BPM AND ORBIT CORRECTION SYSTEMS AT THE DUKE STORAGE RING *

Y. K. Wu†, J. Li, P. Wang, V. Litvinenko, FEL Lab, Duke University, NC 27708-0319, USA

Abstract

Stable and reliable storage ring operation critically depends on the orbit stability. At Duke, an orbit stability program is well under way to achieve the high level of orbit performance necessary for reliable free electron laser (FEL) and gamma-ray operation. Progress has been made to reduce the current dependency of BPM readings via choice of cables and band-pass filters. Beam based alignment has been carried out to accurately determine the locations of quadrupole centers. A global orbit correction system and a slow orbit feedback system have been developed. Integrated with operation, these systems have demonstrated the ability to significantly improve the overall storage ring performance.

1 INTRODUCTION

The Duke storage ring was first commissioned in 1993 [1] with a minimal set of beam diagnostics. In spite of its rapid successful commissioning, the lack of beam position monitor (BPM) system adversely impacted the high bunch-current operation and subsequent commissioning of the free electron laser (FEL). Purchased from Bergoz, a set of 34 BPM electronics modules were installed in 1999 on the storage ring [2]. The initial operation of the BPM system resulted in limited improvements in the storage ring operation.

The system provided relatively reliable orbit measurements, however, BPM readings were found to be strongly dependent on the beam current. Further investigation indicated that this current dependency was the result of the overloading of BPM electronics due to a high peak voltage. Steps have been taken to address this problem by attenuating BPM pickup signals. Although unfinished, this work has significantly improved orbit readings. The improved BPM system has allowed the development and application of a reliable global orbit correction system. With this system, we are able to store a high single bunch current consistently. In addition, well-corrected vertical orbit has significantly lowered transverse coupling, resulting in improved dynamic aperture and FEL operation. A slow orbit feedback system has also been developed. Its operation in the near future will provide the long-term orbit stability necessary for optimal FEL and gamma-ray operation.

In the following sections, we first report our work on resolving the problem of beam current dependency of BPM readings. We then present the beam-based alignment scheme used to determine quadrupole centers. Finally, we report the development and operation experience of a global orbit correction system and a slow orbit feedback system.

* Work Supported by the DoD MFEL Program as managed by the AFOSR, grant F49620-001-0370.

† wu@fel.duke.edu, 1-919-660-2654 (phone).

2 BPM SYSTEM IMPROVEMENTS

The Duke BPM system had been designed to maximize the pickup signals. This decision had resulted in choosing stripline pickup electrodes. Two types of stripline BPM pickups were installed on the Duke ring: arc BPMs with shorter striplines (21.6 mm) and smaller inner radii (17.78 mm) and straight section (SS) BPMs with longer striplines (30.5 mm) with larger inner radii (30.5 mm). Being closer to the electronics modules, arc BPMs were connected with RG223-U cables while straight section BPMs were connected with low loss $1/4$" Helix cables. With this configuration, orbit readings from SS BPMs were found to be strongly dependent on the single bunch current (see Fig. 1.a).

