms error due to real beam motion and Δx_e is the rms error due to BPM electronics noise.

It was determined experimentally that Δx_e is inversely proportional to the single bunch current and inversely proportional to the square root of N . Therefore,

$$\Delta x_e = \frac{k}{I_b \sqrt{N}}, \quad (2)$$

where k is a constant, I_b is the single bunch current, and N is the number of samples averaged.

Since we only want to measure Δx_e , we need to cancel the effect of the beam motion. The beam position is measured by comparing the voltages induced by the beam on four symmetrically placed capacitive "buttons" inserted into the vacuum tube. Therefore, we can cross-connect the cables attached to the BPM buttons and measure x and y separately. For example, if the top or bottom two cables are crossed, the beam motion effect on the x measurement will be negligible.

For this work, a BPM in sector 6 had the top buttons crossed, a BPM in sector 9 had the inboard buttons crossed, and a BPM in sector 7 was normally connected. Figures 1 through 3 show the results of the measurements of the BPM position error, as a function of N , for the single-bunch current $I_b = 0.22, 0.91$, and 7.1 mA. The dependence of the beam position measurement error on the beam current is shown in Figures 4 and 5 for $N=2$ and $N=1024$.

For the BPMs with crossed connections, the dependence of the beam position measurement error decreases according to $1/I_b$. The error decreases with $1/\sqrt{N}$ as shown in Eq. (2). For the normal BPMs in sector 7, the error decreases initially, but approaches asymptotically about 23 microns rms for x and 5 microns rms for y , due to actual beam motion. Since the specification for x is 17 microns rms, there was a problem which was later determined to be a result of power supply ripple (4). From the plots we can determine the constant $k=40$ for Eq. (2). In the case of insertion device (ID) BPMs, the calculation gives $k=25$ due to the smaller chamber size and smaller buttons (1).

FIGURE 1. Beam position measurement error Δx and Δy , as a function of N , for a single-bunch current $I_b = 0.22$ mA.

FIGURE 2. Beam position measurement error Δx and Δy , as a function of N , for a single-bunch current $I_b = 0.91$ mA.

Since the average number N is related to the processing bandwidth, it is convenient to calculate Δx_e in terms of $[\mu\text{mA}/\sqrt{\text{Hz}}]$. From the frequency response of the averager and the turn rate, we obtain (1):

$$\Delta x_e [\mu\text{m}] = \frac{\sqrt{\text{BW}[\text{Hz}]}}{I_b [\text{mA}]} \times \begin{cases} 0.16 & \text{regular BPM} \\ 0.1 & \text{ID BPM} \end{cases}, \quad (3)$$

where BW is the processing bandwidth.

In the APS storage ring, the rf BPMs will be used for global and local beam position feedback to stabilize the particle and x-ray beams. The correction bandwidth is expected to be approximately 100 Hz, with a sampling frequency of

FIGURE 3. Beam position measurement error Δx and Δy , as a function of N , for a single-bunch current $I_b = 7.1$ mA.

FIGURE 4. Beam position measurement error Δx and Δy , as a function of the single-bunch current, for $N = 2$.

4 kHz. With this bandwidth and with the single-bunch current of 1 mA, the resolution will be better than 1.6 microns for regular BPMs and 1 micron for ID BPMs. Beam position perturbations larger than this resolution will be corrected by feedback.

ORBIT STABILITY TEST

An important characteristic of the BPM system is the offset stability as a function of bunch pattern and beam current. In order to measure this characteristic, we measured the beam orbit, using all 360 BPMs in the storage ring. We eliminated

FIGURE 5. Beam position measurement error Δx and Δy , as a function of the single-bunch current, for $N = 1024$.

from the data some "bad" BPMs which showed unusually large offsets or no response. The orbit was measured for the following conditions:

- 5 bunches, every third bucket, current 2.5 to 14.5 mA
- 15 bunches, every third bucket, current 2.8 to 17.5 mA
- 25 bunches, every third bucket, current 3.5 to 18.5 mA

As a reference, we took the 25-bunch pattern at 16.3 mA. In each case we averaged 2048 samples of each BPM measurement and averaged 30 orbits to reduce the effect of beam motion. We calculated the difference between each averaged orbit and the reference, and then calculated the average and standard deviation of the differences for each bunch pattern and each current. Figures 6 through 9 show the results.

FIGURE 6. Average horizontal difference vs. bunch pattern and current.

FIGURE 7. Average vertical difference vs. bunch pattern and current.

FIGURE 8. Horizontal difference standard deviation vs. bunch pattern and current.

The figures show that the short bunch train case differs from the long bunch train cases. This is expected, since the location of the sampling gate is more critical for short bunch trains. Since the bunch is stretched by the input filter to about 100 ns, for bunch trains longer than 100 ns, the change in average offset is less than 5 microns. Including bunch trains shorter than 100 ns, we have a change in average offset of less than 20 microns. As a function of current, the change in average offset is about 5 microns.

SUMMARY

Both the resolution and the offset stability are compatible with the requirement of 4.5 microns rms photon beam stability for the ID. More measurement will be

FIGURE 9. Vertical difference standard deviation vs. bunch pattern and current.

taken for long-term drift, orbit stability at high current, and closed-loop feedback performance.

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