BEAM-BASED CALIBRATION OF BEAM POSITION MONITORS AND MEASUREMENTS OF THE SEXTUPOLE MAGNET OFFSETS AT KEKB

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Abstract

KEKB is an asymmetric electron-positron collider. Both the electron and positron rings (the HER and the LER) consist of ~450 quadrupole magnets, each of which is accompanied by a beam position monitor (BPM)[1]. Each BPM offset is calibrated by finding the position of the closed orbit at that BPM which is insensitive to a change of the field strength of the adjacent quadrupole magnet. The calibration data are taken for different beam orbits and different field strength of the quadrupole magnet. The BPM offsets obtained by this method (`Quad-BPM´) have resulted in a significant improvement in closed orbit distortion (COD) for both rings. The same method is used to measure the offset of a sextupole magnet with respect to the magnetic center of the quadrupole field. The method is explained and the results of the calibration of the BPM and sextupole magnet offsets are presented in this paper.

1 MEASUREMENT SCHEME

When the beam passes through the j-th quadrupole magnet off-center, it receives a kick θ. The COD observed at the i-th BPM position is then given by the following equation:

$$x(s_i) = \frac{\sqrt{\beta(s_i)}\sqrt{\beta(s_j)}}{2\sin \pi\nu}\theta\cos\left[\pi\nu-\left|\phi(s_i)-\phi(s_j)\right|\right],$$

where $\beta(s_i)$, $\phi(s_i)$ and $\beta(s_j)$, $\phi(s_j)$ are the β-functions and the phase advances at the BPM and the quadrupole magnet, respectively. The kick that the beam receives from the quadrupole magnet is written as:

$$\theta = k\Delta x,$$

where k is the field gradient of the quadrupole magnet and Δx is the distance between the beam and the magnetic center. When the beam goes through the magnet center ($\Delta x=0$), θ becomes insensitive to a change of the quadrupole field strength. By changing the field strength, $d\theta/dk$ is obtained for a certain Δx. If the measurements are repeated for various Δx, the beam position that achieves $d\theta/dk=0$ can be found by fitting the data. Assuming that the difference of COD between the quadrupole magnet and its adjacent BPM is small, the BPM offsets can be represented by the beam positions which are insensitive to the field strength change.

2 MEASUREMENTS

A correction coil wound on each pole of a quadrupole magnet was used to change the strength of the quadrupole field. The current on the correction coil, I, was changed from -10 A to 10 A nominally, which corresponds to +/-1 % of the maximum quadrupole field strength. The orbital change, $\delta x(s_i)/\Delta I$ is monitored by the i-th BPM in the ring. In the measurement, the COD was changed 3 times using a couple of vertical or horizontal steering magnets, giving three $\delta x(s_i)/\Delta I$ values for the i-th BPM. Plotting $\delta x(s_i)/\Delta I$ of the i-th BPM against the reading of the BPM to be calibrated (the j-th BPM), the BPM reading where $\delta x(s_i)/\Delta I=0$ is obtained.

2.1 Analysis Example

The data used to calibrate the horizontal offset of #10 BPM are shown in this section as an example. It is a BPM adjacent to a quadrupole magnet named QA4LE, which is located ~100 m upstream of the IP in the HER.

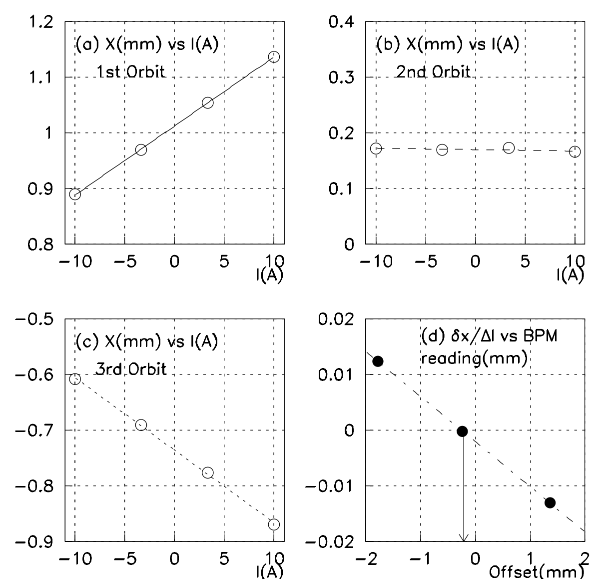

Figure 1: (a)~(c) show $\delta x(s_{14})$ measured by #14 BPM vs current on the quadrupole magnet QA4LE. (d) shows $\delta x(s_{14})/\Delta I$ vs #10 BPM. $\delta x(s_{14})/\Delta I=0$ when Δx=-0.25 mm.

