Performance of 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. Most BPMs (~97%) were aligned in relation to their nearest quadrupole magnet (Qmag) to within 50 μm. The BPM system has been regularly operated to measure beam positions with a resolution of a few microns and at a sampling period of about four seconds. Oscillations of the beam orbits have also been measured by using other functions of this system. This report describes the performance of the system and results 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. All BPMs (454 BPMs for the LER and 443 BPMs for the HER) were set firmly 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 beam (LER 2.6 A, HER 1.1 A) with 5000 bunches. The BPM system requires good performance characteristics as shown in Table 1. Therefore we have done calibration for good absolute accuracy in three steps. These calibration data are used to correct actual measured beam positions in software. For the examination of the actual performance of the BPM system, we measured and analyzed many data points since the start of commissioning. We have obtained good results on system performance.

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

We did careful calibration as follows: mapping measurement of BPM heads; measurement of signal loss ratio of the cables together with the electronics; and alignment of BPM heads.

2.1 Mapping measurement of BPM heads

The BPM heads were fabricated to within a ± 0.1 mm tolerance. But variations of frequency response between button electrodes cannot be ignored considering the accuracy requirements. All BPMs were mapped at a test bench by movable antenna to identify the electrical center of each BPM. The fed signal is at the same frequency as the detection frequency (1018 MHz) for signal processing. All BPMs were calibrated in a clean room at about 20 μm accuracy. Typical mapping plots of LER and HER BPMs are shown in Figure 1.

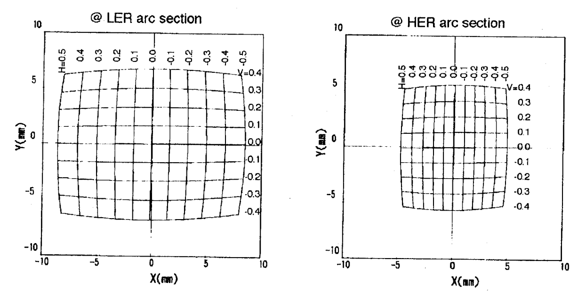

Figure 1: Calibration of the BPM heads of the LER and HER arc sections

2.2 Alignment of geometrical offset of BPM head

After installation of BPM heads in the KEKB ring, we measured the geometrical offset of the BPM heads relative to the Qmags. Two reference plates on top of a Qmag are adjusted during magnetic measurements. A special instrument equipped with 8 laser displacement sensors was put on the reference plates to align exactly as shown in Figure 2. The geometrical offsets were measured with good reproducibility: 38 μm horizontally, 16 μm vertically.

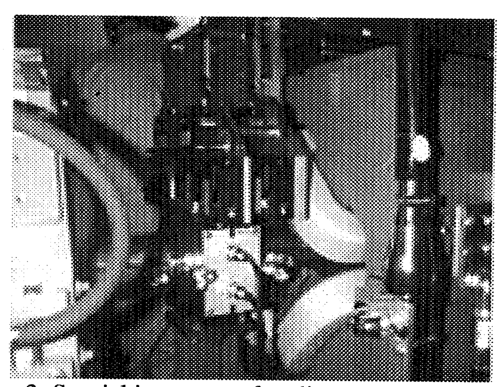

Figure 2: Special instrument for alignment of geometrical offset of BPM head.

2.3 Attenuation ratio of transmission line

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. Since all signals from the 4 pickup electrodes are transmitted through independent cables, low pass filters and RF switches to the detection circuits, their unequal loss leads to noticeable error in beam position. The cables together with the electronics were also calibrated to a 50 μm accuracy. Instead of actual beam signal, four equal signals (within 0.2%) distributed from a continuous wave signal generator were connected to transmission cables in the tunnel, and the signal amplitudes were measured by the electronics for the BPM system in the local control room. Thus, all of these errors were calibrated as the attenuation ratio of B, C and D to the A pickup electrode in all BPMs. The ratios of HER and LER are summarized as shown in Figure 3.

