A PRELIMINARY EXPERIMENT FOR THE BEAM BASED CALIBRATION OF BEAM POSITION MONITORS AT BEPC

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Abstract

By varying an individual quadrupole magnet and observing the effect on the orbit, the offset of the adjacent beam position monitor (BPM) with respect to the magnetic center of that quadrupole magnet can be determined. At BEPC, 4 BPM offsets in the vertical plane were measured by using this beam-based method. The measurement results will be shown in this paper.

1 GENERAL DESCRIPTION

The properties of an electron positron collider are mainly determined by the quadrupole magnets. The highest luminosity and best performances are obtained when the beam is well centered in the quadrupole magnets. The quadrupole magnets of the Beijing Electron-Positron Collider (BEPC) are aligned with an accuracy of better than 0.2 mm rms to form the absolute closed orbit reference. Thirty-two button-type beam position monitors (BPMs) are installed in the BEPC storage ring close to the quadrupole magnets.

In order to measure and correct the beam orbit to the reference orbit, it is necessary to know the relative offset between the beam position monitor's electric center and the adjacent quadrupole's magnetic center. Despite careful alignment and electric calibration of the beam position monitors, there can still be residual offsets. These residual offsets can be measured by a beam-based alignment technique.

Figure 1 shows the principle of the beam-based calibration. When the integrated strength of a quadrupole magnet at the location s_0 of the storage ring is changed by Δkl, the beam obtains a local angular kick $\Delta y'(s_0) = \Delta kl y(s_0)$, where $y(s_0)$ is the transverse beam position displacement or offset in the quadrupole magnet. This angular kick consequently changes the beam orbit at any location s in the ring by [1]

$$\Delta y(s) = \frac{\sqrt{\beta(s_0)\beta(s)}}{2\sin(\pi\nu)}\cos[|\varphi(s)-\varphi(s_0)| - \pi\nu]\cdot\Delta y'(s_0)$$

where $\beta(s_0)$, $\varphi(s_0)$ and $\beta(s)$, $\varphi(s)$ are the betatron function, the betatron phase advance at the location of the quadrupole magnet and the observation point respectively, ν is the betatron tune.

From the above equation, one can know that the change in the beam orbit $\Delta y(s)$ from a change in the quadrupole strength is a linear function of the beam position displacement in the quadrupole magnet $y(s_0)$. if the beam goes though the center of the quadrupole magnet then the change in the strength of that quadrupole will have no effect on the beam orbit.

Because the change in the quadrupole strength disturbs the whole beam orbit in the ring, one can select an auxiliary BPM to monitor the orbit change at any position where the betatron phase advance is adequate. It can be seen from the equation that the betatron phase advance between the quadrupole magnet (BPM under test) and the observation point (auxiliary BPM) should be selected in such a way that the absolute value of the cosine term in the equation is large so that the orbit change at the observation point can be detected easily.

2 BBA EXPERIMENT

We tried to calibrate beam position monitors with respect to the magnetic center of the adjacent quadrupole magnets as early as in 1991. The position resolution of the BPM system at that time was not high enough for the beam-based alignment experiment and the results of the experiment were not satisfied.

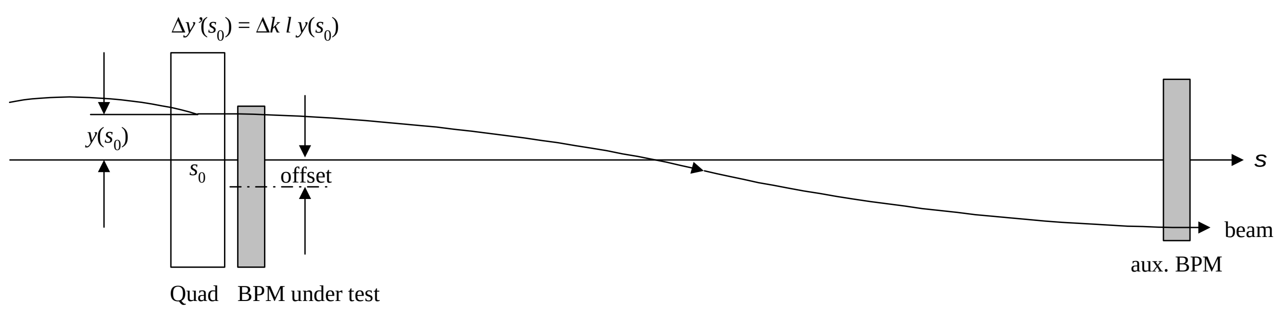

Figure 1: Principle of the beam-based alignment

In 1996 the BPM system was upgraded and the averaged position resolution of 32 beam position monitors in the BEPC storage ring can reach to 10 μm rms [2]. With this upgraded system we measured the offsets of some beam position monitors again at the end of 1998 and at the beginning of 1999.

