# COMMISSIONING RESULTS OF THE NARROW-BAND BEAM POSITION MONITOR SYSTEM UPGRADE IN THE APS STORAGE RING

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*Abstract*

When using a low emittance storage ring as a high brightness synchrotron radiation source, it is critical to maintain a very high degree of orbit stability, both for the short term and for the duration of an operational fill. A fill-to-fill reproducibility is an additional important requirement. Recent developments in orbit correction algorithms have provided tools that are capable of achieving a high degree of orbit stability. However, the performance of these feedback systems can be severely limited if there are errors in the beam position monitors (BPMs). The present orbit measurement and correction system at the APS storage ring utilizes 360 broad-band-type BPMs that provide turn-by-turn diagnostics and an ultra-stable orbit: < 1.8 micron rms vertically and 4.5 microns rms horizontally in a frequency band of 0.017 to 30 Hz. The effects of beam intensity and bunch pattern dependency on these BPMs have been significantly reduced by employing “offset compensation” correction. Recently, 40 narrow-band switching-type BPMs have been installed in the APS storage ring, two in each of 20 operational insertion device straight sections, bringing the total number of beam position monitors to 400. The use of narrow-band BPM electronics is expected to reduce sensitivity to beam intensity, bunch pattern dependence, and long-term drift. These beam position monitors are used for orbit correction/feedback and machine protection interlocks for the insertion device beamlines. The commissioning results and overall performance for orbit stability are provided.


## 1 INTRODUCTION

The third-generation synchrotron light sources, such as the Advanced Photon Source (APS) storage ring, must meet very tight orbit stability requirements needed for low-emittance charged particle beams. These requirements get even tighter as the beam size reduces further. The orbit stability work at APS is at the forefront in many ways; here, we will discuss results of recently commissioned narrow-band switching-type beam position monitors (NBBPMs), connected to the insertion device chambers.

This type of BPM, first developed in the late 1980s [1], was followed by several design improvements [2,3], particularly a significant increase in the input dynamic range. The bulky chassis-type package has been reduced to a single height Euro-type module with several practical built-in features. Such a unit now is commercially available. Forty of these units have been integrated together with the existing 360 broad-band-type or monopulse beam position monitors (MPBPM). Front-end upgrade work on the MPBPM system is also in progress, which will enhance the global orbit stability performance [4].

Two orbit correction systems – “fast” [5] and “slow” [6] – that correct the orbit up to about 50 Hz have been employed at the APS storage ring. Both systems make orbit correction only for the long spatial wavelength motions, taking great statistical advantage of a large number of BPMs, thus not responding to local artificial effects that may be exhibited by individual BPMs. The “offset compensations,” based upon “scrape down” fitted data [6], are made to the raw BPM data. This reduces a large number of systematic errors, such as intensity/bunch pattern dependency and thermal effect in the data, presented to the orbit correction algorithms.

The bench data for NBBPMs show that the beam intensity dependence is less than 2 microns in the upper 40 dB of the power range, but it is challenging to make similar claims in the storage ring. Uncertainty in the orbit itself and the thermally induced chamber motion are some of the culprits that contaminate the measurements. The high performance x-ray-type beam position monitors (XBPMs) [7] have been routinely used as a reliable reference, but only for the bending magnet (BM) sources. However, recent work done by modifying the lattice [8] for one insertion device may hold the key to future use of XBPMs as a reference for ID sources as well.

## 2 INSTALLATION/COMMISSIONING

There are ten Eurocrates installed around half the ring, each housing NBBPM modules for two sectors. The NBBPM output signals are sent to a digitizing beam position limit detector (DBPLD) for machine protection [9]. The response time requirement of 350 microseconds for a beam deflection of +/- 1 mm is easily met. A 300-Hz anti-aliasing filter module is used to provide input to a 16-bit orbit measurement digitizer that samples at the orbit feedback rate of 1.6 kHz. This sampled data is fed to the real-time feedback system and to an averager that then passes data to the “slow” correction system. The NBBPM calibrations for the 8-mm chamber are 3V/mm and 5V/mm for vertical and horizontal planes, respectively.

