Beam-based Measurement of BPM Offsets

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1. Abstract

As presented in the previous report [1], we estimated "offsets" of beam position monitors (BPMs) installed in the SPring-8 storage ring by using high harmonic components of measured orbit data. To check the adequacy of the resulting "offsets", we performed beam-based measurements at some BPMs by perturbing the strength of a nearby quadrupole magnet and searching the most insensitive orbit against this perturbation [2]. In this report the results will be presented and compared with those obtained in Ref.[1].

2. Estimation of BPM Offsets Using COD

Our basic idea is that a part of BPM offsets can be estimated by summing Fourier components of the closed orbit distortion (COD) whose harmonic number is much higher than betatron tunes. In other words, proper BPM readouts should include little high harmonic components. Such high harmonic components of the BPM offsets should be subtracted in orbit corrections. The points of our approach can be summarized as follows:

- Real orbit distortions have dominant harmonic components around the betatron tune as seen from the following formula:

$$\frac{\mathrm{COD}(s)}{\sqrt{\beta(s)}} = \sum_{m=-\infty}^{\infty} \frac{\nu^2}{\nu^2 - m^2} f_m e^{im\phi(s)}$$

where

$$\phi(s) \equiv \int_0^s \frac{ds'}{\nu\beta(s')}$$

$$f_m \equiv \frac{1}{2\pi\nu} \sum_i \sqrt{\beta(s_i)}\theta_i e^{-im\phi(s_i)}$$

and $\beta(s)$ is the betatron function at the position s, ν is the betatron tune and θ_i is the kick due to errors (or due to steering magnets) at the position s_i.

- In the SPring-8 storage ring, the concept of "two-stage magnet alignment with common girders" was introduced [3] and main magnets were aligned carefully with a laser-alignment system [4]: quadrupole and sextupole magnets were aligned on a girder with the accuracy of about $15\mu m$ and girders were aligned so that the magnetic center of these magnets are connected as smoothly as possible. The relative accuracy of the alignment of girders was $50\mu m$ in the horizontal direction and $40\mu m$ in the vertical direction.

- Owing to this alignment scheme, random errors caused by misalignment of magnets almost cancel within a girder and the sensitivity of orbit distortions to errors reduces drastically in high harmonic component regions. Then, dominant harmonic components around the betatron tune are emphasized and the contribution of higher harmonic components coming from real orbit distortions becomes much smaller than that from spurious BPM offsets.

- In order to separate contributions coming from real orbit distortions and those from BPM offsets as clearly as possible, it is better to lower the betatron tune. This can be seen from the formula shown above. In the SPring-8 storage ring we used an optics with horizontal and vertical betatron tunes (ν_H, ν_V) = (21.35, 9.17). The "offsets" obtained in this way are shown in Fig.1 by solid circles. For comparison we also show the "offsets" obtained using other optics with tunes (51.23, 16.32) and (42.20, 15.32). As expected, the optics dependence of the "offsets" is very weak.

3. Beam-based Measurement

To check the adequacy of the resulting "offsets" shown in Fig.1, we measured a beam position at some BPMs by using a beam-based method with respect to the center of a nearby quadrupole magnet. This was carried out in the following way:

- Store the beam and perform orbit corrections. The COD must be reduced sufficiently, since the longitudinal distance between a target quadrupole magnet and a target BPM is (small but) finite and an error will come in if the orbit has large angle deviations.
- Change the strength of a target quadrupole magnet.
- Measure the orbit along the ring before and after the change of the quadrupole strength.
- Make a Fourier decomposition of the difference of these two orbit data to obtain the amplitude of

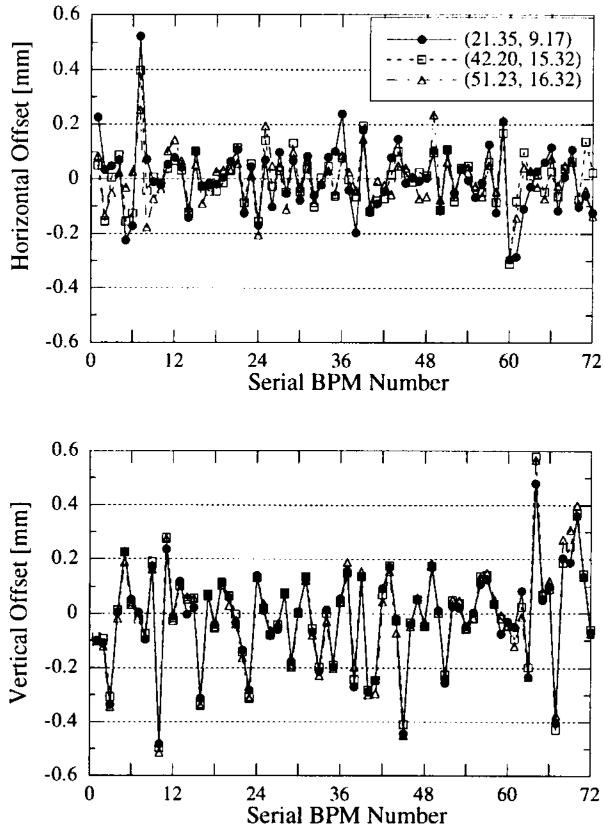

Fig. 1: BPM "offsets" for a quarter of the ring obtained from high harmonic components of COD in horizontal (above) and vertical (below) directions.

a generated betatron oscillation. The difference of the orbit is proportional to the distance δ between the beam position and a magnetic center of the target quadrupole magnet:

$$\frac{\Delta\mathrm{COD}(s)}{\sqrt{\beta(s)}} = -\frac{\Delta KL}{2\sin\pi\nu}\sqrt{\beta(s_0)}\delta\cos(\nu(\pi-|\phi(s)-\phi(s_0)|))$$

where ΔKL is the change of the integrated strength of the target quadrupole magnet with s_0 being its position.

