AN ALTERNATIVE FAST ORBIT FEEDBACK DESIGN OF HEPS*

Xiyang Huang#, Yanhua Lu, Shujun Wei, Qiang Ye, Fang Liu, Yaoyao Du, Xinger Zhang, Yufei Ma, Dechong Zhu, Yanfeng Sui, Jianshe Cao, Key Laboratory of Particle Acceleration Physics and Technology, Institute of High Energy Physics, Chinese Academy of Sciences, Beijing, China

Abstract

The High Energy Photon Source (HEPS) is a fourth generation light source in China and will be built in this year. The emittance of HEPS storage ring is approaching diffraction limit and the circumstance of the ring is about 1.3 kilometres. To stabilize the electron beam, fast orbit feedback (FOFB) system is prerequisite. In this paper, the requirements on the HEPS beam stability are discussed and an alternative FOFB design based on DBPM are introduced with algorithm and architecture.

INTRODUCTION

In the past few decades, the exploration of ring and linac based light sources is promoted with the development of accelerator technology. In order to reach the diffraction limit, some ring based fourth generation light source facilities has been under construction or proposed with multi-bend achramt (MBA) [1]. The new lattice design can decrease the natural emittance by reducing the bending angle for each dipole magnet. As a result, by using MBA, the natural emittance of the fourth light sources can be achieved to around 100 pm and the brilliance can be achieved to around 10^{22} photons /sec/mm^2/mrad^2/0.1%BW.

High Energy Photon Source (HEPS) is proposed early in 2008 and will be built in this year [2, 3]. The lattice of hybrid 7BA with anti-bends and super-bends is tentatively adopted, see in Fig 1. In a hybrid 7BA lattice, the outer dipoles provide two dispersion bumps and the chromatic sextupoles are placed in the dispersion bumps. To cancel most of the nonlinearities induced by the sextupoles, the optics is matched to form a –*I* transportation between each pair of sextupoles in which the phase advances are at or close to $(2n+1)\pi$ in both transverse and vertical planes. The main parameters of HEPS lattice are listed in Table 1.
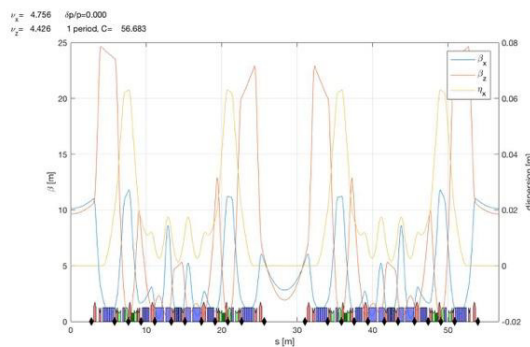

Figure 1: The lattice of one period.

The closed orbit of HEPS lattice will be affected by several kinds of perturbations, such as ambiance ground vibrations and power supply ripples. According to the beam stability requirements, the rms position/angular motion of the electron beam should be less than 10% of the beam size/divergence in both transverse planes for undulators and vertical plane for bending magnet sources in the frequency range of 0.01 Hz~1 KHz. For HEPS, some critical reference values of the orbit distortions for the final lattice are less than 1 μm and 0.3 μm in transverse and vertical plane, respectively [4].

In order to eliminating the fast fluctuation of the beam orbit, a FOFB system with the bandwidth up to 1 KHz is considered, the structure of FOFB is similar to the NSLS II's feedback system [5-7]. In the following, we will present another design as an alternative FOFB scheme for HEPS, which includes the brand new algorithm to correct the beam positions for global and local orbit.

Table 1: Main Parameters of Present HEPS Lattice

Parameters	Values
Energy	6 GeV
Circumference	1360.4 m
Tune ν_x/ ν_y	114.144/106.232
Natural emittance	34 pm
Beam current	200 mA
Momentum compaction	1.3e-5
Periodicity	24

PRINCIPLE OF THE NEW ALGORITHM

Given the matrix,

$$R_{mn} = \frac{\sqrt{\beta_m \beta_n}}{2\sin \pi\nu} \cos(|\varphi_m - \varphi_n| - \pi\nu) , \qquad (1)$$

$R \in \mathbb{R}^{m \times n}, \theta \in \mathbb{R}^n, x \in \mathbb{R}^m, n < m$, in which R is the response matrix related to the BPMs and correctors, θ is the corrector strengths, x is the orbit measured by BPMs. The global correction algorithm is aiming to minimize the orbit residual $\min \| R\theta + x \|_2$. However, sometimes we want to correct the local beam positions or angular motions at arbitrarily selected positions around the ring (such as the light source points or the injection point). Then the unconstraint least square (LS) problem turns to the constraint least square (CLS) problem. Therefor we are interested in finding a set of θ such that

$$\min \| R\theta + x \|_2 \text{ subject to } \min \| B\theta + d \|_2 , \qquad (2)$$

where $B \in \mathbb{R}^{p \times n}, d \in \mathbb{R}^m, p < n$, the vector d are parameters related to the corrector strength, B is the response matrix related to d and θ.

