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Optimum Steering of Photon Beam Lines in SPEAR*

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Abstract

A common operational requirement for many synchrotron light sources is to maintain steered photon beamlines with minimum corrector strength values. To solve this problem for SPEAR, we employed the Singular Value Decomposition (SVD) matrix-inversion technique to minimize corrector strengths while constraining the photon beamlines to remain on target. The result was a reduction in corrector strengths, yielding increased overhead for the photon-beam position feedback systems.

I. INTRODUCTION

The SPEAR storage ring is a 234-m-circumference device operating with 3 GeV electrons. It is presently equipped with nine photon beam ports to serve a range of synchrotron radiation user needs in the uv and x-ray regions. As with all synchrotron radiation devices, there is a premium on maintaining the photon beams on target.

Using closed three-magnet bumps, Hettel [1] pioneered the first feedback-stabilized servo loops to reduce photon-beam motion at detectors located about 10 m from the radiation source point. These systems proved to be reliable and are still in use today. The only problem with the servo loops, however, was the occasional tendency for the feedback circuit to drive corrector currents to the power supply limits. Painstaking manual efforts were therefore made to reduce the initial corrector strengths so that the feedback loops had maximum operational overhead.

To further complicate the problem, the SPEAR BPM system contains large DC readback errors, making it difficult to steer the beams on target following realignment of the magnets. In addition, the corrector to photon-beam position response can be non-linear because the photo-ionization chambers are non-linear. As a result, attempts to reduce the corrector strengths while maintaining steered photon beams via measured response-matrix techniques proved futile. A solution was then found which utilizes the unique mathematical properties of singular-value matrix decomposition [2] which was applied succesfully on SPEAR.

II. SINGULAR VALUE DECOMPOSITION

In the course of studying modeling techniques for SPEAR, we found that we could adapt a 'corrector ironing' algorithm, originally developed by one of the authors for the SLC final focus [3], to SPEAR. In the SLC application, the RMS excitation of correctors was reduced subject to the constraint that the beam position remained constant in the sextupoles, and the beam trajectory remained constant at the collision point. Since there were typically more correctors than constraints, the technique of Singular Value Decomposition (SVD) was used to solve the under-determined linear system, exploiting the advantageous property of SVD to minimize the RMS of the solution vector which contains the corrector excitations.

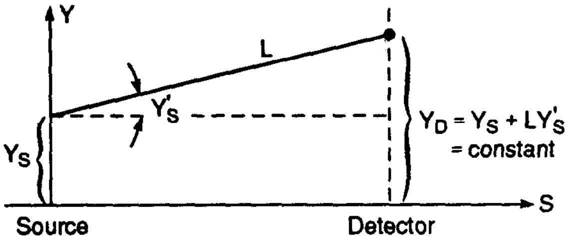

Figure 1. Photon beam positioning at detector requires $x_s + Lx_s$= constant.

In SPEAR, the problem translated into reducing corrector strengths across regions of the storage ring with four or five consecutive photon beamlines while keeping the photon beams fixed on target. Geometrically, the constraint of constant photon-beam position required the electron-beam coordinates (y, y') at the photon beam source point to satisfy $\Delta(y + Ly') = 0$, where L is the distance from source point to detector as shown in Figure 1. The Δ-operator indicates the change after the steering correction.

For the SVD calculations, typically, five target photon-beam positions and two bump closure constraints were used, with about twelve (variable) corrector strengths to be minimized. To optimize performance of the system, the accelerator-optics model used for the corrector-response calculation was derived using numerical fitting techniques to match the measured data [4]. For this application, the virtues of the SVD solution were two-fold: (1) the solution satisfied the constraints exactly (beams fixed on target), and (2) RMS reduction of the corrector-strength vector caused the

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reduction of the corrector-strength vector caused the largest current decrease in the initially strongest correctors. The new corrector configuration therefore exhibits optimum steering of the photon beams, leaving maximum overhead for the feedback systems to operate.

III. EXPERIMENTAL RESULTS

Initial tests of the algorithm produced a 60% RMS reduction in the vertical-corrector strengths relative to the nominal steered configuration. More important, after a three-month shutdown with magnet realignment and the decision to operate SPEAR with a new high-brightness lattice [5], a new corrector configuration had to be found in which all photon-beam lines were steered properly. Using the corrector-ironing program, the steering procedure was simplified to a series of closed-bump corrector adjustments to position the photon beams, followed by ironing the correctors to gain overhead for the next iteration. In addition to producing an optimally steered orbit, it was estimated that the corrector ironing program saved about one week of accelerator commissioning time.

One of the most dramatic demonstrations of corrector strength reduction came about after rough vertical beam steering was completed. In the first iteration for the horizontal correctors, the RMS excitation of the horizontal correctors in SPEAR was reduced from 1 mrad to 35 μrad, and still the beams remained on target.

IV. FURTHER APPLICATIONS

Possible applications for the SVD-based, corrector-ironing program used at SPEAR range from generating closed bumps to modern orbit feedback systems [6]. Here, we list a few:

Commissioning Tool: A terminal-interactive (X-Windows) system is planned for SPEAR which will allow the operator to adjust the electron-beam orbit at selected photon-beam position monitors (BPMs) using a subset of corrector magnets with strengths computed via SVD. This tool will allow the operator to quickly steer photon beams on target with optimum corrector settings. In general, local beam bumps can be constructed for injection, photon-beam steering, or coupling control, for example. The corrector-strength weighting feature allows the user to depress individual correctors.

Photon Beamline Alignment: By assigning variables to the positions of BPMs, low-strength solutions can be determined for the corrector pattern which would require realignment of the photon beamlines. Conversely, with accurate knowledge of the BPM elevations relative to the plane of the storage ring, SVD (or direct computation) can be used to estimate magnet misalignments.

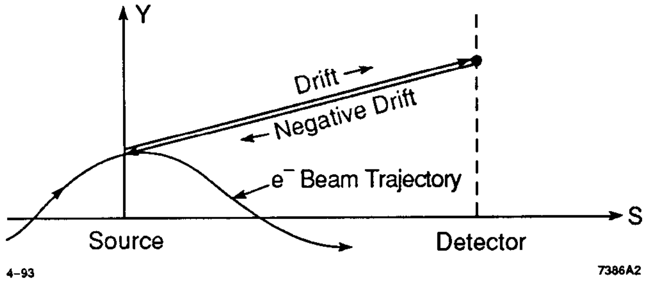

Fig. 2. Drift/Negative Drift modeling technique allows photon-beam detector to be treated similar to nominal BPM.

Closed Orbit Control: The original closed-bump SVD program for corrector ironing in SPEAR has been modified for closed-orbit operation. In addition, the photon-beam position constraint, $\Delta(y+Ly')=0$, was replaced with a new drift/negative-drift model whereby the photon beam is propagated along a drift of length L from the source point to the detector, followed by a negative-drift back to the source point. The electron-beam motion is then simulated farther downstream (see Fig. 2). Effective response-matrix coefficients can be computed at the photon BPMs.

Orbit Feedback: Many third-generation light sources are considering SVD algorithms as drivers for fast-orbit feedback systems.

Acknowledgments

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