- Give a single kick by using a suitable steering magnet and shift the orbit at the target quadrupole magnet so that the shifted orbit becomes parallel to the initial one.
- Change the strength of the target quadrupole magnet again, measure the difference of the orbit and calculate the amplitude of a generated betatron oscillation.
- Repeat the above procedures by changing the strength of the steering magnet so that the orbit sweeps a suitable range at the target quadrupole magnet.
- Plot the amplitude of the generated betatron oscillation as a function of a readout value of the target BPM. The offset defined with respect to the magnetic center of a nearby quadrupole magnet is then obtained from a BPM readout at the minimum point.

In Fig.2 we show an example data taken at the SPring-8 storage ring.

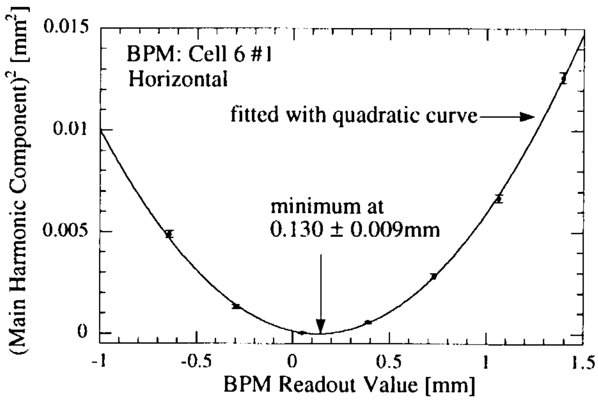

Fig. 2: An example of beam-based measurements of BPM offsets in the horizontal direction.

We note that though the technique used is essentially the same as those in Refs.[5, 6], our method is different in the point that a single kick is used instead of a local bump and a main harmonic component corresponding to the betatron tune is plotted against a BPM readout.

4. Comparison

In the SPring-8 storage ring, there are 480 quadrupole magnets and 40 of them in the missing-bend straight sections can change their strengths independently by using an auxiliary power supply system (by about 3~16%). Then, the offsets of 24 BPMs in these straight sections can be measured by the method described in the preceding section.

The results are shown in Fig.3 by solid circles [8]. For comparison, we also shown the "offsets" obtained from high harmonic Fourier components by open circles. We see that the agreement between open and solid circles is not perfect but satisfactory: both have very similar tendencies. The rms value of the difference is about $150\mu m$ in both horizontal and vertical directions. The reason for this difference is not clearly understood yet. Parts of the difference will come from some components of the BPM offsets that were not taken into account in obtaining solid circles or from some systematic errors.

We note that an important thing in orbit corrections is not to reduce BPM readout values rigorously but to make a smooth orbit: we do not need to pass the beam through exact magnetic centers of quadrupole magnets, since random error kicks

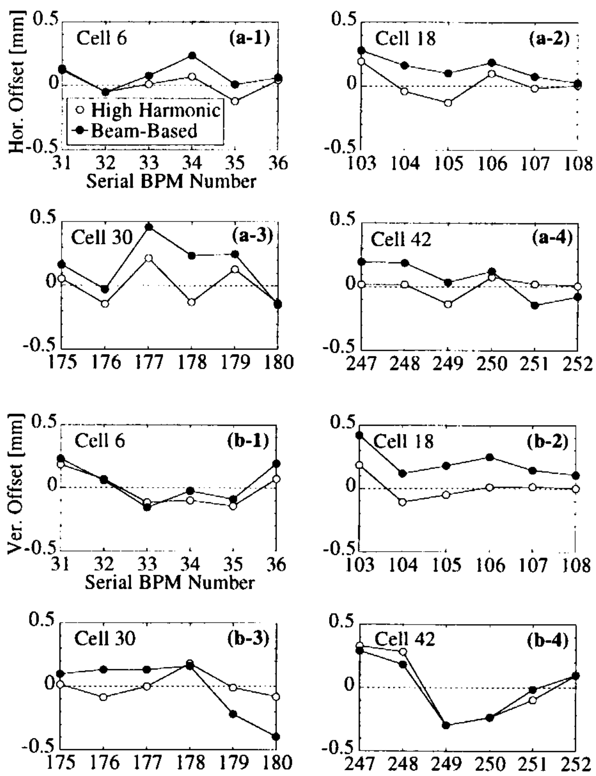

Fig. 3: Comparison of BPM offsets obtained from high harmonic components of COD (open circles) and from beam-based measurements (solid circles). Figs.(a-1,2,3,4) are for the horizontal direction and Figs.(b-1,2,3,4) for the vertical direction. One figure corresponds to one unit cell. Estimated errors are smaller than the marker size.

due to misalignment within a common girder cancel with each other [3]. By using the BPM "offsets" shown in Fig.1 we could reduce COD and the leakage of the dispersion function into straight sections. The strengths of steering magnets needed in these corrections were not strong. We also note that the coupling ratio of the horizontal and vertical betatron oscillations had been deduced and found to be very small [7], being much less than 1% without corrections by skew quadrupole magnets. All of these facts indicate that the BPM "offsets" shown in Fig.1 worked well in orbit corrections.

References

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[8] Since the origin of a BPM readout is defined to be the magnetic center of a nearby sextupole magnet, the origin of the offsets obtained by the beam-based measurement has been shifted from a magnetic center of a nearby quadrupole magnet to that of a nearby sextupole magnet by using the alignment data.