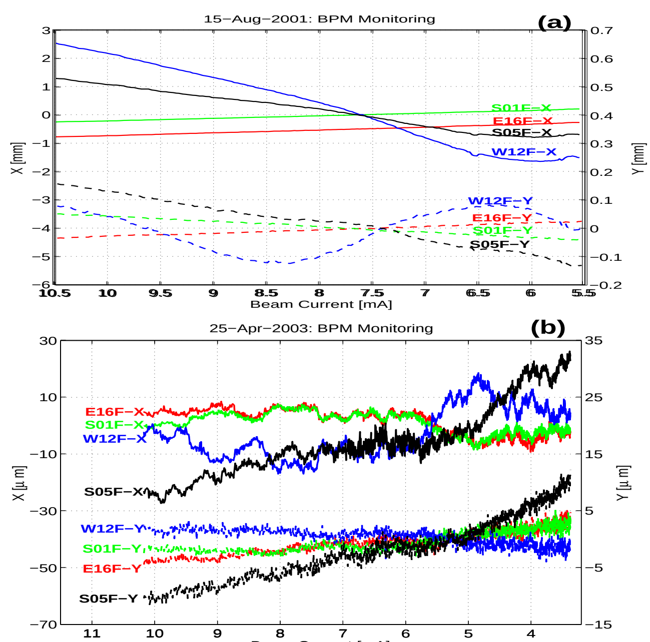

Figure 1: BPM reading variations with the single-bunch current: (a) Helix cables were used for straight section BPMs (including S01QF and S05QF BPMs) while RG223 cables were used for arc BPMs (including E16QF and W12QF BPMs); (b) RG223 cables were used for all BPMs. In addition, 20 MHz band-pass filters were used for E16QF and W12QF BPMs.

The raw BPM pickup voltage was measured at tens of volts level (0-1 GHz), far exceeding the 5 V threshold allowed for the multiplexer in the Bergoz's electronics. The severity of this problem was altered by the type of cables used, for the cable could serve as an effective low pass filter in case of RG223 cables. For example, the arc BPM readings were found less dependent on the bunch current (see Fig. 1.a). Further improvements were realized with band-pass filters installed on arc BPMs (see Fig. 1.b). With filters, the small changes in arc BPM readings could be attributed to the real orbit motion during the 1.4 hour test run. The maximum BPM reading variations in various configurations are summarized in Table 1.

BPM & location	Before upgrade (X, Y) [μm]	After upgrade (X, Y) [μm]	Upgrade
S01QF, SS	(4176, 206)	(36, 8)	RG223
S05QF, SS	(2082, 292)	(54, 24)	RG223
E16QF, ARC	(508, 60)	(18, 10)	BP filter
W12QF, ARC	(460, 93)	(16, 9)	BP filter

Table 1: Maximum BPM reading variations. Before upgrade, I = 10.5 to 5.5 mA; after upgrade, I = 10.2 to 3.3 mA;

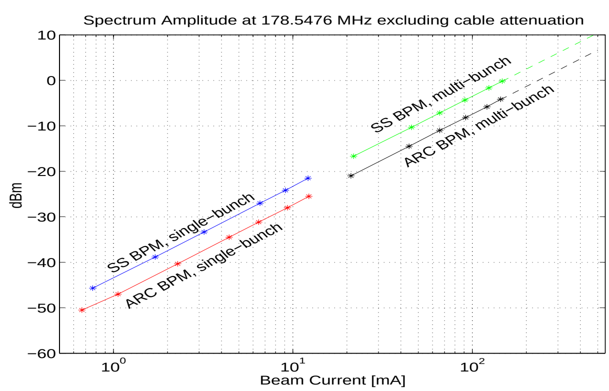

Figure 2: Measured spectrum power at 178 MHz for both shorter striplines (arc BPMs) and longer striplines (straight section BPMs). Two segments of data covering a large current range were collected from single-bunch and multi-bunch runs.

The Duke storage ring operates over a wide beam current range with several bunch patterns: from a few mA to tens of mA in the single-bunch mode and from tens of mA to hundreds of mA in the multi-bunch mode. To achieve optimal BPM operation over such a wide range of currents, it is essential to find a proper combination of cables and filters for BPMs. For example, a large insertion loss due to band-pass filters would limit the usefulness of BPMs at the low current end in the single-bunch operation. The maximum allowed power loss in the cable and filter can be determined from carefully measured power spectra (Fig. 2). We are in the process of finalizing the cable/filter configuration for both types of BPMs.

3 BEAM BASED ALIGNMENT

The desirable closed orbit should go through the centers of quadrupoles. The offset between the quad centers and adjacent BPM centers can be determined using beam based alignment (BBA) techniques. A straightforward beam based alignment method used in the ALS [3] has been adopted for the Duke ring.

Using this method, a corrector steers the beam orbit in the quad under measurement. For each orbit, the focusing strength of the quad is varied and the difference orbit around the ring is then recorded. The quad center is defined as an orbit in the quad at which the focusing strength adjustment produces no orbit changes around the ring.

