ORBIT STABILIZATION FOR THE HLS-II STORAGE RING*

Wei Xu, Ke Xuan, Haiyan Zhang, Jingyi Li†
National Synchrotron Radiation Laboratory,
University of Science and Technology of China, Hefei, Anhui 230029, China

Abstract

Hefei Light Source has successfully completed a major upgrade project, which greatly improves the light source performance. As one of the most important criteria, the stability of the beam orbit in the storage ring can greatly influence the overall performance of the light source. In this paper we present our efforts on stabilizing the beam orbit during the commissioning of the HLS-II storage ring. We optimized the performance of the power supplies of the ring corrector magnets. The target beam orbit is obtained by measuring the center of the quadrupole magnets using the beam-based alignment method. We also developed a multi-functional orbit feedback system to keep the beam moving on the golden orbit. With these measures, the beam orbit gets more stable than ten percent of the beam size at the light source points.

INTRODUCTION

For a synchrotron light source, the closed orbit distortion of a electron beam circulating in the storage ring can severely impact its performance. The deviation of the beam orbit can affect the beam dynamics, including causing betatron tune shift, increasing nonlinear effects and decreasing the beam lifetime. What is more, the beam orbit variation can cause the dithering of the photon beams transmitted to the experimental stations, causing the reduction of the photon flux, increase of the data noise, decrease the reliability and thus the accuracy of the experimental results. Generally speaking, the orbit stability at a source point should be better than 10% of the beam size at this point. Hefei Light Source (HLS) has recently successfully completed a major upgrade project (named HLS-II) and now is open to the users [1]. Table 1 shows the beam size at the source points of the HLS-II storage ring. The horizontal beam orbit stability should be better than 40 μm and the vertical better than 8 μm in order to provide stable synchrotron light for user experiments. In this paper, we present our efforts on stabilizing the beam orbit during the commissioning of the HLS-II storage ring by (1) optimizing the performance of the power supplies of the ring corrector magnets including the static stability and dynamic feature, (2) targeting the beam orbit by measuring the center of the quadrupole magnets using the beam-based alignment method, and (3) developing a multi-functional orbit feedback system to keep the electron beam moving on the targeted beam orbit.

Table 1: Size of the electron beam at the source points of the HLS-II storage ring.

Light Source	σ_x (μm)	σ_y (μm)
QPU	542	83
U92	820	84
WIG	437	91
IVU	437	91
EPU	621	83

OPTIMIZATION OF CORRECTOR POWER SUPPLIES

In a storage ring, the electron beam circulates along a close orbit under the guidance of the main magnets, including the dipole magnets, quadrupole magnets and sextupole magnets. However the beam orbit is always distorted by various reasons such as the field error of the magnets, the misalignment and mechanical vibration of the machine. To eliminate those effects and stabilize the beam orbit, magnets used for orbit correction are commonly introduced to modern accelerators, which are called orbit correctors. The orbit correctors are essentially small bending magnets providing weak kicks on the electron beam. Different from the main magnets, the correctors continuously change the magnetic fields by varying the exciting currents during the operation of the storage ring to maintain a stable beam orbit. In the HLS-II storage ring, there are 32 sets of correctors which are combined with the 32 sextupoles in order to save installation space for the straight sections. Those correctors together with the 32 sets of beam position monitors (BPMs) are used to build the orbit feedback system of the HLS-II storage ring. The performance of the corrector power supplies influence the beam orbit from two aspects: (1) the jitter of the power supplies can directly cause the variation of the beam orbit; (2) the consistency of the field changes of all correctors determines the performance of the feedback system. Therefore the improvement of the power supplies includes their static stability and dynamic features.

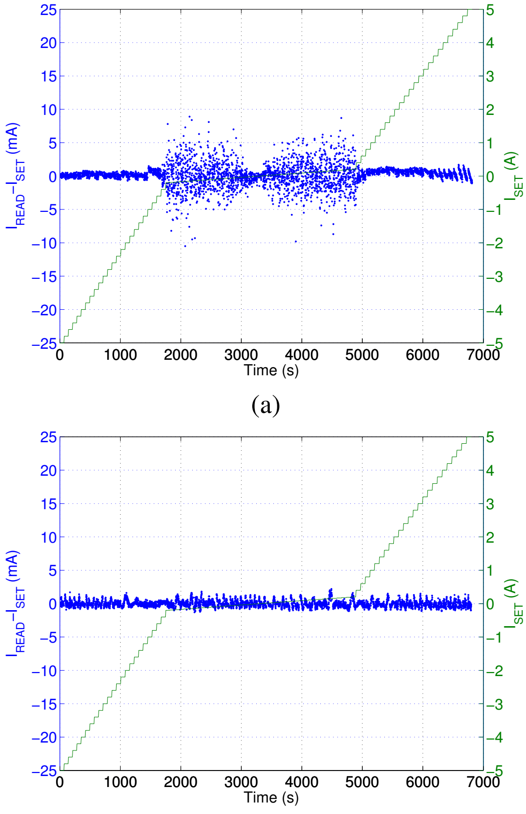
Static Stability

In order to maintain the beam orbit, the corrector magnets work with a certain range of magnetic fields. The corrector power supplies should provide stable exciting current within this range. We simulated the orbit distortion with field errors of all correctors. The result shows that the current error should be less than 2 mA (rms) so that the induced orbit distortion would be smaller that 10% of the beam sizes listed in Table 1. To meet this requirement, we measured the stability of the power supplies and did the optimization accordingly. Figure 1 shows the current stability measurement of one corrector before and after the optimization. We can see

---

* Work supported by Fundamental Research Funds for the Central Universities of China (WK2310000048) and National Natural Science Foundation of China (No. 11375177).