Figs.1-(a)~(c) show the horizontal beam positions recorded by #14 BPM as a function of the current of the correction coils of QA4LE, for three different beam orbits. $\delta x(s_{14})/\Delta I$ is plotted against the readings of #10 BPM in Fig.1-(d). The beam position which gives $\delta x(s_{14})/\Delta I=0$ is the offset of this BPM when #14 BPM is used to monitor the orbital change. The orbital change due to ΔI can be monitored not only by #14 BPM but by any BPM in the ring. Fig. 2 shows the offset position observed by all BPMs when the QA4LE field strength is changed. The data are fitted by a Gaussian distribution and its central value, which corresponds to the horizontal offset of the #10 BPM, is obtained to be -0.25 mm.

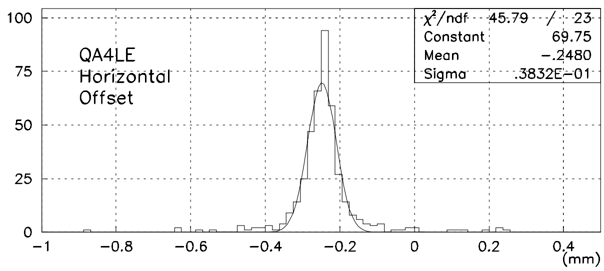

Figure 2: The beam position which is insensitive to a ΔI of the adjacent quadrupole magnet, QA4LE. The beam position change is monitored by every BPM in HER when QA4LE strength is changed.

2.2 BPM Offset Results

The vertical and horizontal offsets were obtained for 443 BPMs in the HER and 454 BPMs in the LER by this method. Figs.3-(a)-(d) show the offset distributions for the HER and the LER BPMs. The error of this method is estimated by measuring the same BPM offset twice with different beam orbits.

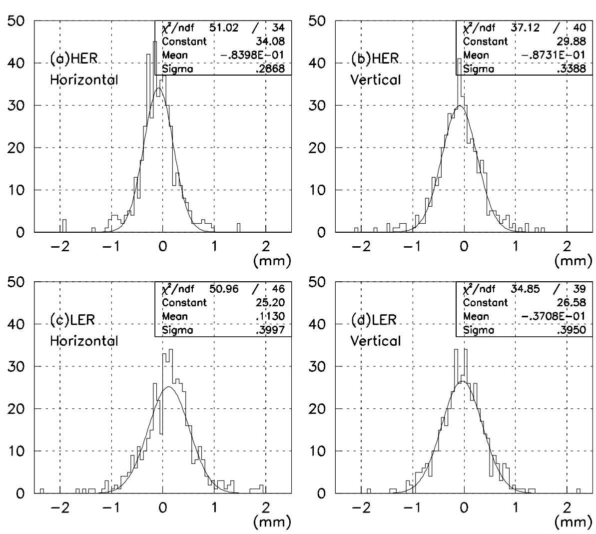

Figure 3: (a) and (b) show the HER BPM horizontal and vertical offsets. (c) and (d) show the LER BPM horizontal and vertical offsets. The standard deviations are ~0.3 mm for the HER BPMs and ~0.4 mm for the LER BPMS.

Fig. 4 shows the two measurements performed for 21 arbitrary BPMs. The data were taken on different days. The variation is ~0.07 mm in RMS, which is mainly introduced by the COD between the BPM and the center of the adjacent magnet. The error of the mechanical center of a magnet with respect to the field center had been measured[4] to be ~0.05 mm for the quadrupole magnets. Both errors are small compared to the RMS of the BPM offset distributions and therefore the BPM offset errors are not dominated by those errors.

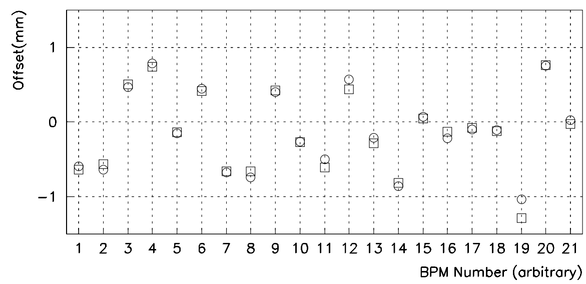

Figure 4: Measurement reproducibility. Open squares and circles correspond to different measurements for 21 BPMs.

The BPM offsets from the Quad-BPM method were installed in the database. The effects of the BPM offset correction can be seen in the beam orbit. Figs.5-(a) and (b) show the COD with and without the offset correction for the LER. The orbit is smoother, especially in the arc sections, after the offset correction is included. The spikes in Fig. 5-(b) indicate dead BPMs..

