BEAM POSITION MONITOR SYSTEM FOR KEKB

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Abstract

The Beam Position Monitor (BPM) System for KEKB has been in use to measure closed orbit distortion since the start of commissioning in December 1998. The High Energy Ring (HER) and the Low Energy Ring (LER) for KEKB are each equipped with about 450 BPMs. The BPM system has been regularly operating to measure beam positions with a resolution of a few microns and at a sampling period of about two seconds. Oscillations of the beam orbits have also been measured by using a special mode of this system. All BPM heads were aligned in relation to the magnetic field center of their nearest Quadrupole magnet (Qmag) by beam measurement. We have also commissioned the eight-electrode BPM system (OCTPOS) for simultaneous measurement of both electron and positron beam positions from their composite signal near the interaction point. This report describes the performance of the system as a result of operation.

1 INTRODUCTION

The performance of the KEKB[1] optics is sensitive to various magnet errors and to the beam orbit at coupling elements. The Beam Position Monitor System for KEKB[2] is the most important beam diagnostic instrumentation for measuring beam orbits in KEKB. BPMs (454 BPMs for the LER and 443 BPMs for the HER) were set rigidly on every Qmag. The critical elements such as BPM heads, transmission lines and electronics were made to close tolerances, because the KEKB rings store very high current beams (LER 2.6 A, HER 1.1 A) with 5000 bunches. The BPM system requires good performance characteristics as shown in Table 1. In order to satisfy these performance requirements, the BPM electronics have two main features. The first one is the principle of detecting a higher harmonic component of beam signal and the second one is the method of switching four signals to a common detector. Since the BPM system measures beams in any bunch configuration, a pickup frequency of 1018 MHz has been chosen, that is, twice the accelerating RF frequency.

Table 1: Performance characteristics

Relative accuracy	≤ 10 µm
Absolute accuracy	≤ 100 µm
Speed	≤ 1 sec / closed orbit
Dynamic range	10 mA ~ 2.6 A

2 CALIBRATIONS OF THE BPM SYSTEM

2.1 Calibration before the commissioning

We have done careful calibration of almost all BPM heads in three steps before the commissioning:

1. The BPM heads were fabricated to within a ±0.1 mm tolerance. However, variations of frequency response between button electrodes cannot be ignored considering the accuracy requirements. All BPMs were mapped at a test bench with a movable antenna to identify the electrical center of each BPM, and were calibrated to about 20 µm accuracy.
2. Most BPMs (~97%) were aligned in relation to their nearest quadrupole magnet (Qmag) within 50 µm. After installation of BPM heads in the KEKB ring, we measured the geometrical offsets of the BPM heads relative to the Qmags. The geometrical offsets were measured with good reproducibility: 38 µm horizontally, 16 µm vertically.
3. We employed 4 twisted coaxial cables with foamed Polyethylene insulation between BPMs in the tunnel and electronics at a local control room above ground. To measure signal attenuation at 1018 MHz frequency, the cables together with the electronics were also calibrated to 50 µm accuracy.

2.2 Beam based calibration for the BPM

Usually the beam position is calculated from the output of four electrodes (A, B, C and D) of a BPM. Then four beam positions are also obtainable from the output voltage of any three electrodes chosen out of four electrodes. If the four outputs have ideal correlation, these four beam positions ((A, B, C), (B, C, D), (C, D, A), (D, A, B)) should coincide with each other. The software procedure for the BPM system perform calculation of not only a beam positions by four electrodes but also four beam positions by three electrodes to examine consistency among these positions. We found that almost all BPM readings included noticeable error in which the differencees of the four positions were larger than 0.1mm. To correct these errors, we have performed beam-based calibration for all BPMs in KEKB. The beam-based calibration estimated an offset value from the magnetic field center of a quadrupole magnet according to the Quad-BPM method [3]. The histograms of their measured offsets in the LER are shown in Figure 1. The offsets of the LER and the HER were used to correct their beam positions in software. The RMS of the measured CODs were improved from 0.4 ~ 0.5 mm without offset correction to 0.3 ~ 0.4 mm with offset correction as shown in Figure 2-a,b.