† jingyili@ustc.edu.cn



(a)

(b)

Figure 1: Measurement of the current stability of one corrector power supply: (a) Measurement before the optimization and (b) Measurement after the optimization.

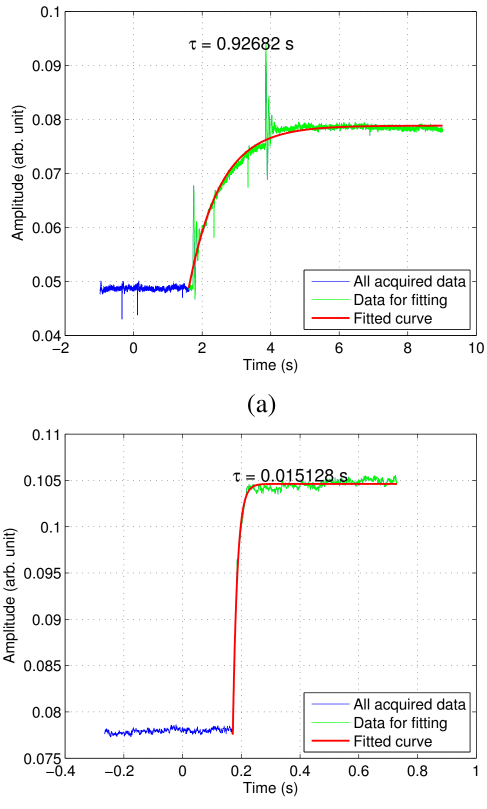
that the peak-to-peak amplitude of the difference between the current set and read back values is as high as ±10 mA when the current is around 0. After the effective optimization of the digital switching power supplies, the current errors (peak-to-peak) of all correctors are within ±2 mA.

Dynamic Features

The exciting currents of the correctors change from time to time when the orbit feedback is woking. From the principle of a basic RL circuit, we know that the current change obeys the following formula:

$$I(t) = I_1 - (I_1 - I_0)\mathrm{e}^{-\frac{t}{\tau}} = I_1 - \Delta I \cdot \mathrm{e}^{-\frac{t}{\tau}}, \qquad (1)$$

where I_0 and I_1 are the start current and target current, respectively.τ is the time constant $\tau = \frac{L}{R}$, where L and R are the inductance and resistance of the circuit. The current change obeys the same rule which depends on the time constant, no matter what the start current is and how much the current is going to change. The current approaches the set value over time —when t equals 3τ, the difference between the actual current and the target current is only $0.05\Delta I$. As the time constant determines the current change rate, we need to shorten the time constant of the magnet exciting circuit in order to perform a faster orbit feedback. Furthermore, the current change should be as smooth as possible to avoid disturbance to the beam orbit. Figure 2(a) shows the dynamic performance of the corrector power supply before the optimizing. The time constant is almost 1 second which means the orbit feedback should act no faster than 3 times per second. Besides, the current change curve has too much noise on it which can obviously cause additional orbit distortion. With the help from the power supply manufacturer, we improved the PS performance, see Figure 2(b). After the optimization, the time constant is greatly reduced to only 15 ms (3τ is less than 50 ms) which means the feedback can act at a frequency as high as 20 Hz. Moreover, the current change curve gets much cleaner than before.



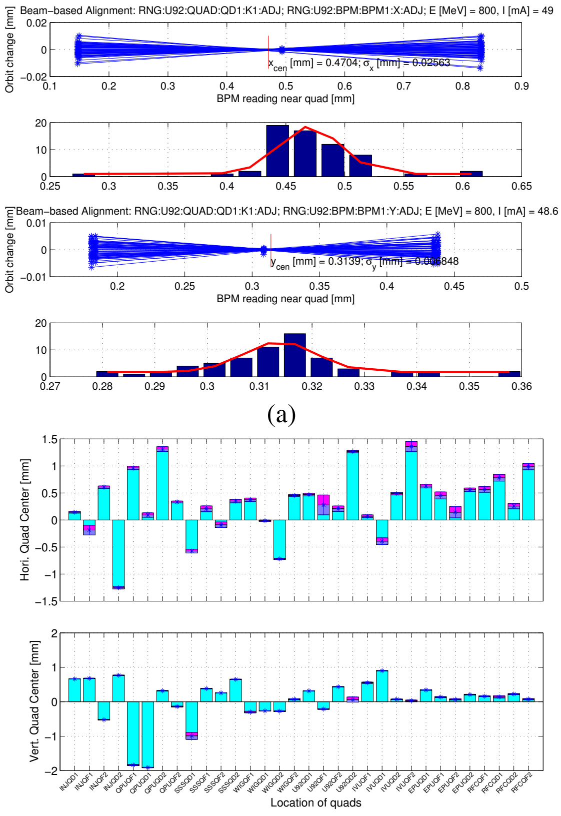
(a)

(b)

Figure 2: The dynamic feature of the corrector power supplies during the current change: (a) before optimization and (b) after optimization. The current change curve is fitted according to Eq. (1).

