VARIOUS CANTING SCHEMES FOR UTILIZING MORE THAN ONE INSERTION DEVICE IN AN INSERTION DEVICE STRAIGHT SECTION *

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Abstract

Presently, the APS utilizes one simple canting scheme for separation of radiation generated by two insertion devices (IDs) located in the same ID straight section. This scheme is based on triangular horizontal orbit bump with one corrector located between the IDs and orbit distortion limited to the ID straight section only. However, this scheme does not allow for switching between the upstream and downstream devices, nor does it allow for one beamline to accept the combined radiation of both devices. These capabilities are being requested for future APS Upgrade. In this paper, we describe more advanced canting schemes that allow for these capabilities, and also present test results. The main complication here is that the orbit distortion is required to go through the storage ring magnets thus generating optics errors, which have to be corrected.

INTRODUCTION

The Advanced Photon Source (APS) is a 7-GeV third-generation synchrotron light source that has been serving a wide variety of users since operations began in 1996. 34 straight sections are used for installation of insertion devices, and each straight section allows space for up to two 2.4-meter-long devices. Because of ever-increasing demand for beam time from experimenters, over time several straight sections were modified to double the beamline capacity. This was done by introducing so called dual-canted undulators [1]. In this configuration, a chicane is created with a trio of dipole magnets with an undulator in each leg as shown in Figure 1 (1-mrad dipoles used to separate dipole radiation from the ID radiation [2] are omitted for simplicity). The result is an angular separation between the x-ray beams that can be exploited downstream to create two independent beamlines from a single straight section.

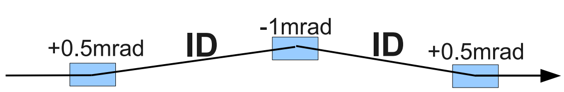

Figure 1: Canted ID straight section configuration presently used at the APS.

Since then, there have been a number of requests from user programs about the possibility of modifing this simple canting scheme to allow for better utilization of the insertion devices. The biggest problem with the present configuration is that the radiation from upstream and downstream devices cannot be switched between the two experimental stations. It is not a big issue presently because most of the insertion devices at the APS are similar to each other. But as more and more narrowly optimized devices are installed, the issue of switching the two photon beams can become more important. For example, the request to explore such a possibility already has come from the user group that plans to install one permanent magnet and one superconducting undulator in their straight section. In this paper, we will present several canting schemes and evaluate their performance from the accelerator physics point of view.

* Work supported by the U.S. Department of Energy, Office of Science, under Contract No. DE-AC02-06CH11357.

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SWITCHABLE CONFIGURATIONS

The most straightforward way to switch radiation of upstream and downstream undulators is just to flip the signs of the correctors that create the triangular orbit bump. The advantage of this approach is its simplicity and the fact that the orbit does not change outside of the ID straight section. This approach, however, has a major deficiency — the position of the radiation source will be shifted transversely by several mm after the switching, as shown in Figure 2. The shift will present challenges in both designing the beamline front end and the beamline optics. Therefore, it is desirable to create such an orbit bump that the source position does not change during the switch.

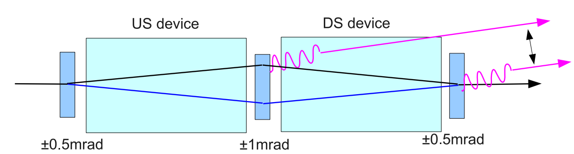

Figure 2: Diagram showing a position shift during ID switch in a triangular-bump configuration.

Symmetric Five-Corrector Bump (W-bump)

Using additional SR correctors outside of the ID straight section, we can make a bump such that source positions stay on the same line after the switch. Figure 3 illustrates the idea: when the beam travels along the trajectory shown in blue, the radiation of the upstream device goes into the inboard beamline; when the orbit is switched to the one shown in red, the downstream ID's radiation goes into the same inboard beamline. This configuration is strongly preferred by the users, but it presents difficulties for the storage ring operation – now the orbit will be changing outside of

ISBN 978-3-95450-138-0

the straight section. Non-zero orbit through sextupoles will result in optics distortion that needs to be corrected.

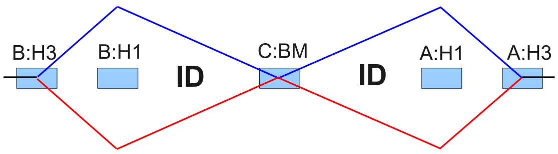

Figure 3: Five-kicker bump that allows photon beams to be sent from both undulators along the same line.