The BEPC storage ring is the four-fold symmetry. There are 17 quadrupole magnets labeled from Q1 to Q17 in each quadrant of the ring. All quadrupole magnets are powered with one power converter for at least two quadrupole magnets. At present, only Q1 and Q2 quadrupole magnets in the straight sections to both sides of the two interaction points (IP) of the ring are equipped with the additional windings which can be power by an individual power converter. The strength of other quadrupole magnets cannot be changed separately. Out of 68 quadrupole magnets, 32 have a beam position monitor close to it. Because there are no beam position monitors close to Q2 quadrupole magnets, we can only select BPM16, BPM17, BPM32 and BPM1 for the beam-based alignment experiment. The 4 beam position monitors are located close to the corresponding Q1 quadrupole magnets as shown in Figure 2. Unfortunately, these beam position monitors have a relative worse measurement reproducibility compared with other monitors in the ring due to their mechanical structure [2].

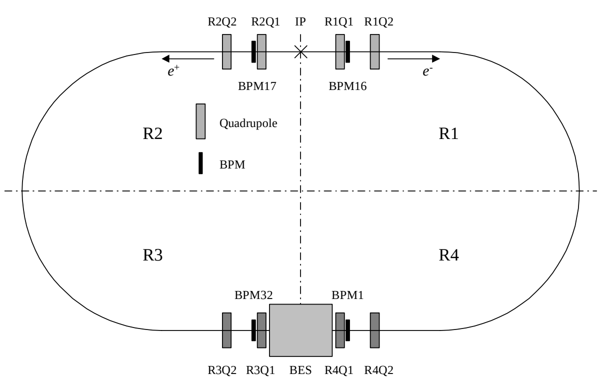

Figure 2: Locations of the beam position monitors and the quadrupole magnets in the BEPC storage ring for the preliminary beam-based alignment experiment

The Q1 is a vertically focusing quadrupole magnet. There is a large vertical β-function at the location of the Q1. The relative change of the beam orbit is easily to be detected in the vertical plane due to the change of the strength in the Q1. As the first step of the experiment we decided to measure the vertical offsets of the selected 4 beam position monitors.

The experiment was performed in the following way. The vertical beam position in a Q1 quadrupole magnet is changed step by step using the most effective corrector magnet to maximize the orbit change in the Q1 quadrupole magnet. At each step, the excitation current in the additional windings of that Q1 quadrupole magnet is changed between 0 A and 2 A, and the resulting variation of the vertical beam position is recorded by the auxiliary beam position monitor at the location with a proper betatron phase advance.

3 EXPERIMENTAL RESULTS

Figures 3, 4, 5 and 6 plot the vertical beam positions measured by beam position monitors BPM16, BPM17, BPM32 and BPM1 versus the variations of the vertical beam position induced by changing the strengths of quadrupole magnets R1Q1, R2Q1, R3Q1 and R4Q1, respectively. The square-type markers in each figure depict the measured data points and the solid line is the least square fit of those measured data points to a line.

In principle, one could measure two points and compute the linear function. But the noise of the BPM restricts the measurement accuracy. By increasing the measurement points, one can obtain an accurate measurement result.

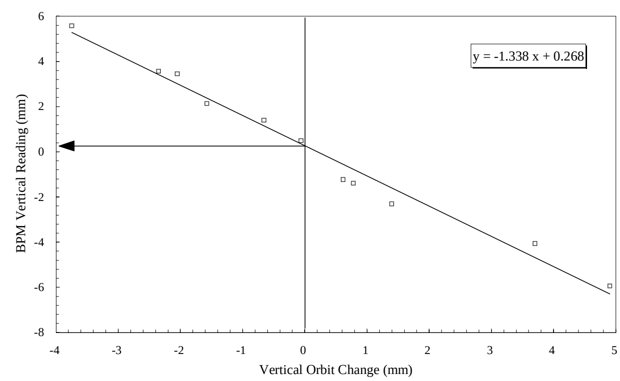

Figure 3: The vertical reading of the BPM16 versus the vertical beam position variation induced by changing the strength of the R1Q1

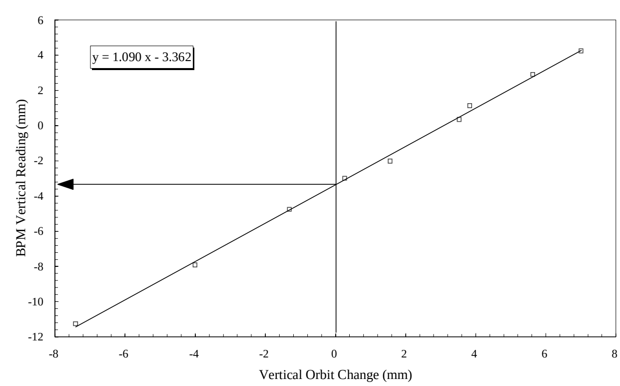

Figure 4: The vertical reading of the BPM17 versus the vertical beam position variation induced by changing the strength of the R2Q1