The MPBPM electronics had previously been connected to the small gap chamber's buttons (P0 buttons), which were moved earlier from the nearby standard chamber

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buttons (P1 buttons), as the insertion device chambers were installed. Since the NBBPM electronics were to be connected to P0 buttons, the MPBPM electronics had to be moved back to P1 buttons. This exchange was done in several stages, by swapping electronics for only a few insertion device chambers at a time. Careful procedures were followed to ensure the user orbit was restored as closely as possible. After the swap, standard practice was to perform an orbit correction without using the swapped BPMs, followed by enabling these BPMs and generating new offset values based on the newly measured orbit. In some cases, further alignment was required at a user's request.

## 3 BENCH MEASUREMENT DATA

The rms noise and linearity error were measured in a bench setup; data is shown in Fig. 1. A continuous wave (CW) signal from an rf source at 351.927 MHz together with a 1-4 power splitter were used to simulate button signals. The power level was varied such that a range of -10 dBm to -70 dBm was achieved at the input of NBBPM electronics. Note that 100 mA in the APS storage ring generates about -30 dBm power at 351.927 MHz (with centered beam), when measured at the NBBPM electronics. The measurement in Fig. 1 shows that the noise and linearity for the full range vary up to 22 microns, but for a normal user run (about -30 dBm to -40 dBm), these variations are only between 1 to 2 microns.

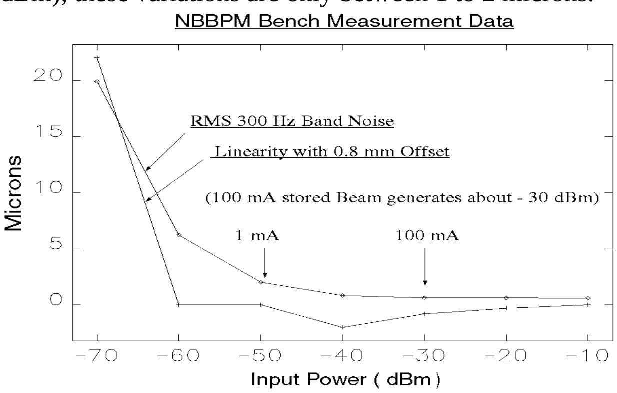


Figure 1: Noise and linearity data vs. input power

As also seen in Fig. 1, the "good" range of -10 to -30 dBm is not used due to the low power level of the stored beam. To boost the power levels, preliminary work has shown that, with minor modifications, an rf matching network, developed for the MPBPM upgrade [4], boosts the power level by 8 to 10 dBm. These matching networks will be installed in the near future at all P0 buttons.

Measurements were also made to characterize the narrow-band filter that rejects the revolution harmonics around the rf frequency. These harmonics, at 271.5 kHz away, were only about 25 dB down from the center frequency amplitude. This could have an impact on the bunch pattern dependency and further studies are needed.

## 4 STORAGE RING DATA

All NBBPMs have been commissioned for the slow orbit correction system, increasing the total number of available BPMs to 400. Work is in progress to include NBBPMs for the real-time feedback system. To quantify the overall performance of NBBPMs in the storage ring is rather difficult, but data show that there are significant improvements both in the intensity and in the bunch dependency. We also make use of XBPM data to compare some results.

The scrape down data shown in Fig. 2 indicate that there is a reduction in the offset compensation by almost a factor of 2. This data is taken in a controlled set of conditions where the orbit is believed to be as stable as possible, as the storage ring current is scraped from 100 mA to 40 mA in about 20 minutes. The MPBPM data were taken in early 1998 when all ID chamber buttons were connected to MPBPM electronics. The NBBPM data were taken in early 1999 when same ID chamber buttons were connected to NBBPM electronics. It is believed that a smaller amount of systematic errors should provide a better estimate for orbit correction.