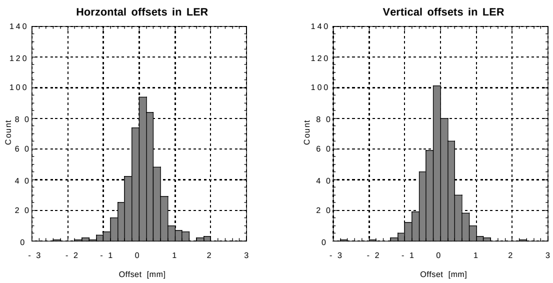

Figure 1: Histogram of offset measured by beam based alignment in LER

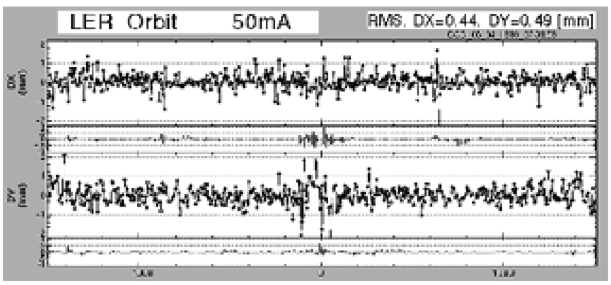

Figure 2-a: LER closed orbit before offset correction

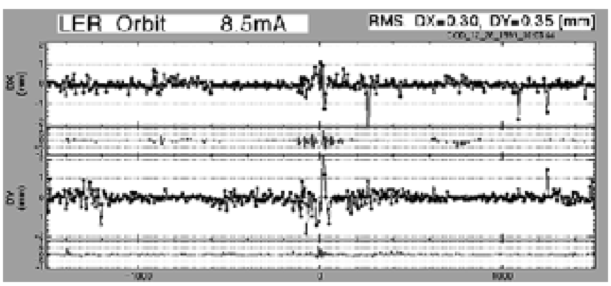

Figure 2-b: LER closed orbit after offset correction

3 POSITION RESOLUTION

3.1 Spectrum data of FFT process at DSP

The electronics for the BPMs have Digital Signal Processors (DSPs) to detect the 1018 MHz component of the beam signal. We can estimate the position resolution by the examining the spectrum data of FFT analysis at the DSP. Figure 3 shows the typical power spectrum distribution when the beam positions were measured with 2048 samples of data.

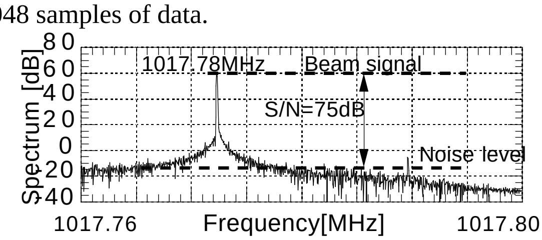

Figure 3: Spectrum data of FFT analysis at DSP

We find an S/N ratio of about 75 dB by the difference between the peak spectrum and the noise level. This S/N ratio is an equivalent to a position resolution of about 2.9 μm. In practical operation, the BPM system gives a better resolution of about 1.5 μm by 4-fold averaging of position data.

3.2 Three-BPM method [4]

In KEKB, the beam orbits are frequently drifting or changing due to ground motion, magnetic fields from another accelerator, power lines, etc. It is necessary to reject these changes to estimate the resolution from beam position data. The three-BPM method is convenient for this. We can calculate position correlation coefficients among three BPMs based on the transfer function. The correlation variances are calculated at all BPMs from 20 sets of closed orbit data. Position resolutions were confirmed to be within a few μm at almost all BPMs as shown in Figure 4. The resolution in the HER BPMs is almost the same as that in the preceding subsection. But that in the LER is relatively large due to orbit oscillations as described in Section 5.

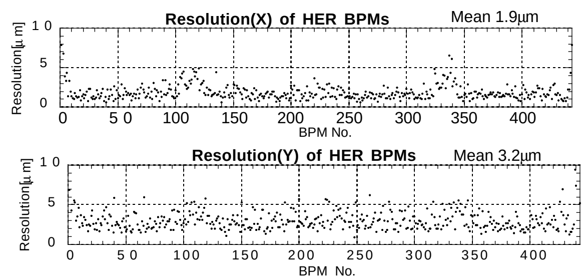

Figure 4: Distribution of all BPM resolutions in HER

4 MEASUREMENT ERROR DUE TO HOM SIGNAL

There are some BPMs with peculiar cross section in regions around the IP such as QC2RE, QC3RE, QC4RE, QC2LE. When beam is passing through these locations, the beam field generates a quite strong wake field of higher order modes in the vacuum chamber. Moreover, in the case that the wave guide cut-off frequency of the chamber is close to the detection frequency of the BPM, the button electrode picks up the beam signal together with the HOM signal and the electronics detect the wrong spectral component. We changed from 1018 MHz detection to 508 MHz detection for these BPMs to avoid the influence of HOMs. The beam positions have been corrected as shown in Table 2.