To generate this bump, we simultaneously matched orbit and beta functions using matching in `elegant` [3]. Two correctors on each side of the bump as shown on Figure 3 were used for orbit matching and eight quadrupoles around the straight section were used to match lattice functions. Figure 4 shows the resulting orbit and corresponding lattice functions for two sectors around the ID for no bump configuration and for positive and negative bumps. Lattice function changes are minimal and should not affect users.

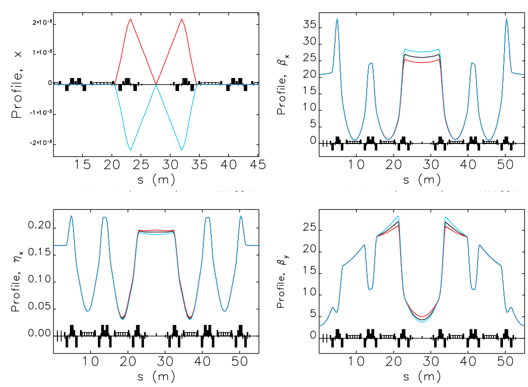

Figure 4: Lattice functions and orbit for two sectors around the ID straight section for W-bump. Starting from top left in clockwise order: orbit, horizontal beta function, vertical beta function, and horizontal dispersion. No bump, positive, and negative bumps are shown.

We also need to ensure that the nonlinear beam dynamics is not affected by this bump. Figures 5 and 6 show dynamic and local momentum apertures for no bump and for positive bump lattices. No effect on lifetime and injection efficiency is expected based on these simulations.

When combined with the 1-mrad bending angle required for the separation of the dipole and ID radiation, the strength of H1 correctors required to generate the orbit bump exceeds the limit. The easiest way to overcome this problem is to install additional correctors right next to the existing H1 correctors. However, this may shorten the length available for ID installation. Another approach is to involve more correctors in the creation of the orbit bump, but the upstream bending magnet radiation source can be slightly affected. From the storage ring operations point of view, however, all these configurations would work as good as the one presented here, and the choice is up to the user.

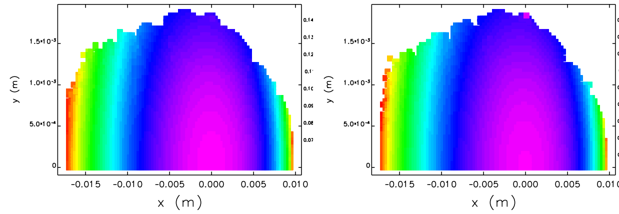

Figure 5: Dynamic aperture for the lattice without orbit bump (left) and with W-bump (right), color coding is horizontal tune.

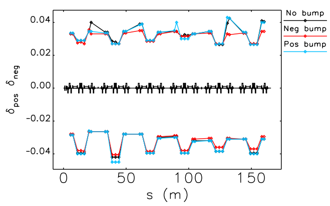

Figure 6: Local momentum aperture for lattice with W-bump.

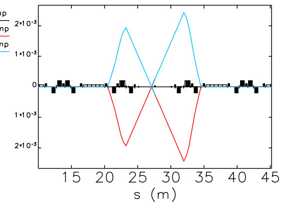

Figure 7: Orbit for W-bump with asymmetrically located central dipole.

One of the possible options for the APS Upgrade is introduction of several longer ID straight sections [4]. It is possible that insertion devices in a longer straight section would have different lengths. In that case, the central dipole does not have to be in the middle of the straight section. The same bump configuration would still work, as shown in Figure 7.

Antisymmetric Four-Corrector Bump

Another option possible in the W-bump configuration is sending the radiation of both devices down the same beamline. To do that, we just need to turn off the central dipole C:BM (Figure 3). Orbit and lattice functions for this bump are shown in Figure 8. Since beta function differences are almost invisible, we don't expect any effects on the nonlinear dynamics in this bump configuration.

