Methods of measurement for the beam-based alignment system in HLS

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Abstract The beam-based alignment system is given in HLS (Hefei Light Source), in which a switchable shunt resistor was installed on quadrupole to bypass a small percentage of the magnet current. The system can measure BPM-to-quadrupole offset which can be used to position the beam in the magnetic center of quadrupoles. In measurement, some methods (linear fitting with single corrector, parabola fitting with single corrector, linear fitting with local bump, and parabola fitting with local bump) are used. These measurement results are given, and compared among the methods mentioned above.

Key words Beam-based alignment, BPM-to-quadrupole offset, Linear fitting, Parabola fitting, Local bump

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1 Introduction

It is expected to have the beam orbit pass as close as possible to the center of the quadrupole magnets in a storage ring for many reasons. If the beam orbit passes exactly the quadrupole's center, the quadrupoles will not bring any orbit distortion. Beam Position Monitors (BPM) typically abuts on quadrupole magnets[1]. In order to know the precise center of the quadrupole, it is necessary to have a direct measurement of the relative offset between the quadrupole's magnetic center and the BPM's electrical center. Knowing these BPM-to-quadrupole offsets, beam orbit can be corrected to the magnetic center of the quadrupoles by the orbit correction system. At HLS, a beam based alignment system has been developed to measure the offsets of 24 BPMs in the storage ring. Four different measurement methods have been put in practice.

2 Theory

One can vary the beam orbit by changing the strength of an individual quadrupole at location $\overline{s}$ [2]. The variation of beam orbit depends on how far the beam orbit is from the magnetic center of the quadrupole. Assuming that the change of the quadrupole strength is very small, the effect on the transverse orbit at a location s is[3]

$$\Delta x(s) = -\frac{ec\Delta k \bullet u \bullet l}{E_0} \times \frac{\sqrt{\beta(\overline{s})}\sqrt{\beta(s)}}{2\sin(\pi v)} \times \cos[\phi(s) - \phi(\overline{s}) - \pi v] \tag{1}$$

where Δk is the integrated strength variation of the quadrupole, u is the beam orbit position in the quadrupole, l is the length of the quadrupole, $\beta(\overline{s})$ and $\beta(s)$ is the beta functions at the location of the quadrupole and the observation point, respectively, E_0 is the nominal energy, v is the betatron tune, and $\phi(\overline{s})$ and $\phi(s)$ are the betatron phases at the location of the quadrupole and the observation point, respectively.

The variation of the beam orbit is proportional to the beam position at the quadrupole if the quadrupole's strength is changed. When the orbit passes through the magnetic center of the quadrupole, a change of the quadrupole's strength will not affect the beam orbit.

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3 Constitution of hardware

For every quadrupole, we have installed a shunt resistor[4] which can bypass a small percentage of the magnet current under control (Fig.1). The shunt resistor is connected to a solid-state relay array. Relay control logic allows one to shunt one single quadrupole's current with the shunt resistor. Thus, quadrupole strength can be changed a certain value when the shunt resistor is working.

There are 24 BPMs that can be modulated by this means in the switchable shunt resistor system. In order to make the electronic beam in the storage ring work properly, the shunt resister cannot shunt too much current from quadrupole power supply. Therefore, the shunt resister is chosen to have a resistance of 1.5Ω, which can make a small change of quadrupole's strength about 1.0%~1.5%[4].

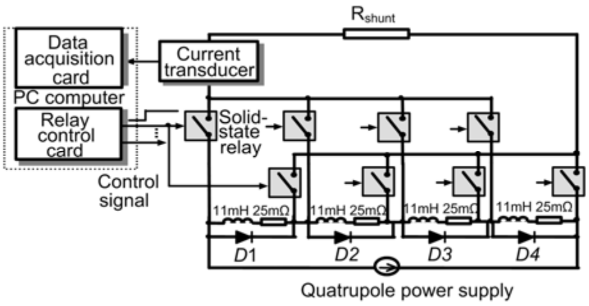

Fig.1 Block diagram of the switchable shunt resistor system.

4 Experimental technique

There are two ways to alter the beam orbit in the quadrupole. One is to use the corrector magnets around the quadrupoles to establish local bump. The other is to alter a single corrector magnet.

Corrector magnets are installed in the HLS storage ring besides the quadrupoles. Quadrupoles are installed in pairs, and there is one corrector magnet installed on each side of the quadrupole pair. Using corrector magnets, with the assistance of the quadrupole itself, one can make a local bump at the quadrupole. A system has already been developed to make local bump in any quadrupole.

With local bump, the beam orbit in the quadrupole can be altered to different position vertically or horizontally. But only a part of the beam orbit is changed when applying local bump. There is another way to get beam orbit altered. By changing one single corrector magnet one can also alter the beam orbit position in the specific quadrupole. The magnitude of beam orbit change according to the corrector magnet variation depends on the phase advance between the corrector magnet and the quadrupole. A test procedure was applied in the HLS storage ring to find out the corrector magnet which can get adequate beam orbit change for the specific quadrupole.

