Development of photon beam position feedback system based on two PBPMs at HLS

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Abstract In this paper, in order to stabilize the position and angle of the light source point, a new photon beam position feedback system based on the Photon Beam Position Monitors was developed on Hefei Light Source, and used to correct the position drift and angle variation of the light source at the same time. On introducing the feedback principle, the transfer function matrix is calibrated, indicating that the new system is workable and effective.

Key words Photon beam position monitor, Position drift, Angle, Local feedback

1 Introduction

The stable performance of beam orbit is very important for the synchrotron radiation light source to directly determine the experimental quality. Also, the user requiring the light source demands to measure and stabilize its beam position and angle. Therefore, many laboratories at home and abroad attach great importance to the technologies of stabilizing photon beam position[1–3].

The slow beam orbit system at Hefei Light Source (HLS)[4] can only feedback and correct the beam position of storage ring of the 24 Beam Position Monitor (BPM), Still, the position drift is very large after long time operation at the other position of the storage ring[5]. Also, the photon beam position feedback system, which has been performed through the HLS based on the Photon Beam Position Monitors (PBPM)[6], can only correct the position of the PBPM in the system, but not the whole beamline. Because the whole beamline is stabilized with the position and angle of the light source, a local feedback system based on the two PBPMs needs to be developed.

2 Local bump of beam closed orbit at HLS

In order to eliminate the distortion of the closed orbit, the strength of the correcting magnetic field is usually adjusted to realizing the local bump of the closed orbit, the beam orbit between these magnets can be changed when its other parts remain constant.

The local bump of beam closed orbit system in HLS[7] can adjust the light source position to meet the experimental requirements, and automatically create a local bump to change the photon beam position at a specific location, but not changing the other beam positions. Similarly, the photon beam position feedback can be achieved by this system.

3 Principle of photon beam position feedback system on two PBPMs

The light source is composed of B3A_2^0, the two BPMs, BPM-Q6E and BPM-Q8E. The new photon beam position feedback system includes two PBPMs in the beamline. A staggered blade-type PBPM1[8] has the linear range of ±2.5 mm and the sensitivity of 1.429 mm^{-1}, and the wire-type PBPM2[9] has the linear range of ±2 mm and the sensitivity of 0.1979 mm^{-1}. The Δy_1 and Δy_2 are the position drift

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between actual and reference orbit at PBPM1 and PBPM2, Δy_{offset} and $\Delta\theta$ are the position drift and angle variation at the light source. The local feedback in machine diagnostic beamline (MDBL) at HLS was performed, as shown in Fig.1.

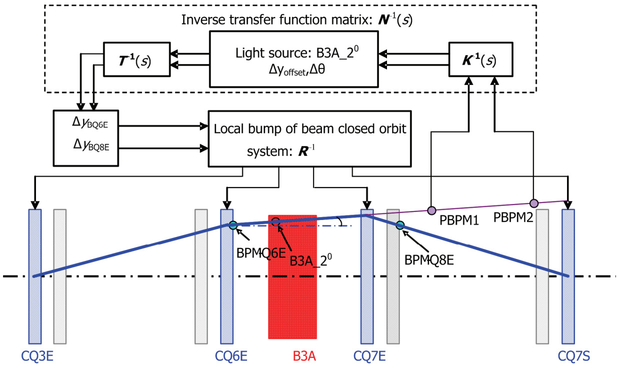

Fig.1 Structure of photon beam position feedback system.

$\boldsymbol{K}(s)$ as the transfer function matrix among Δy_{offset}, $\Delta\theta$, Δy_1, and Δy_2 is expressed by Eq.(1).

$$\begin{pmatrix}\Delta y_1\\ \Delta y_2\end{pmatrix}=\boldsymbol{K}(s)\begin{pmatrix}\Delta y_{\text{offset}}\\ \Delta\theta\end{pmatrix} \tag{1}$$

The Δy_{BQ6E} and Δy_{BQ8E} are the position drift between actual and reference orbits at the BPMQ6E and BPMQ8E. $\boldsymbol{T}(s)$ as the transfer function matrix among Δy_{offset}, $\Delta\theta$, Δy_{BQ6E}, and Δy_{BQ8E} is expressed by

$$\begin{pmatrix}\Delta y_{\text{offset}}\\ \Delta\theta\end{pmatrix}=\boldsymbol{T}(s)\begin{pmatrix}\Delta y_{\text{BQ6E}}\\ \Delta y_{\text{BQ8E}}\end{pmatrix} \tag{2}$$

Eq.(3) is deduced from Eqs.(1) and (2).