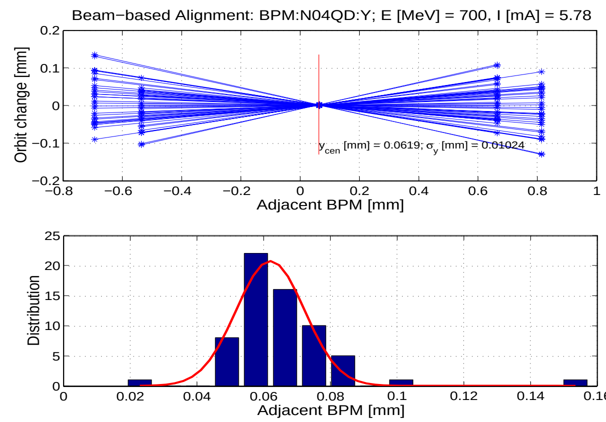

Figure 3: Finding the vertical quad center using a Gaussian fit for quad N04QD, $\beta_y = 12$ m.

Fig. 3 shows the measurement of the N04QD quad vertical center. Each BPM produces its own estimate for the quad center. The distribution of possible quad centers computed using all BPM data is then fitted to a Gaussian form. In this example, the standard deviation of the Gaussian fit is about 10 μm. Fig. 4 shows the measured quad centers around the ring using a 700 MeV beam. The maximum and average sigmas for arc BPMs are 120 and 70 μm respectively with a smaller β-function, $\beta_y = 1.8$ m.

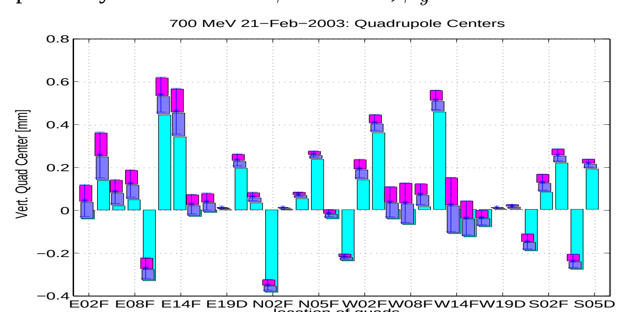

Figure 4: Measured vertical offsets between quad centers and adjacent BPM centers with a 700 MeV beam.

4 GLOBAL ORBIT CORRECTION

Like many high level controls for the Duke ring, the global orbit correction was developed in MATLAB. The correction algorithm is the singular value decomposition (SVD). It utilizes 31 BPMs, 54 horizontal and 25 vertical correctors. With a reasonably updated response matrix, the correction algorithm settles down in 2 to 3 iterations. After the correction, the residual vertical orbit is small: the vertical orbit has a sigma of about 80 μm at injection energy of 274 MeV and a sigma of about 60 μm at 700 MeV at which the BBA is performed.

A well-corrected orbit significantly improves the ring performance. First of all, it helps increase the beam lifetime. Second, by suppressing the skew quad excitation in sextupole elements, a good vertical orbit helps significantly reduce the transverse coupling. For example, when correcting the vertical orbit from 1.2 mm to 0.1 mm (RMS), the vertical η-function is reduced from 20 mm to 4 mm (RMS). Third, a good vertical orbit suppresses the excitation of head-tail instabilities, allowing storage of higher single-bunch current, which is essential for the FEL and Compton gamma-ray operation.

The global orbit correction has been fully integrated with the machine setup and operation. Whenever needed, this tool can be used to correct the orbit drift to maintain a good orbit. This practice has resulted in significant improvement in the reliability of the storage ring operation.

5 SLOW ORBIT FEEDBACK

To achieve a higher level of orbit stability, an active orbit feedback is necessary. A slow orbit feedback system has been developed for the Duke ring via optimization of the global orbit correction program described above. This system is capable of correcting orbit up to 4 times per second. Fig. 5 shows the effectiveness of the slow orbit feedback. First, the orbit feedback system ran for about one hour, maintaining the straight section orbit to less than 10 μm (peak-to-peak). Later, the feedback was turned off and the orbit started to drift with maximum horizontal orbit drift exceeding 100 μm in the next 45 minutes.