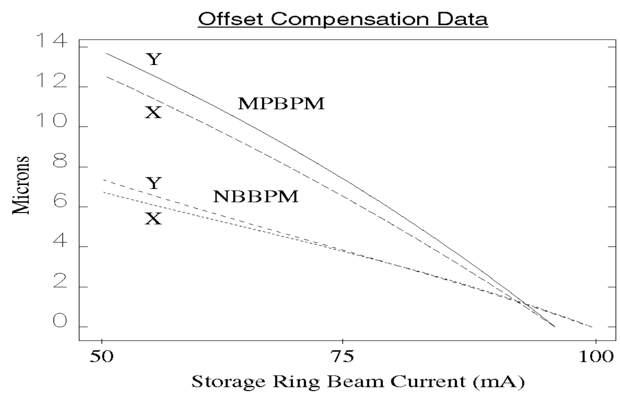


Figure 2: Scrape down data for MPBPMs and NBBPMs

We performed an experiment where we did almost the opposite of scrape down. The storage ring was filled at about two-minute intervals from 50 mA to 100 mA. The data in Fig. 3 shows that orbit drift, as measured by all NBBPMs, is less than 3.5 microns for both planes as compared to seven microns measured during scrape down. In this experiment, all designated bunches were filled except those used by the MPBPMs, making the MPBPM system insensitive to the intensity changes (not the case during scrape down), and thus perhaps providing a better orbit control. Note that horizontal drift cannot be observed in the bottom trace due to a higher orbit noise level exhibited in the horizontal plane. However, it can safely be concluded that the intensity/bunch dependency effects in NBBPMs are less than 3.5 microns for a fill of 50 to 100 mA.

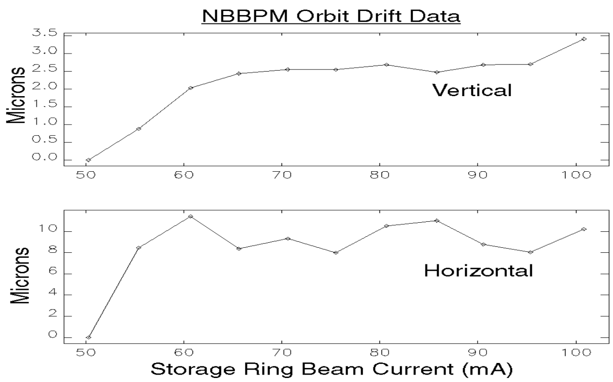


Figure 3: Orbit drifts as measured by NBBPMs

The NBBPMs can measure submicron level changes. The top trace in Fig. 4 is horizontal XBPM data shown for a period of about seven hours during a user run; it shows a downward motion. This XBPM is located ~ 15 m away from the ID source and therefore has an angular advantage of ~ 12 over NBBPMs. The bottom trace is a computed signal (called forward-mapped) at the XBPM location derived from NBBPMs straddling the ID source. This trace shows a combination of a downward motion overlapped with a periodic motion that is about 33 minutes long. Since the similar periodic motion is not seen on the XBPM, it is apparently not a real orbit motion. The observed periodic motion in NBBPMs is probably due to submicron level motion of the chambers to which these BPMs are attached, and is caused by a correlated periodic variation that has been observed in the chamber cooling water temperature. It is noteworthy to point out that the orbit correction system does not respond to such variations, as it only corrects for long spatial wavelength orbit changes.

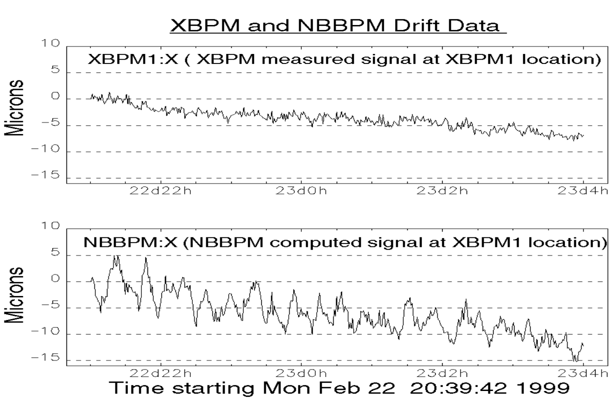


Figure 4: X-ray BPM and rf BPM forward-mapped data

The NBBPM also provides signals for the digitizing beam position limit detector (DBPLD), an interlock that detects beam missteering conditions. This system works well for stored beam, but has not yet been commissioned for top-up operation. The vertical BPM sensitivity (V/mm) for the small-gap insertion device chambers has a strong dependence on horizontal beam position. This was evident during injection when several mm horizontal orbit transient occurred, inducing a false vertical transient. It was also observed that this coupling showed a minimum as DC vertical orbit was varied. The vertical position where minimum is observed probably indicates the vacuum chamber's geometric center. Further work is in progress, so that the DBPLD can be used in the near future. Presently, the older system (BPLD) connected to P2 buttons is used to protect the machine.

## 5 CONCLUSIONS

Data from the bench and storage ring show improvements in orbit measurement by the NBBPM system. The intensity and bunch dependence effects are smaller. Further work is in progress to characterize these BPMs more precisely utilizing XBPMs.

## 6 ACKNOWLEDGEMENTS

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