Asymmetric Three-Corrector Bump

Recently, a user expressed interest in a configuration where most of the time the undulators will be used in an in-line configuration and only occasionally will the radiation be separated into two beamlines. The two configurations described above would completely satisfy this request. However, for simplicity of everyday operation it would be preferable to have the simplest possible in-line configuration — the straight non-canted configuration. This, however, would require the beamline front end to have an opening at 0 mrad angle relative to the line connecting closest to the ID dipoles. But the existing canted front-end design has only two openings at ± 0.5 mrad relative to that line. This design could still be used if the front end is moved by 0.5 mrad inboard. In the canted mode, this

ISBN 978-3-95450-138-0

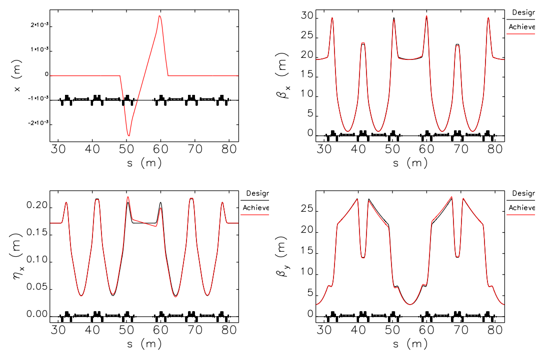

Figure 8: Lattice functions and orbit for two sectors around the ID straight section for an antisymmetric 4-corrector bump. No bump and negative bumps are shown. The order of the plot is the same as in Figure 4.

bump would start with C:BM magnet (see Figure 3). Orbit and lattice functions for this bump are shown in Figure 9.

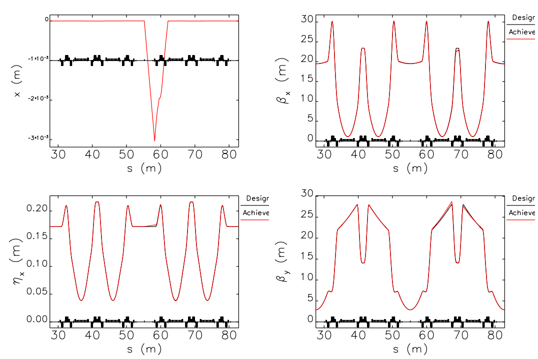

Figure 9: Lattice functions and orbit for two sectors around the ID straight section for an asymmetric 3-corrector bump. No bump and negative bumps are shown. The order of the plot is the same as in Figure 4.

LATTICE CORRECTION

For every case shown above, we first used matching in `elegant` to simultaneously create required orbit bump and adjust the quadrupoles to correct beta functions on the new orbit. For some cases, the matching turned out to be not an easy task and required clever choice and adjustment of varying parameters. This is a valid approach that we have used many times. However, in the real world we would probably just create a required orbit bump, then measure and correct beta functions. We might also change the quadrupoles to some pre-calculated values together with the orbit, but in the end we would still need to measure and correct beta functions.

We decided to test if we could skip beta function matching in the design of a canted lattice and just do optics correction on the new orbit. We wrote a script that performs two steps: runs `elegant` to match orbit bump and then runs our standard beta function correction program *calculateTwissCorrection* that uses SVD inversion of a beta function response matrix. Since the closed-orbit bump condition breaks after beta function correction, this two-step process is repeated for several iterations. The program is bump configuration-independent and can be used for different orbit bumps — it will only require a proper orbit-matching `elegant` file; the beta function correction part is universal. This process usually takes less time than direct matching, is easy to automate, and actually provides better corrected optics. Figures 8 and 9 actually show the results obtained this way.

OTHER ISSUES

To make it out of the vacuum chamber and into the beamline, the radiation would have to fit between the two absorbers that protect the vacuum chamber from dipole radiation and without touching them. Ray tracing shows that this condition is satisfied for all configurations discussed here. However, if the sign of the asymmetric 3-corrector bump is switched to the outboard, then the radiation of the downstream device will hit the wedge absorber W2. Therefore, this canting bump can only exist in the inboard configuration.

Another concern is the pollution of the x-ray BPM signal by the radiation from quadrupoles and sextupoles inside the orbit bump. We have calculated the magnetic fields that the electron beam will see along the canted orbit as a function of the orbit angle. We found that the strongest field encountered by the beam is in the central C:BM magnet, which is the same case as in the present triangular canting configuration.

There are some other issues that would need to be considered. For example, the good field region of the undulators would need to be about 5 mm wider to satisfy the field quality requirements on the switching orbit. Also, rf BPMs on the ID vacuum chamber would need to have an operational range of about ± 2 mm horizontally. This would require an increased distance between the BPM buttons.

CONCLUSIONS

We have simulated several orbit bump configurations that allow for dual-switchable undulator operation. For W-bump and for antisymmetric 4-corrector bump the required corrector strength exceeds the limit, but relatively easy solutions exist that slightly degrade the beamline performance. We have also shown that existing optics correction software can be used to recover lattice functions on the orbit bumps such that the nonlinear beam dynamics is only minimally affected.

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