Changing single corrector magnet will influence the orbit in the whole storage ring, but it is more convenient than local bump in practice. It can be done by control power supply of corrector magnet only.

One can read the beam orbit position in the quadrupole from the adjacent BPM. This reading result u' contains two parts: beam orbit position with respect to the quadrupole's magnetic center u and the BPM-to-quadrupole offset u_{off} that has been mentioned above (shown in Fig.2). Thus Eq.(1) can be simplified to

$$\Delta x(s) = A(u' - u_{\mathrm{off}}) \tag{2}$$

where A is a constant for a specific observation point. Changing the beam orbit in the quadrupole to a series of different positions, one can read a series of results from BPM at the observation point respectively.

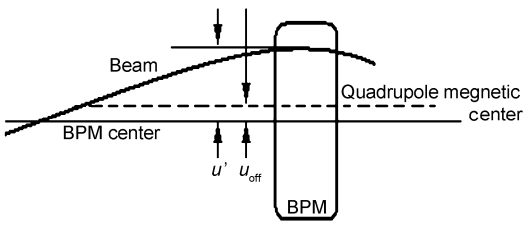

Fig.2 BPM-to-quadrupole offset.

To process the result data, there are two algorithms: linear fitting and parabola fitting. Using linear fitting, one can obtain the value of u_{off} without knowing the constant A which depends on beta functions, tune and phase advance, as well as the change in quadrupole strength precisely.

Parabola fitting can be used to process the result data, and it can also be used to search for the position that minimizes the orbit distortion. There are 24 BPMs involved in this process. They are installed by the quadrupoles. Using single corrector magnet or local bump, one can search and determine the position that minimizes the orbit distortion. In order to find the position that brings a minimum orbit distortion, the above step is repeated several times. The merit function[5] for the search is

$$f(u') = \sum_{n=1}^{24} (\Delta x_n)^2 \tag{3}$$

where n is the BPM number and Δx_n is the orbit variation. From Eq.(2), one can see that the merit function will be shaped like a parabola. The parabola meets its minimum value when the beam orbit meets the quadrupole's magnetic center. One can determine the quadrupole's magnetic center from Eq.(3). The following section will give the measurement results.

5 Result

Fig.3 shows the experimental results for quadrupole BQ5S in the HLS storage ring. First, local bump is applied to change beam position for the measurement process. The linear fitting result is given in Fig.3(a), and the computer simulation result is given in Fig.3(b). The parabola fitting result is given in Fig.3(c). Then single corrector is used in changing beam position in the quadrupole. The results are shown in Fig.3(d),(e),(f).