In the following we will introduce the new SVD with Constraints (SVDC) algorithm. For clarity, we assume matrix B has full rank and the constraints are consistent. Computing the QR decomposition of B^T [8],

$$(Q_1, Q_2)^T B^T = \begin{pmatrix} P \\ 0 \end{pmatrix} \begin{matrix} n \\ n-p \end{matrix} \qquad (3)$$

Then the columns of Q_2 span the null space of B^T and the new unknowns become $y = Q^T\theta$, the constrains are

$$B\theta = BQy = (P^T, 0)y = P^T y_1 \approx -d \text{ , with } y = \begin{pmatrix} y_1 \\ y_2 \end{pmatrix}. \quad (4)$$

Eq. (4) is the general solution of the constraints and y_2 is arbitrary. Introducing

$$R\theta = RQQ^T\theta = RQ\begin{pmatrix} y_1 \\ y_2 \end{pmatrix} = R(Q_1 y_1 + Q_2 y_2) \qquad (5)$$

into $\| R\theta + x \|_2$, we get the unconstrained LS problem

$$\min \| RQ_2 y_2 + (RQ_1 y_1 + x) \|_2. \qquad (6)$$

SVD can help solve Eq. (6). Combining the above, we see that following vector solves our CLS problem,

$$\theta = Q\begin{pmatrix} y_1 \\ y_2 \end{pmatrix}. \qquad (7)$$

In a more general case, if the efficient rank of B is less than p and $d \notin \Re(B)$, which means the constraints are not consistent, then it is natural to devise a similar procedure using SVD instead of QR. In conclusion, the calculation of correct strengths includes one QR, SVD (or two SVD) factorizations and a matrix multiplication when we need to correct the local and global orbit simultaneously.

Simulations have done to compare the preliminary results of the new SVDC algorithm and the original SVD algorithm. The numbers of BPM and fast corrector are 576 and 192, respectively. For simplicity, we choose the first BPM locations in each cell as the constraint points. For the assumed quadrupole uncorrelated vibration of 100 nm, the correction orbit at the constraint points utilizing SVDC algorithm can be suppressed one to two orders lower than the original SVD algorithm without considering other perturbations, see in Fig. 2 and Fig. 3. The beam stability requirements are close to be fulfilled with the help of FOFB in straight sections and BPM locations, but not all over the ring [4].
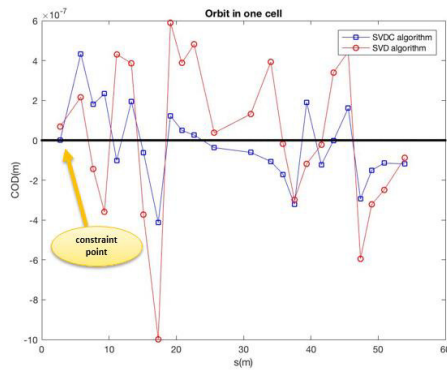

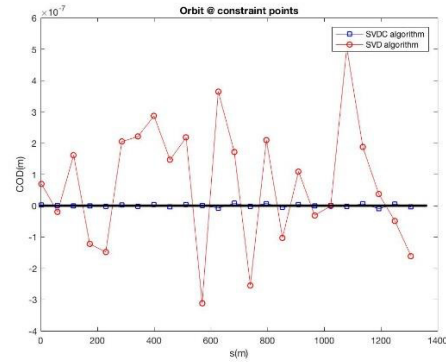Figure 2: The orbit after correction in one cell.

Figure 3: Comparison between the SVDC and SVD algorithm at the constraint points (the first BPM in each cell) around the ring. The SVDC can suppress the closed orbit distortion effectively at specific places.

STRUCTURE OF FOFB AND DBPM

In this section, we will present the structure design of the alternative fast orbit feedback system. As sketched in Fig. 4, the system will adopt hybrid communication with star and ring architecture. FOFB system will use 12 switches to deliver BPM data around the ring. In each cell, the serial device interface is used to transfer 48 BPM data to the switch. All the data communications are dominated by the controller of switch, BPM and PS controller. Figure 5 shows the preliminary time consumption estimations in each step. Until now, the matrix calculation is designed to complete in FPGA chips equipped in BPMs rather than in switches, but need more consideration about the balance among the difficulties, complexities and time consumptions.
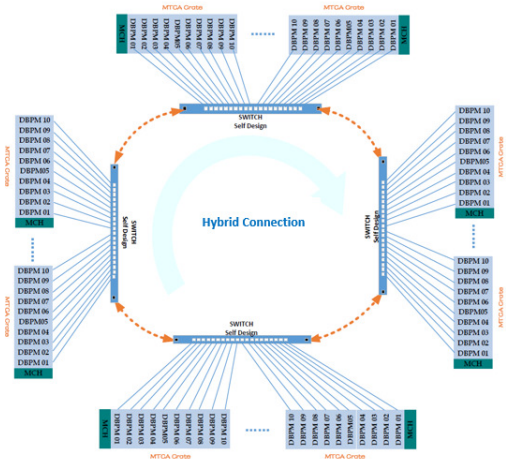

Figure 4: Alternative HEPS fast orbit feedback system.