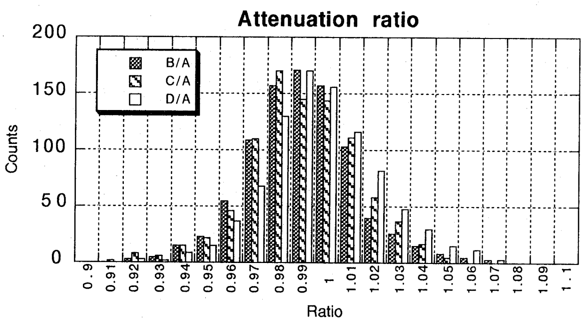

Figure 3: The distribution of attenuation ratio of transmission line together with electronics.

3 Measurements at commissioning

3.1 Observation of the first beam

In the KEKB ring, we did not prepare special beam diagnostics such as screen monitors to watch the position and profile of the beam at first commissioning. We substituted the BPM button signals and digitizing oscilloscopes for screen monitors. We observed the wave form of the first turn beam with 2 mV peak-to-peak by high speed digitizing oscilloscope even at beam intensities less than 0.3n coulomb, as shown in Figure 4.

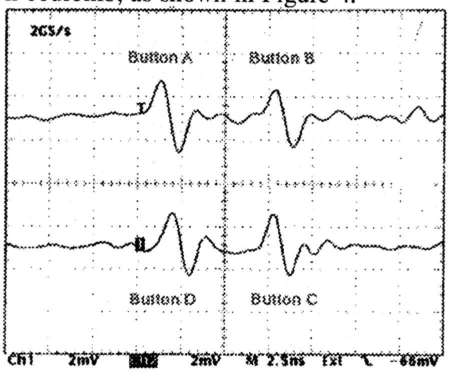

Figure 4: Display of wave forms of BPM buttons at first beam commissioning.
Upper are combined signals of buttons A and B.
Lower are combined signals of buttons C and D.

This method has a disadvantage of being troublesome due to adjustment of the triggering to capture beam signal, but has an advantage as follows: the number measuring points is great compared to probable numbers of screen monitors and the cost is very low. We could immediately find out the location of beam loss at the first commissioning.

3.2 Measurement of Closed Orbit Distortion

The signal processor consists of a super-heterodyne circuit, an 18-bit ADC and a Digital Signal Processor (DSP). In order to measure beams in any bunch configuration, a pickup frequency of 1018 MHz has been chosen, that is, twice the accelerating RF frequency. The super-heterodyne circuit converts the pickup frequency into an intermediate frequency (IF = 19 KHz). The IF signal is digitized directly by the ADC with 100 KHz sampling rate. The frequency spectra are calculated by a DSP with an N (= 32, 64, 128, 256, 512, 1024, 2048, 4096) points FFT (Fast Fourier Transformation) and the spectral peak is identified. When a low current beam less than 0.1 mA was stored in the HER for the first time, the closed orbit was measured by the BPM system. The first-time closed orbit is shown in Figure 5.

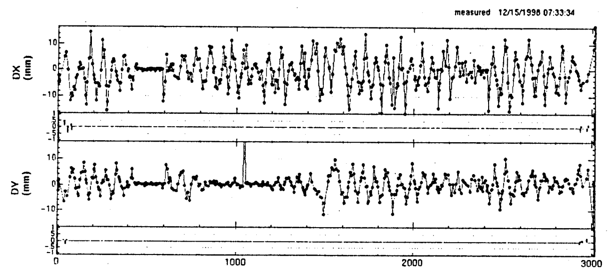

Figure 5: The first-measured closed orbit in the HER.

4 Position resolution

4.1 Spectrum data of FFT process at DSP

We can estimate position resolution by spectrum data of FFT analysis at DSP. Figure 6 shows the typical power spectrum distribution when the beam positions were measured by 2048 samples data.