Table 2: Comparison of 1018 MHz and 509 MHz detection

	1018 MHz detection		508 MHz detection	
QMag	X[mm]	Y[mm]	X[mm]	Y[mm]
QC4RE	-0.351	4.497	-2.168	-0.230
QC3RE	1.159	-3.860	-0.042	-0.897
QC2LE1	-0.868	1.849	-1.527	-0.237
QC2LE2	0.391	3.014	-0.298	-0.165

5 ORBIT OSCILLATIONS

Since oscillations of the beam orbits exist in the HER and the LER, we improved the software of the IOC (Input / Output Controller) of the EPICS system[5]. The local systems for the BPMs were distributed to 20 local buildings around the KEKB ring. These local systems are normally processed at random, but new event code enables every local system to start measurement simultaneously. The BPM system has been typically operated to measure beam positions at two seconds interval. Slow oscillations of the closed orbit over several seconds have been continually corrected by orbit correction system to maintain the golden orbit. Moreover, the BPM system enables us to measure oscillations of orbits above 1 Hz, because the sampling speed can changed by choice of parameters of the DSP. In the case of fast sampling mode, the operational computer cannot read whole EPICS records for BPM at the same repetition because of traffic of computer network. To store a series of sampling data, "waveform" records with a record length of 512 points are added for every BPM. After the completion of sampling data, the computer can read all "waveform" records without network traffic. We can obtain amplitudes within 1 µm and frequency of orbit oscillations by analysis of "waveform" records. Their amplitude of 0.47 Hz component were overlapped on the folded phase advance of optical function in the LER [6] as shown in Figure 5. In addition, the amplitude was traced in the phase advance in neighboring oscillation source as shown in Figure 6. The result discovered the oscillation source to be a 0.47 Hz component of the magnetic field of the nearby proton synchrotron.

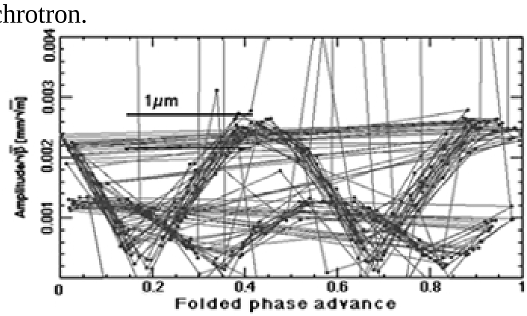

Figure 5: Overlapping of the amplitude of 0.47 Hz component on the folded phase advance of optical function in the LER

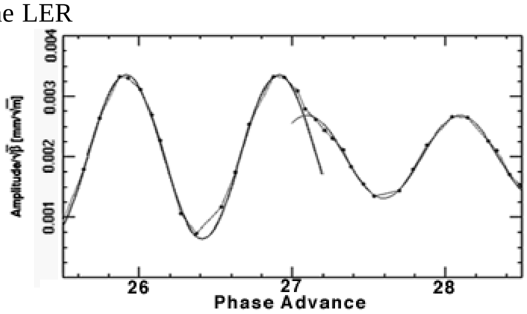

Figure 6: Trace of the amplitude of 0.47 Hz component over the phase advance of the optics function.

6 BPMS FOR INTERACTION POINT

To maintain the optimum collision condition of the two rings, two special BPMs with 8 button electrodes called OCTPOS were installed inside the QCS magnets as shown in Figure 7. Four normal BPMs with 4 electrodes at the exit of the QCSs were also incorporated into this IR BPM system to back up the OCTPOS BPMs. We have commissioned the OCTPOS BPMs for simultaneous measurement of both electron and positron beam positions from their composite signal. Separation of both beams by the finite orbit separation method[7] was verified, however it did not give a position resolution less than a few micron.

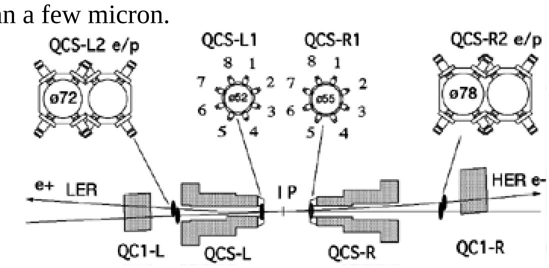

Figure 7: Layout of BPMs around IP in KEKB

7 SUMMARY

When all the above calibration errors are added in quadrature, the total error has a 66 µm absolute error. The relative accuracy has also been measured to a few µm resolution. The BPM system has been operated regularly at a sampling period of about two seconds. The orbit correction of KEKB has been successful to below 0.4 mm (rms.) according to correction of offsets by beam based alignment. The OCTPOS BPM system for the IR has not yet been used to optimize the collision at two beams but it has been available for single beam operation.

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REFERENCES

[1] "KEKB B-Factory Design Report",KEK Report 95-7.

[2] M.Tejima et al., "BEAM POSITION MONITOR SYSTEM for KEKB", Proc. 1997 the 11th sympo. on Accel. Sci. and Tech., SPring 8, Hyogo, Japan.

[3] M. Masuzawa, et al., "Beam-Based Calibration of Beam Position Monitors and Measurements of the Sx. Magnet Offsets at KEKB",Proc. EPAC2000.

[4] H. Fukuma, private communications.

[5] A.Akiyama, et al., "KEKB control system: the present and the future", Proc. PAC99.

[6] N. Akasaka, private communications.

[7] K.Satoh, "Detection of the position of two beams with a common BPM",Proc. PAC99.