Figure 6 shows the structure of FOFB with SVDC algorithm. The performance of the system will be studied by the frequency-amplitude curve of the function of feedback loop.
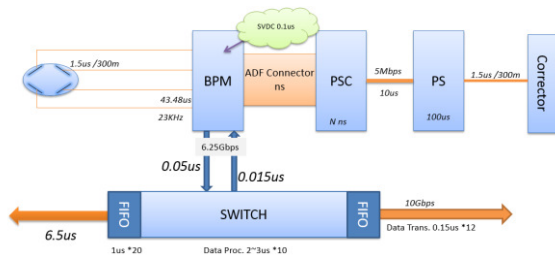
Figure 5: Preliminary time consumption estimation in each step.
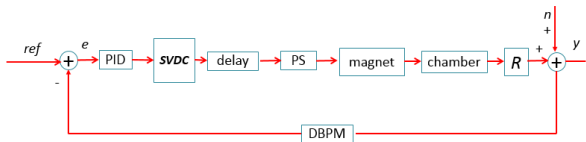

Figure 6: Structure of fast orbit feedback system with SVDC.

The digital BPM electronics system for HEPS is based on the MTCA.4 structure and is divided into a front-end analog signal processing board called Rear Transition Module (RTM) and a digital processing signal board called Advanced Mezzanine Card (AMC) [9]. The front-end analog signal processing card adjusts the four BPM pick up signals to ±10 MHz bandwidth signals which are acceptable by analog to digital converter (ADC) and centred on the RF frequency through multi-step amplification and attenuation. Then the digital signals are sent to the processing card preforming ADC sampling and processing. AMC card uses a 16-bit ADC to sample the signal. It also need to complete the algorithm processing and data transmission function. The ADC sampling clock is synchronized to the input revolution frequency, which is given by the accelerator timing system. Discrete Fourier Transform (DFT) method is adopted as the BPM algorithm. The structure of RTM and AMC card are shown in Fig. 7.
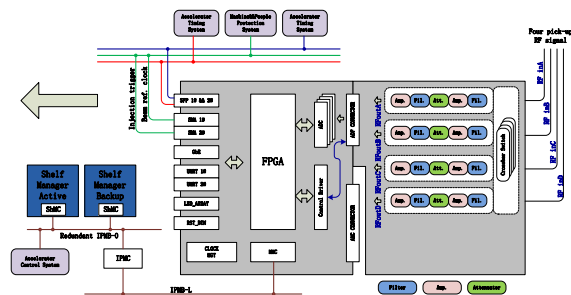

Figure 7: Hardware structure of RTM and AMC card.

CONCLUSION

In this paper, we proposed a fast orbit feedback system design with a new SVDC algorithm and regarded it as an optional orbit correction method for HEPS. The preliminary simulations compared the results of SVDC to SVD and shown that SVDC algorithm can help correct the global and local orbit simultaneously time without interfering mutually of two different (fast and slow) feedback systems. As the preliminary results shown, the SVDC algorithm is more useful for orbit feedback scheme than the conventional SVD. The structure of the FOFB and DBPM are also discussed in the paper. We will provide more detailed simulations of the new method with more practical perturbations in the future.

ACKNOWLEDGEMENT

REFERENCES

[1] H. Maesaka, "Comparison of beam diagnostics for 3rd and 4th generation ring-based sources", in *Proc. IPAC'15*, Richmond, USA, May 2015, paper THYC1, pp. 3657-3661.

[2] G. Xu, *et al.*, "Recent physical studies for the HEPS project", in *Proc. IPAC'16*, Busan, Korea, May 2016, paper WEPOW026, pp. 2886-2888.

[3] Y. Jiao, *et al.*, "Status of HEPS lattice design and physics studies", in *Proc. SAP'17*, Jishou, China, Aug. 2017, paper MOBH2, pp. 7-9.

[4] Z. Duan, "Estimation of the orbit feedback performance for HEPS", report in workshop *GM'17*, Beijing, China, Dec. 2017.

[5] L. H. Yu, S. Krinsky, O. Singh and F. Willeke, "The performance of a fast closed orbit feedback system with combined fast and slow correctors", in *Proc. EPAC'08*, Genoa, Italy, JUN. 2008, paper THPC140, pp. 3315-3317.

[6] Y. K. Tian, *et al.*, "NSLS-II fast orbit feedback system", in *Proc. ICALEPCS'15*, Melbourne, Australia, Oct. 2015, paper MOC3O05, pp. 34-37.

[7] D. P. Jin, "Preliminary Design and Performance Analysis of the FOFB System of HEPS", report in workshop *GM'17*, Beijing, China (2017).

[8] G. H. Golub and C. F. Van Loan, Matrix Computations 3rd Ed., Baltimore, USA: Johns Hopkins University Press, 2011

[9] F. Liu, *et al.*, "The algorithm research of DBPM for HEPS", presented at the 9th Int. Particle Accelerator Conf. (IPAC'18), Vancouver, Canada, Apr.-May 2018, paper WEPAL004, this conference.