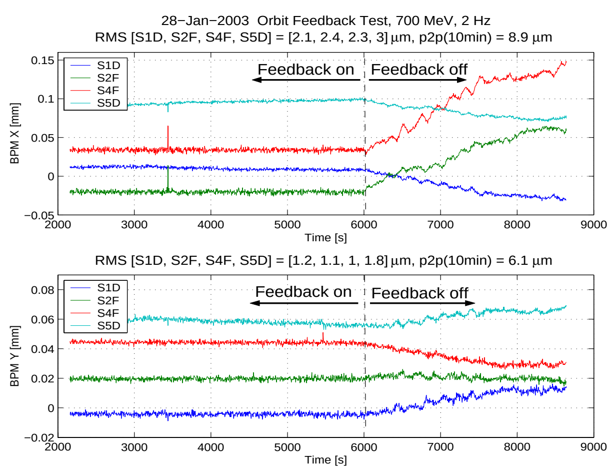

Figure 5: Orbit stability with a slow orbit feedback system. All 4 BPMs are located in the straight section with large β-functions.

It is worth pointing out that the typical beam sizes in the straight section are 300 and 60 μm (RMS) respectively. The ability to maintain orbit stability within 10% of the beam sizes will significantly improve the light source operation and enhance user capabilities. For example, both the FEL and Compton gamma-ray operation requires a good transverse alignment of the optical pulse with the electron beam orbit in the interaction region. By sustaining a good e-beam orbit continuously, aligning the optical axis with a fixed beam orbit becomes a much easier task. For gamma-ray users, the stable beam orbit angle means a stable on-target gamma-ray energy after the collimator. A higher level of orbit stability also significantly simplifies and improves the two-color biological and chemical experiments using both infrared synchrotron radiation from bending magnets and UV radiation from the FEL.

The orbit feedback has been tested in several operation conditions. Since the feedback system utilizes a fixed response matrix, it is important to find out whether it can maintain its effectiveness when the ring lattice is somewhat changed. The feedback was tested with abrupt orbit changes, lattice tuning, and field strength tuning of the FEL wigglers. The test result indicated that the feedback system was able to adapt to these operation environments.

Our ultimate goal is to allow transparent storage ring operation with the orbit feedback running in the background. Mechanisms have been developed to automatically switch off the feedback during energy and lattice ramping and when there is not enough beam current. In addition, at restart, the feedback system will select and load in an appropriate response matrix suitable for the present lattice. This sophisticated feedback system will be fully commissioned after the current dependence problem of the BPMs is completely addressed.

6 SUMMARY

The current dependency of BPM readings has been found to be caused by overloading BPM electronics with a high peak voltage. Using low-pass cables, this problem has been reduced to a manageable level. Further improvement is expected as the result of an on-going effort to find an optimal configuration of cables and band-pass filters.

The quad centers have been accurately determined using a beam based alignment technique. This work has paved the way for the development of a global orbit correction scheme using SVD. Integrated with operation, the orbit correction system has significantly improved the overall storage ring operation. A slow feedback system is being tested to maintain long-term orbit stability. This system will simplify the light source operation and further improve the light source performance.

We would like to thank I. Pinayev at DFELL for providing reference orbit measurement using his optical BPM and S. Hartman at DFELL for significantly improving the BPM readback system. We also would like to thank Jim Hinkson at GMW for advice and help on resolving the BPM electronics overloading problem.

7 REFERENCES

[1] V. N. Litvinenko, Y. Wu, B. Burnham, et al., Proc. of PAC95, Dallas, Texas, p. 213 (1995).

[2] P. Wang, et al. Proc. of PAC99, New York, p. 2099-2101 (1999).

[3] D. S. Robin, Berkeley National Lab, private communication.