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NEW ORBIT CORRECTION METHOD BASED ON SVDC ALGORITHM FOR RING BASED LIGHT SOURCES*

X.Y. Huang#, Y. H. Lu, S. J. Wei, Q. Ye, Y. Y. Du, Y. Y. Wei, D. C. Zhu, Y. F. Sui, X. E. Zhang, M. Y. Fei, M. H. Zhou, J. S. Cao, Key Laboratory of Particle Acceleration Physics and Technology, Institute of High Energy Physics, Chinese Academy of Sciences, Beijing, China

Abstract

Orbit feedback system is essential for realizing the exceeding beam stability in modern ring based light sources. Most advanced light sources adopt the global correction scheme by using singular value decomposition (SVD) algorithm. In this paper, a new SVD with constraints method (SVDC) is proposed to correct the global and local orbit simultaneously. Numerical simulations are presented with the case of High Energy Light Source (HEPS) by comparing classic algorithms. The results show that SVDC is very effective for orbit correction and very easy to implement.

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 achromat (MBA) [1]. The new lattice design can decrease the natural emittance by reducing the bending angle for each dipole magnet.

High Energy Photon Source (HEPS) is proposed early in 2008 and will be under construction in this summer [2-4]. The lattice of hybrid 7BA with anti-bends and super-bends is tentatively adopted, see in Fig. 1. In this lattice, two families of antibends are used to achieve as low as possible emittance. A dipole combined with longitudinal gradient dipoles instead of transverse gradient is adopted in the middle of each 7BA, with its central slice as source of bending magnet beam lines. In addition, by accepting alternating high- and low-beta optics design, it can provide high brightness of the order of 10^{22} photons /s/mm^2/mrad^2/0.1%BW by reducing both horizontal and vertical beta functions towards 1 m in half of the 6-m straight sections. Some main parameters are listed in Table 1.

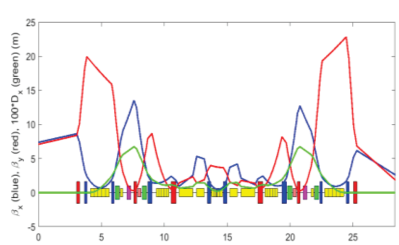

Figure 1: The lattice of one cell

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#huangxy@ihep.ac.cn

The closed orbit of HEPS lattice will be affected by several kinds of perturbations, such as peripheral ground vibrations and power supply ripples. According to the beam stability requirements of advanced light sources, 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 DC to 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 [5]. In order to eliminating the fast fluctuation of the beam orbit, a fast orbit feedback (FOFB) system with the bandwidth up to 1 kHz is considered [6-8]. In the following, firstly we will illustrate the brand new algorithm principle and the numerical simulations, secondly we will depict the architecture of HEPS FOFB system.

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

THE NEW SVDC ALGORITHM

Given the matrix,

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

$A \in \mathrm{R}^{m\times n}, \theta \in \mathrm{R}^n, x \in \mathrm{R}^m, n < m$, in which A 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 $\min \| A\theta + x \|_2$. 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:

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

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where $B \in R^{p \times n}, d \in R^m, p < n$, the vector d is the parameter 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 [9, 10],

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

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:

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

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

$$A\theta = AQQ^T\theta = AQ\begin{pmatrix} y_1 \\ y_2 \end{pmatrix} = A(Q_1 y_1 + Q_2 y_2) \tag{5}$$

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

$$\min \| AQ_2 y_2 + (AQ_1 y_1 + x) \|_2 . \tag{6}$$

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

$$\theta = Q\begin{pmatrix} y_1 \\ y_2 \end{pmatrix}. \tag{7}$$

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. The solution of two SVD procedure is

$$\theta = -T_1 S_r^{-1} X_1^T d - T_2 V_1 \Sigma_r^{-1} U_1^T (-AT_1 S_r^{-1} X_1^T d + x), \tag{8}$$

where T, S_r, and X are SVD of B^T, T_1, T_2, X_1, X_2 are the partition of T and X by columns according to the efficient rank, respectively. U, Σ_r, V are SVD of AT_2, U_1, and V_1 are the partition of U and V by columns according to the efficient rank, respectively.

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.

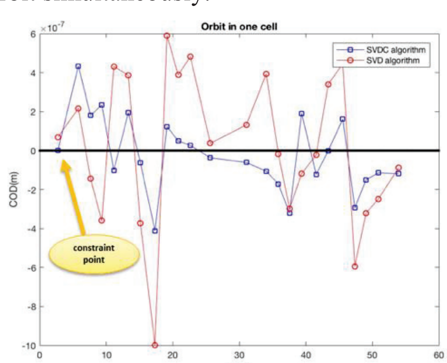

Figure 2. The orbit after correction in one period.