$$\begin{pmatrix}\Delta y_1\\ \Delta y_2\end{pmatrix}=\boldsymbol{K}(s)\boldsymbol{T}(s)\begin{pmatrix}\Delta y_{BQ6E}\\ \Delta y_{BQ8E}\end{pmatrix}= \\ \boldsymbol{N}(s)\begin{pmatrix}\Delta y_{\text{BQ6E}}\\ \Delta y_{\text{BQ8E}}\end{pmatrix}=\begin{pmatrix}n_{11} & n_{12}\\ n_{21} & n_{22}\end{pmatrix}\begin{pmatrix}\Delta y_{\text{BQ6E}}\\ \Delta y_{\text{BQ8E}}\end{pmatrix} \tag{3}$$

where $\boldsymbol{N}(\boldsymbol{s}) = \boldsymbol{K}(\boldsymbol{s})\ \boldsymbol{T}(\boldsymbol{s})$.

When operating, the deviation between actual and reference orbits means $[\Delta y_{\text{BQ6E}}\ \Delta y_{\text{BQ8E}}]^{\boldsymbol{T}}\neq[0\ 0]^{\boldsymbol{T}}$ in the two BPMs, $[\Delta y_{\text{offset}}\ \Delta\theta]^{\boldsymbol{T}}\neq[0\ 0]^{\boldsymbol{T}}$ affects $[\Delta y_1\ \Delta y_2]^{T}\neq[0\ 0]^{\boldsymbol{T}}$ in the beamline. The photon beam position feedback system is kept $[\Delta y_{\text{BQ6E}}\ \Delta y_{\text{BQ8E}}]^{\boldsymbol{T}}=[0\ 0]^{\boldsymbol{T}}$ by creating local bump to achieve $[\Delta y_1\ \Delta y_2]^{\boldsymbol{T}}=[0\ 0]^{\boldsymbol{T}}$. Because the photon beam is rectilinear propagation, the $[\Delta y_1\ \Delta y_2]^{\boldsymbol{T}}=[0\ 0]^{\boldsymbol{T}}$ shows that the actual and reference orbits are the same in whole beamline.

Turning on the photon beam position feedback system, the height of the local bump at the position of BPMQ6E and BPMQ8E is obtained from Eq.(4).

$$\begin{pmatrix}\Delta y_{\text{BQ6E\_feedback}}\\ \Delta y_{\text{BQ8E\_feedback}}\end{pmatrix}=-\boldsymbol{T}^{-1}(s)\boldsymbol{K}^{-1}(s)\begin{pmatrix}\Delta y_1\\ \Delta y_2\end{pmatrix} \\ =-\boldsymbol{N}^{-1}(s)\begin{pmatrix}\Delta y_1\\ \Delta y_2\end{pmatrix} \tag{4}$$

4 Calculation and calibration of $\boldsymbol{K(s)}$

4.1 Calculation of $\boldsymbol{K(s)}$

Figure 2 shows the schematic diagram of the MDBL at HLS. Eq.(5) can be analogized by similar triangle, where L_1=3.833 m is the distance from light source to PBPM1; and L_2 = 6.333 m to PBPM2.

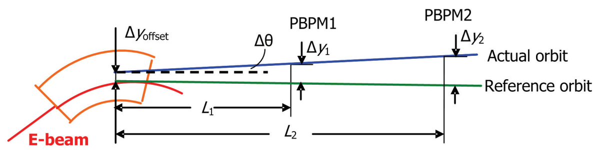

Fig.2 Schematic diagram of the MDBL.

$$\begin{cases}\Delta y_1=\Delta y_{\text{offset}}+\Delta\theta\times L_1\\ \Delta y_2=\Delta y_{\text{offset}}+\Delta\theta\times L_2\end{cases} \tag{5}$$

$\boldsymbol{K}(s)$ is expressed by Eq.(6)

$$\boldsymbol{K}(s)=\begin{pmatrix}1 & L_1\\ 1 & L_2\end{pmatrix} \tag{6}$$

And the inverse $\boldsymbol{K}^{-1}(\boldsymbol{s})$ is

$$\boldsymbol{K}^{-1}(s)=\begin{pmatrix}\dfrac{L_2}{L_2-L_1} & -\dfrac{L_1}{L_2-L_1}\\ -\dfrac{1}{L_2-L_1} & \dfrac{1}{L_2-L_1}\end{pmatrix}= \\ \begin{pmatrix}2.53 & -1.53\\ -0.4 & 0.4\end{pmatrix} \tag{7}$$

The position drift and angle variation is calculated from Eq.(7) as following.

$$\begin{pmatrix}\Delta y_{\text{offset}}\\ \Delta\theta\end{pmatrix}=\boldsymbol{K}^{-1}(s)\begin{pmatrix}\Delta y_1\\ \Delta y_2\end{pmatrix} \tag{8}$$

4.2 Calibration of *N*(*s*)

In Eq.(3), the beam position at BPMQ6E varies and keeps at BPMQ8E, deducing the Eq.(9).