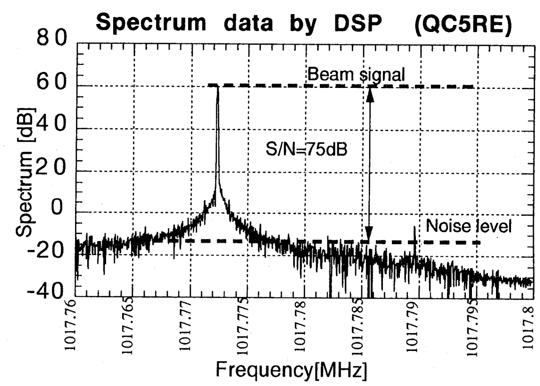

Figure 6: Spectrum data of FFT analysis at DSP

We could confirm an S/N ratio of about 75 dB by the difference between the peak spectrum and the noise level. This S/N ratio is a 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.

4.2 Three-BPM method [3]

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 10 sets of closed orbit data as shown in Figure 7. The resolution is relatively large compared to that in the preceding subsection for the orbit oscillations as described in Section 6. Position resolutions were confirmed within 10 μm at almost all BPMs.

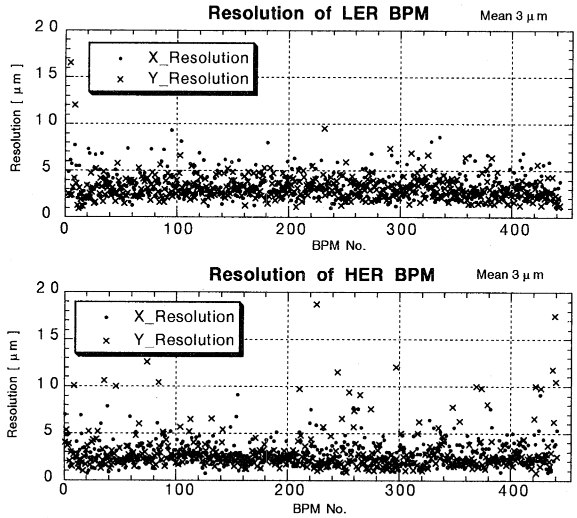

Figure 7: Distribution of all BPM resolutions in LER and HER

5 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 HOM. Then the beam positions have been corrected as shown in Table 2.

Table 2: Comparison of 1018 MHz and 508 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

6 Measurement of 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[4]. The local systems for BPMs were distributed to 20 local buildings around the KEKB ring. These local systems are normally processed at random, but new event code enable every local system to measure simultaneously. To get a series of beam position data, waveform records are added for every BPM. The sampling speed of these records is able to be changed by choice of parameters of the DSP. We could measure the frequency of oscillations of the beam position by FFT analysis of waveform records. Figure 8 shows the frequency spectrum of a BPM (QEAP in LER). Since this frequency spectrum appeared in all BPMs in the LER, we determined the oscillation source to be a 0.47 Hz component of the magnetic field of the nearby proton synchrotron.

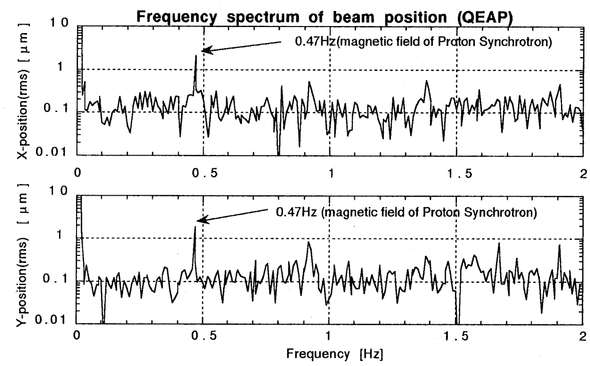

Figure 8: The frequency spectrum of beam position.

7 Conclusion

When all the above calibration errors are added in quadratic, the total error has a 66 μm absolute accuracy. The relative accuracy have also been measured to within 10 μm resolution by the three-BPM method. The BPM system has been operated regularly at a sampling period of about four seconds, but the measuring period can reduce as required down to 0.5 sec. The performance of the BPM system is well within specifications. But the orbit correction of KEKB has been unsuccessful to below 0.5 mm (rms). The cause has been undetermined so far.

Acknowledgment

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