Simulations have done to compare the preliminary results of the new SVDC algorithm and the classic SVD algorithm. The numbers of BPMs and fast correctors are 576 and 192, respectively. For simplicity, we choose the first BPM locations in each period as the constraint points. There are 24 constraints. 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].

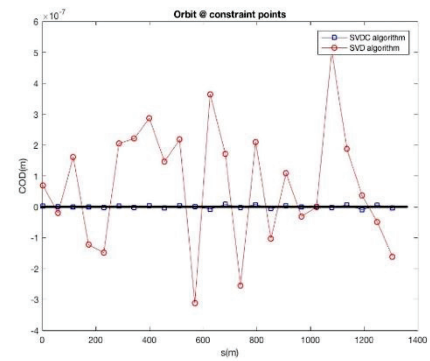

Figure 3: Comparison between the SVDC and SVD algorithm at the constraint points (the first BPM in each cell) around the ring. The SVDC can suppress the closed orbit distortion effectively at specific places.

Another result with more constraint points are presented. We choose the BPMs at both ends of straight sections, which means there are 96 constraints. As we see in Fig. 4, the rms orbit of all 576 BPMs with two algorithms (red circle and blue hexagonal) are nearly the same, however, the rms orbit of 96 constraint points are obviously lower with SVDC (blue x) algorithm than with SVD algorithm (red dot).

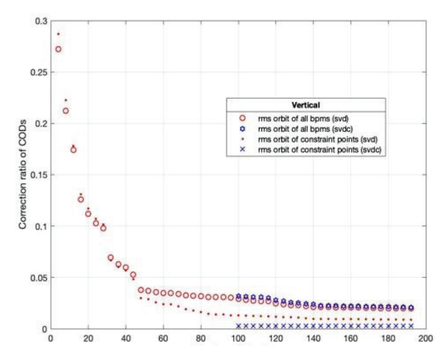

Figure 4: Results comparison of SVDC and SVD, SVDC algorithm can help suppress the orbit at constraint points.

STRUCTURE OF FOFB AND DBPM

In this section, we depict the structure design of HEPS fast orbit feedback system. As sketched in Fig. 5, the system will adopt hybrid communication with ring architecture. In our design, the FOFB system contains 24 local cell controllers, which are fairly well distributed around the storage ring. Each controller receives 24 local BPM FA data (22 kHz) and delivers them to other cell

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controllers by 10 Gbps fibre links. Then all the cell controllers compute and distribute new power supply setpoints to eight local fast correctors in every 45 μs. Orbit feedback processing are based on a FPGA and multi-core DSPs integrated in each cell controller. SDI link and some data pre-processing are handled by the FPGA, while the DSPs performs the corrector setpoints computations by SVD or SVDC algorithm. The inverse response matrix is computed offline and will be uploaded to the cell controller as vector parameters in advance. Figure 6 shows the preliminary time consumption estimations in each step.

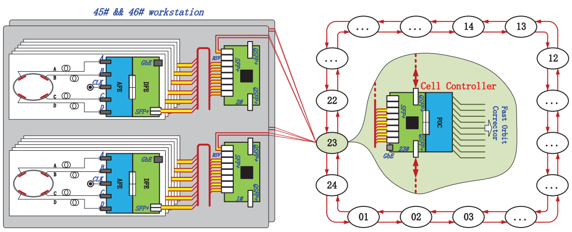

Figure 5: Alternative HEPS fast orbit feedback system.

Figure 7 shows the feedback loop of FOFB with SVDC algorithm. The performance of the system will be studied by the frequency-amplitude curve of the function of feedback loop.

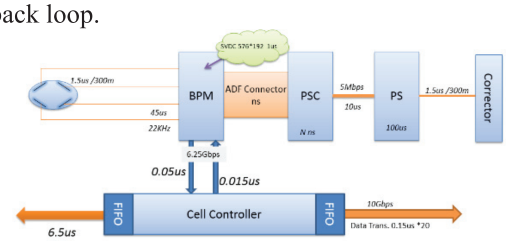

Figure 6: Preliminary time consumption estimation in each step.

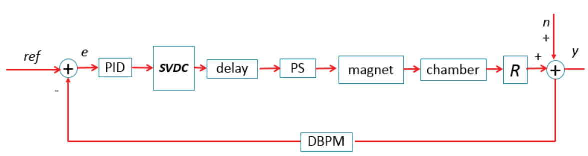

Figure 7: Feedback loop of fast orbit feedback system with SVDC.

CONCLUSION

In this paper, we proposed a fast orbit feedback system design with a new SVDC algorithm and regarded it as an orbit correction method for light sources. The preliminary simulations compared the results of SVDC to SVD and shown that the SVDC algorithm can help correct the global and local orbit simultaneously 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 classic SVD since it can help correct the light source point orbit more efficient. The architecture of the FOFB are also discussed in the paper. We will provide more detailed simulations of the new algorithm with more practical orbit perturbations in the future.

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