$$\begin{cases}\Delta y_1 = n_{11}\times\Delta y_{\mathrm{BQ6E}}\\ \Delta y_2 = n_{21}\times\Delta y_{\mathrm{BQ6E}}\end{cases}\tag{9}$$

And the beam position at BPMQ8E varies and keeps at BPMQ6E, deducing the Eq.(10).

$$\begin{cases}\Delta y_1 = n_{12}\times\Delta y_{\mathrm{BQ8E}}\\ \Delta y_2 = n_{22}\times\Delta y_{\mathrm{BQ8E}}\end{cases}\tag{10}$$

N(*s*) is calibrated by creating the local bump manually, and the relationship between the position and time is shown in Fig.3.

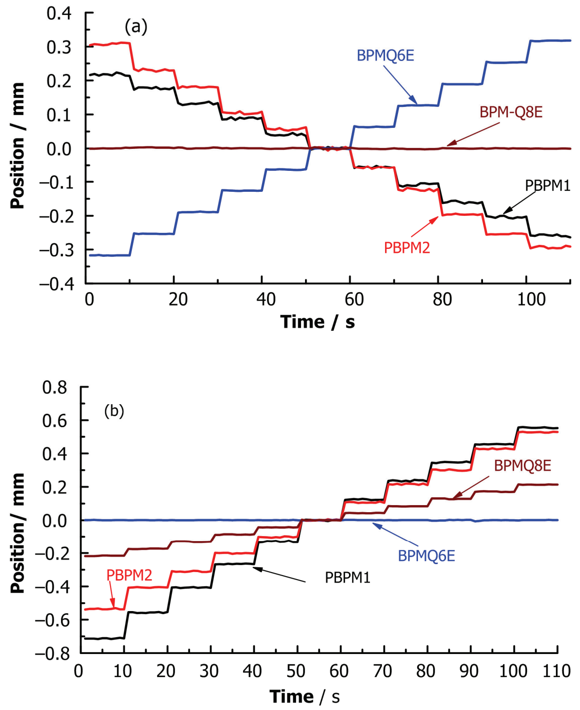

Fig.3 Information of beam position and photon beam position.

The relationship between beam position and photon beam position is fitted by their data in Fig.3 using Eqs.(9) and (10), as shown in Fig.4.

From Fig.4, ***N***(*s*) can be expressed by Eq.(11).

$$\boldsymbol{N}(s)=\begin{pmatrix}-0.77 & 2.93\\ -0.96 & 2.39\end{pmatrix}\tag{11}$$

And $\boldsymbol{N}^{-1}(s)$ is

$$\boldsymbol{N}^{-1}=\begin{pmatrix}\dfrac{n_{22}}{n_{11}n_{22}-n_{12}n_{21}} & -\dfrac{n_{12}}{n_{11}n_{22}-n_{12}n_{21}}\\ -\dfrac{n_{21}}{n_{11}n_{22}-n_{12}n_{21}} & \dfrac{n_{11}}{n_{11}n_{22}-n_{12}n_{21}}\end{pmatrix}=\begin{pmatrix}2.46 & -3.01\\ 0.99 & -0.79\end{pmatrix}\tag{12}$$

The local bump is created by Eq.(4), correcting the real-time position drift and angle variation.

5 Application of feedback system on two PBPMs

Figure 5 shows the positions of two PBPMs in three time intervals. Within one hour, both slow beam orbit feedback system and photon beam position feedback system were turned off, and turned on sequentially at the beginning of the second and the third hour.

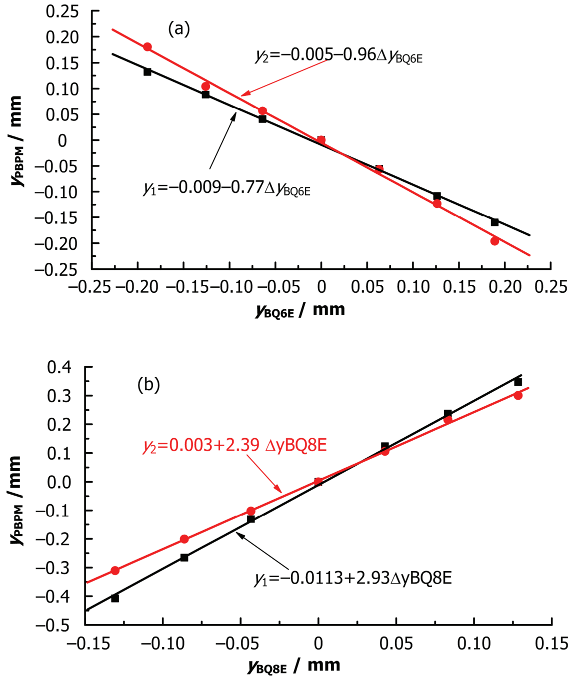

Fig.4 Relationship between beam position and photon beam position.