MEASUREMENT OF BEAM GOLDEN ORBIT

The electron beam circulating in the storage ring on an ideal beam orbit (also called golden orbit) should traverse the centers of the quadrupole magnets. For various reasons such as the machining error and misalignment, the quadrupole centers often deviate from the BPM electrical centers. The quadrupole centers can be measured using the beam-based alignment method (BBA) [2]. The basic principle of the BBA method is to measure the location of the electron beam in the quadrupole which has least impact on the beam orbit around the storage ring when the focusing strength of this quadrupole varies. In the measurement, we



(a)

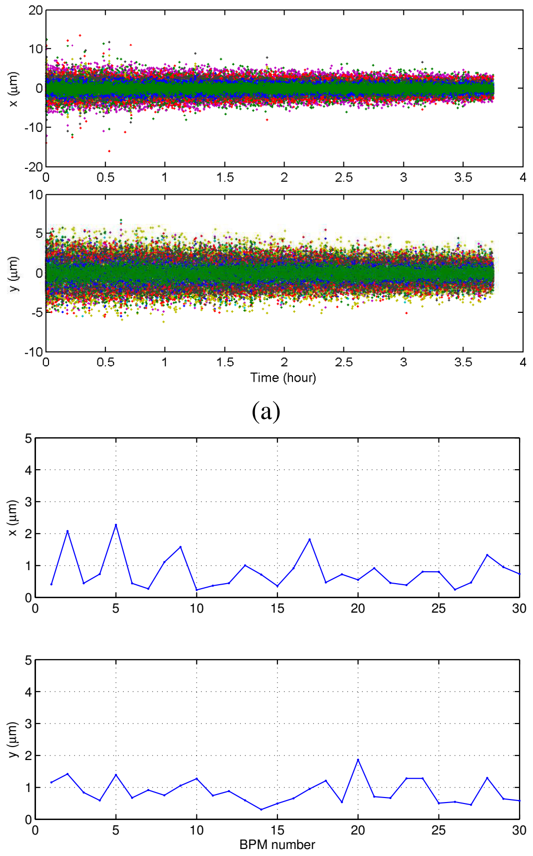
(b)

Figure 3: The measurement of the quadrupole centers at the HLS-II storage ring using the beam-based alignment method.

move the beam orbit in one quadrupole to three different positions and measure the orbit change from the BPMs near this quadrupole by varying its K value. For each BPM reading, we can linearly fit the orbit change as a function of the beam position in the quadrupole. The fitted quadrupole centers from these BPMs have the Gaussian distribution and thus the quadrupole center is then obtained. Figure 3(a) shows the measurement of the horizontal and vertical centers of one quadrupole magnet. Figure 3(b) shows the measured centers of all quadrupoles of the HLS-II storage ring, of which the measurement errors for most quadrupoles are within ±20 μm.

ORBIT FEEDBACK SYSTEM

Based on the previous work, we developed a MATLAB-based orbit feedback system to stabilize the beam around the golden orbit measured using the BBA method. The main program was originally developed at Duke Free-electron laser Lab (DFELL) with necessary upgrade and useful extension [2]. The feedback adopts the singular value decomposition algorithm (SVD) as most modern accelerators do [3]. The correctors and BPMs can be excluded from orbit correction in case of malfunction. Using this feedback system, we also can easily generate orbit bumps in the storage ring. Figure 4 shows the measured beam orbit in the HLS-II storage ring. The peak-to-peak orbit distortion is within ±10 μm horizontally and within ±5 μm vertically. The rms orbit distortion at all BPMs is less than 2μm in both vertical and horizontal plane, which is much better than the requirements at the light source points.



(a)

(b)

Figure 4: Beam orbit stability at the HLS-II storage ring. (a) Measured beam orbits from all BPMs. (b) The rms value of the beam orbits at each BPM.

SUMMARY

The efforts on stabilizing the beam orbit at Hefei Light Source is presented in this paper. We improved the performance of the corrector power supplies by optimizing their static stability and dynamic features. The golden orbit is obtained by measuring the quadrupole centers using the beam-based alignment method. We also developed a multifunctional orbit feedback system to maintain the beam orbit. With all these efforts, we finally achieved an electron beam orbit which is close to the third-generation light source level.

REFERENCES

[1] Jingyi Li, *et al.*, "Operation status of HLS-II.", THPOY028, this conference, IPAC16, Busan, Korea.

[2] Y. K. Wu, *et al.*, "BPM and orbit correction systems at the Duke storage ring.", Proceedings of PAC2003, Oregon, USA.

[3] Y. Chung, *et al.*, "Closed orbit correction using singular value decomposition of the response matrix." Proceedings of PAC1993, Washington, D.C., USA.