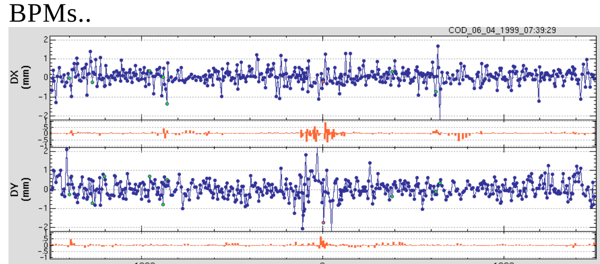

Figure 5-(a): The LER orbit before the offset correction.

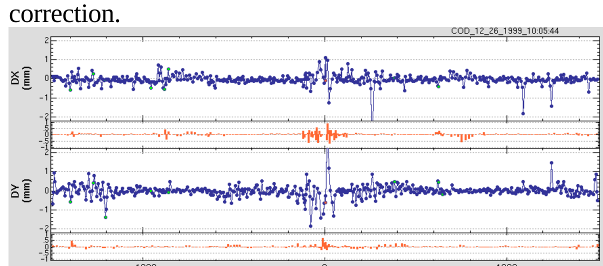

Figure 5-(b): The LER orbit after correcting for the BPM offsets. The horizontal and vertical orbits correspond to the upper and lower plots, respectively, in (a) and (b). The vertical scale is +/- 2 mm in all plots.

The BPM resolution is about a few microns when the beam current is greater than a few mA. Both orbits were recorded when the beam current satisfied this condition.

3 SEXTUPOLE MAGNET OFFSETS

The sextupole magnet center is estimated similarly. Instead of using the adjacent quadrupole magnet, the correction coils wound on 4 poles of the sextupole magnet are used to create quadrupole field. By changing the strength of the quadrupole field for different orbits, the magnet center with respect to the adjacent BPM center can be obtained in the same manner as discussed in the previous section. This is an easy and quick way to find a misaligned sextupole magnet. There is no need to turn off the main sextupole field and therefore no need to change the optics specifically to perform this measurement. The accuracy, however, is not expected to be as good as in the K-modulation method[2,3]. Figs.6-(a) and (b) show the horizontal and vertical offsets for the HER sextupole magnets obtained by this method. The analysis of the LER sextupole magnets is underway.

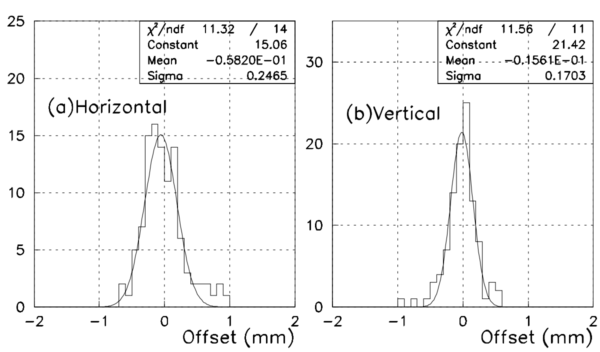

Figure 6: The offsets of the HER sextupole magnets, (a) horizontal and (b) vertical direction.

The position of each sextupole magnet can be adjusted both horizontally and vertically by a mover within +/- 1 mm. For the measurement, three movers in the HER were moved from their home positions by more than 200 µm. From the comparison between the mover position and the answer from the Quad-BPM analysis, one can estimate the error. Table 1 shows the comparison.

Table 1: Comparison between the mover positions and the Quad-BPM analysis results for three sextupole magnets in the HER.

Magnet Name	Mover (mm)	Quad-BPM (mm)	Δ (mm)
SF2ORE_1x	-0.30	-0.37	0.07
SD7TLE_1y	-0.62	-0.51	-0.11
SD7FLE_1y	+0.41	+0.53	-0.12

The RMS of the difference between the magnetic and the mechanical center of the sextupole magnets had been measured to be ~0.04 mm[4]. If we assume the BPM offset calibration error and the analysis error on the sextupole magnet to be ~0.07 mm and ~0.1 mm, the sextupole alignment error with respect to the quadrupole magnets can be obtained. The alignment error is roughly estimated to be ~0.2 mm in RMS horizontally and ~0.1 mm in RMS vertically. The errors should be compared with the magnet alignment data[5] when the study of the measurement accuracy and the analysis error is completed.

4 SUMMARY

The HER and LER BPM offsets with respect to the magnet center have been calibrated by the Quad-BPM method. The RMS of the offsets are found to be ~0.3 mm for the HER BPMs and ~0.4 mm for the LER BPMs. There were several BPMs with offsets greater than 1 mm. Subtraction of the offsets resulted in smoother orbits for both rings. The same method was applied to obtain the sextupole magnets in order to estimate the magnet alignment offsets. The correction coil was used to create the extra quadrupole field. The RMS of the alignment was estimated to be 0.1~0.2 mm. No HER sextupole magnet was found to be misaligned more than 1 mm.

REFERENCES

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