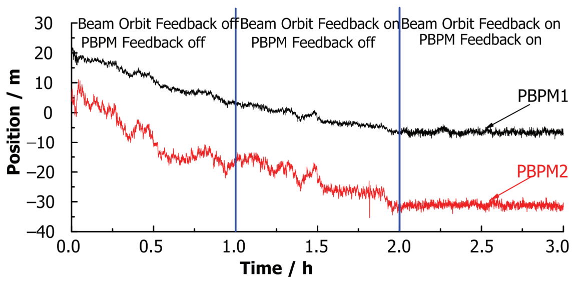

Fig.5 Photon beam positions in three time intervals.

When turning off the two systems, the drift position of PBPM1 is 15 μm; and PBPM2, 30 μm. When turning on slow beam orbit feedback system, the drift position of PBPM1 is 10 μm; and PBPM2, 17 μm. When turning on the two systems, the drift position of PBPM1 and PBPM2 are repressed, and their statistical results are shown in Fig.6, thus achieving that the drifts of PBPM1 and the PBPM2 are about 0.67 μm and 0.81 μm.

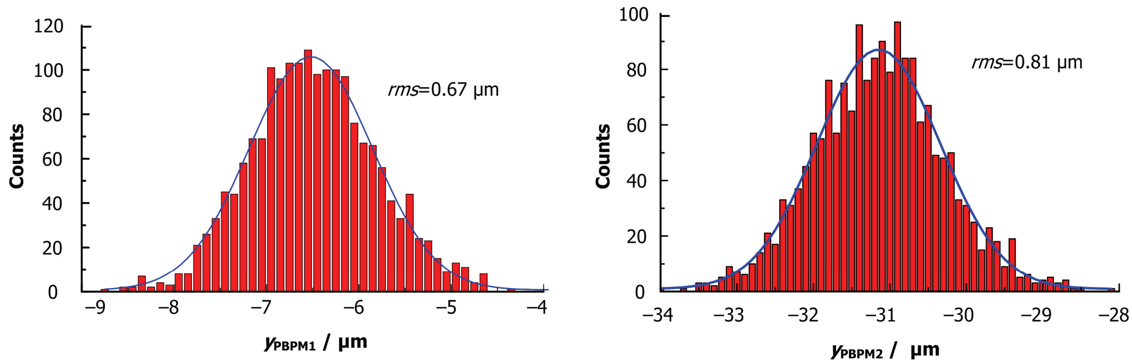

Fig.6 Drifts of two PBPM.

The position drift and angle variation at HLS in these three conditions can be calculated by Eq.(8), as shown in Fig.7.

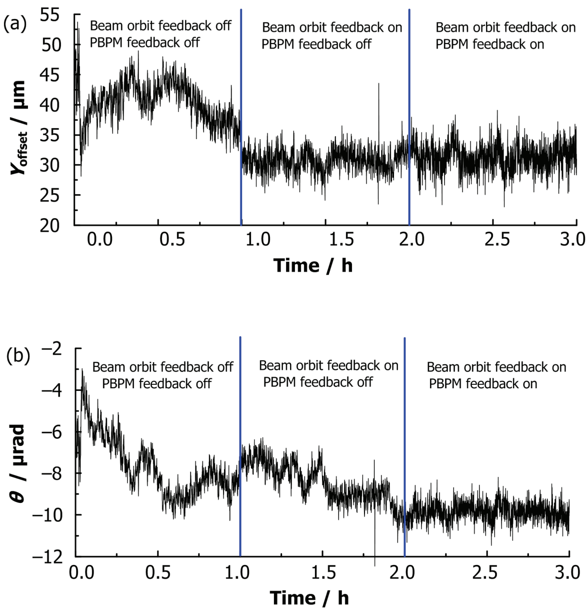

Fig.7 Position drift (a) and angle variation (b) at HLS.

When turning off the two systems, the position and angle at HLS fluctuate up to 18 μm and 6 μrad within one hour, and the position in the beamline changes with the interaction of the position drift with angle variation. When only turning on slow beam orbit feedback system in the second hour, the position drift becomes very small, and the angle variation is about 4 μrad, the position in the beamline changes mainly with the angle variation. When turning on the two systems in the third hour, the position drift and the angle variation are repressed, and the photon beam position in the beamline is stable.

6 Conclusions

Based on two PBPMs, the developed local feedback system for photon beam can correct the position drift and angle variation at HLS, thus stabilizing the photon beam position in the beamline. In the future, the technology may be used in undulator beamline to correct the photon beam position in the horizontal and vertical directions.

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