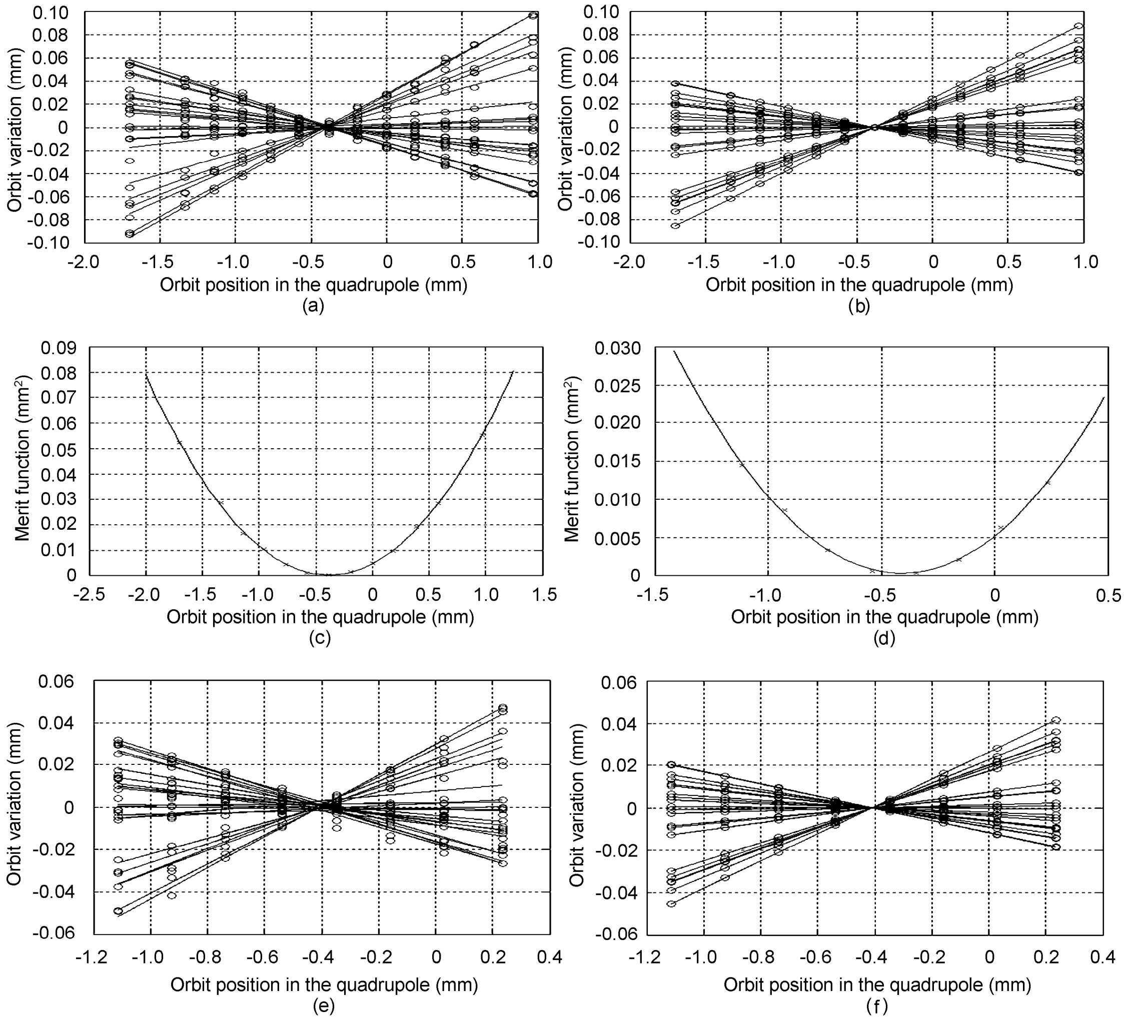

Fig.3 BBA result on quadrupole BQ5S at HLS.
(a) Linear fitting with local bump; (b) Computer simulation result with local bump; (c) Parabola fitting with local bump;(d) Parabola fitting with single corrector; (e) Linear fitting with single corrector; (f) Computer simulation result with single corrector.

There are 24 BPMs involved in data acquisition. Therefore, 24 different curves can be found in Fig.3(a). From Eq.(1), the slope of the curve depends on the phase advance from the corresponding BPM to the quadrupole. Some BPM has a very small absolute value of slope. It means that the corresponding beam orbit variation in the BPM near the quadrupole which strength was changed will be very small. Considering the precision of BPM, the measurement result of orbit variation in such BPM contains large relative system error. Therefore, these measurement results should be omitted when calculating the BPM-to-quadrupole offset.

Computer simulation result matches the experimental results perfectly. The lattice parameters are fed to a program running under MAD8 which will calculate the phase advance, beta-function value, etc. at every quadrupole. From these data one can simulate the BBA process. Fig.3(b) and Fig.3(f) show the simulation result. It is very convenient and fast to get the result of simulation. Thus, if this result is calculated first, and then the "bad" BPMs, which are less sensitive to the strength change of the target quadrupole, is picked out, one will avoid the large relative system error caused by these "bad" BPMs. And, it will also save much time.

Results of parabola fitting are shown in Fig.3(c) and Fig.3(d), and results of linear fitting are shown in Fig.3(a) and Fig.3(e). Both of the two fitting algorithms will bring fitting error. Parabola fitting error(x-coordinate) of Fig.3(c) is 0.0097 mm, and for Fig.3(d) it is 0.0080 mm. Fitting error can be regarded as a system error. Linear fitting error of different BPMs is typically in the range of [0.005, 0.012] mm. "Bad" BPMs have very large linear fitting error, thus they are not considered.

The BPM-to-quadrupole offset read from Fig.3(e) is -0.46mm. If omitting "bad" BPMs, the result is -0.40mm. One can see that these BPMs' measurement data affect the ultimate result evidently. The offset read from Fig.3(a) is -0.40mm, and -0.38mm if omitting "bad" BPMs.

Comparing the results of different measurement methods and data processing methods, one can choose a superior combination of them. It is the way one processes the result data whether using linear fitting or using parabola fitting. However, parabola fitting can reduce the system error effect on the final result of the BPM-to-quadrupole offset. It is more convenient to use single corrector to get the orbit change in the quadrupole than to use local bump. Thus, single corrector and parabola fitting are selected for the future beam-based alignment at HLS.

6 Conclusion

The result of the measurement for beam-based alignment shows that these methods are all effective and reliable. One can choose one of them which are faster and easier to put in practice. It is important to get rid of the effect of the error brought by the BPMs less sensitive to the strength change of the target quadrupole. It is better to choose several BPMs that have appropriate phase advances for BBA measurement. Increasing the number of points also help to mitigate the measurement error. Using single corrector magnet will allow the whole measurement process to be performed automatically.

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References

1 Wang J H, Liu Z P, Sun B G, *et al*. The updated BPM system of HLS, Proceedings of the 2001 Particle Accelerator Conference, Chicago, 2001, 2320-2322

2 Jin Y M. Physics of electronic storage ring, University of Sci. & Tech. of China Press, 1994

3 Sands M. The physics of electron storage rings, An introduction, SLAC-121, UC-28(ACC)

4 Sun B G, He D H, Lu P, *et al*. High Power Laser and Particle Beams, 2001, **13**(6): 777-780

5 Portmann G, Robin D, Schachinger L. Automated beam based alignment of the ALS quadrupoles, LBL-36434, LSGN-209, 1995