If the beam is off center in the Q1 quadrupole magnet, the relative change of the beam orbit depends linearly on the change of the Q1 quadrupole strength and on the beam displacement in the Q1 quadrupole magnet. Obviously, if the relative beam orbit change is zero, the beam is centered in the Q1 quadrupole magnet. The reading of the beam position monitor closed to that Q1 quadrupole magnet should be zero. Otherwise the non-zero reading of the beam position monitor gives the relative offset we want to measure.

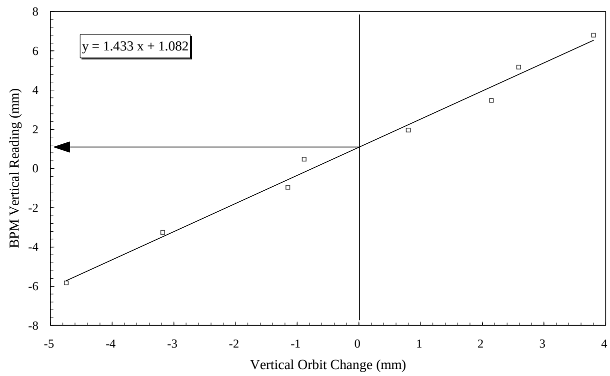

Figure 5: The vertical reading of the BPM32 versus the vertical beam position variation induced by changing the strength of the R3Q1

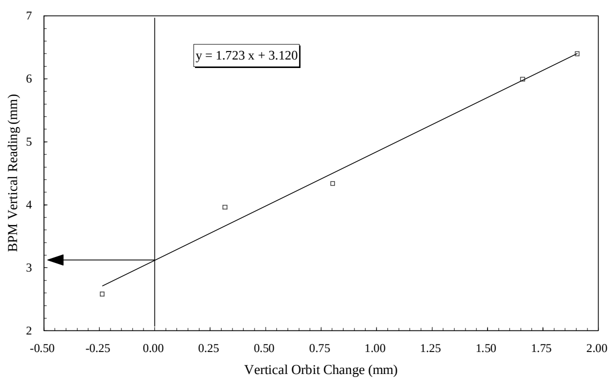

Figure 6: The vertical reading of the BPM1 versus the vertical beam position variation induced by changing the strength of the R4Q1

The linear equations displayed in Figures 3-6 give the results of the fit. The coefficient of the zero order term in the right hand of the equation determines the relative BPM offset. The coefficient of the first order term gives the slope value of the line, which represents the sensitivity of the orbit change to the beam position in the changed quadrupole magnets. The BPM offsets from the fit are 0.27 mm, -3.36 mm, 1.08 mm and 3.12 mm for BPM16, BPM17, BPM32 and BPM1, respectively.

The measurement errors on the BPM offsets are between 90 μm rms and 200 μm rms. The quite large errors are mainly caused by the noise of the wide band signal processing electronics in the beam position monitoring system.

4 POTENTIAL IMPROVEMENTS

In order to measure the relative offsets for other 28 beam position monitors in the BEPC storage ring, we need to add the additional windings for each of the quadrupole magnets. This work is under consideration. A prototype of the windings on the spare quadrupole magnet has passed the test. The multiplex system can be economically adapted by using only one power converter for the additional windings of all quadrupole magnets.

To increase the accuracy of the measurement, the resolution of the beam position monitoring system should be further improved. We plan to use the narrow band signal processing electronics to replace the current wide band electronics in the system.

To reduce the time and the manpower for the BPM offset measurement, the automation of the measurement is also important. The present measurement is performed manually. A computer program is preparing for the measurement so that the BPM offsets can be measured frequently within a reasonable time.

As a side effect the additional windings of the quadrupole magnets and their power converter will be used to measure the β-functions in those quadrupole magnets in conjunction with the betatron tune measurement system of the BEPC storage ring.

5 CONCLUSION

The technique of the beam-based alignment is widely used in particle accelerators. A preliminary experiment with this technique was carried out at the BEPC storage ring. We measured the vertical offsets of 4 beam position monitors with respect to the magnetic center of the quadrupole magnets. The errors between 90 μm rms and 200 μm rms are given by fitting a linear function to the measured data. These measured BPM offsets ware stored in the control computer and taken into account by the beam position measurement system during the BEPC run 1999/2000. Since the maximum value of the measured BPM offsets is as large as unexpected several millimeters, the absolute measurement accuracy of the beam position monitoring system can be significantly improved if all BPM offsets are determined by the beam-based alignment technique.

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