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STUDY ON BEAM DYNAMICS OF A KNOT-APPLE UNDULATOR PROPOSED FOR SSRF

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Abstract

A new type of undulator, Knot-APPLE undulator, is proposed for SSRF as a solution to reduce the heat load of on-axis high harmonics without losing its capability of tuning synchrotron polarization. It will be applied for SSRF Photoemission Spectroscopy beamline (PES-beamline) in the near future. Impact of the undulator on the beam dynamics has been studied based on the 3D magnetic field model and kick map analysis. Linear optics can be retained by quadrupole compensation within two adjacent cells. Dynamical aperture (DA) shrinkage has been found in the tracking and optimized with sextupoles. An active correction scheme of current strips is studied to compensate the kick maps, and both the linear and nonlinear effects are suppressed.

INTRODUCTION

Shanghai Synchrotron Radiation Facility (SSRF) is an intermediate energy light source opened to users since 2009 [1]. There are 7 beamlines in operation, 5 of which are from insertion devices including IVUs, wigglers and EPU. Another 6 beamlines are under commissioning, including the 'dreamline' based on a double EPU, two canted beamlines from canted IVUs in one straight section, and some other beamlines from IVUs or bending magnets. In near future, a new type of undulator, Knot-APPLE undulator, will be equipped in SSRF storage ring for PES-beamline [2]. Main parameters of the existing IDs and Knot-APPLE in SSRF are listed in Table 1.

Table 1: Main Parameters of Existing IDs and Knot-APPLE in SSRF

	Type	λ_{ID}	L_{ID}	$B_{y,peak}$
H08U	EPU	10cm	4.2m	0.6T*
H09U58	EPU	5.8cm	4.9m	0.68T*
H09U148	EPU	14.8cm	4.7m	0.67T*
H13W	Wiggler	14cm	1.4m	1.94T
H14W	Wiggler	8cm	1.6m	1.2T
H15U	IVU	2.5cm	2m	0.94T
H17U	IVU	2.5cm	2m	0.94T
H18U	IVU	2.5cm	1.6m	1T
H19U1	IVU	2cm	1.6m	0.84T
H19U2	IVU	2cm	1.6m	0.84T
Knot-APPLE	EPU	20cm	4.4m	0.7T*

* For horizontal polarization mode

In this paper we will firstly give a brief introduction of Knot-APPLE undulator, and then estimate its effects on beam dynamics using kick map analysis. Quadrupole compensation is studied, and the linear optics could be retained. The nonlinear effect, which brings significant reduction of dynamical aperture, was optimized with sextupoles. Furthermore, an active correction scheme of current strips is also considered to compensate the kick maps, so as to suppress both the linear and nonlinear effects. The preliminary simulation gives us an encouraging result that the linear effect would be an order less and the dynamical aperture is tolerable for operation.

KNOT-APPLE UNDULATOR

Knot-APPLE combines the advantages of both the Knot and the APPLE type of structure in EPU fabrication, and could reduce the on-axis heat load without lose its ability to generate variable polarization [2]. With such a complicated structure, Knot-APPLE would significantly impact on beam dynamics. To estimate its effects, the 3D magnetic field model has been established, as shown in Fig. 1.

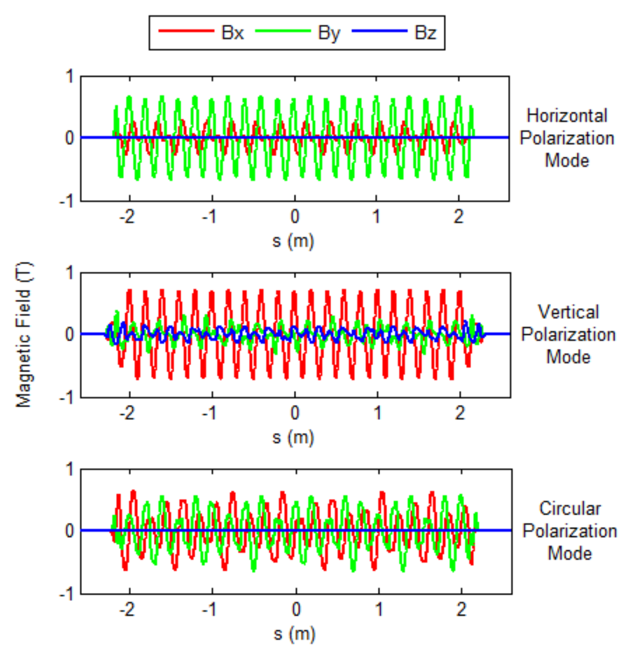

Figure 1: Magnetic field of the Knot-APPLE undulator at minimum gap.

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EFFECTS ON BEAM DYNAMICS

Kick map analysis [3] is used to estimate the effects of Knot-APPLE based on the 3D magnetic field model. As shown in Fig. 2, the kicks are larger in vertical polarization mode than horizontal or circular polarization mode.

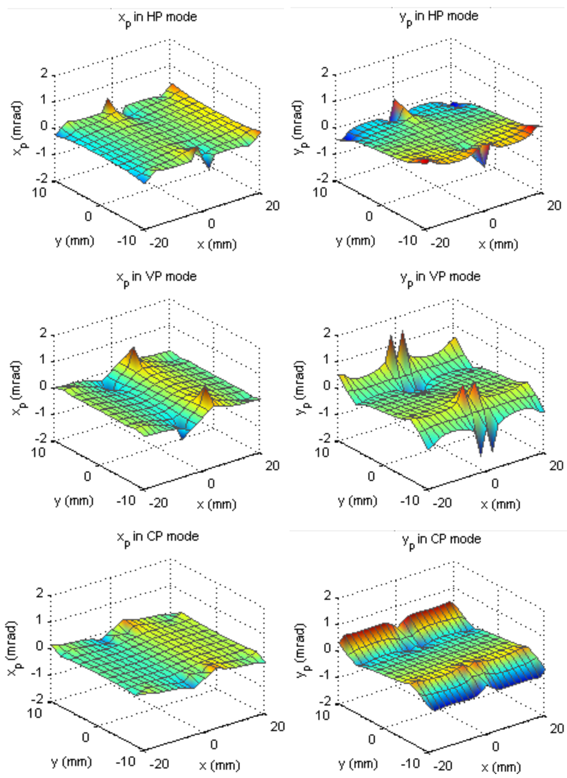

Figure 2: Kick maps of the Knot-APPLE undulator at minimum gap.

The tune shift could reach up to 0.01/-0.007 (horizontal/vertical) in vertical polarization mode, while it is -0.0005/0.0004 and 0.004/-0.003 for horizontal and circular polarization mode, respectively. The RMS of global beta beating is 5%/3% (horizontal/vertical) in vertical polarization mode, and 0.4%/0.3% and 2%/1% in horizontal and circular polarization mode, respectively.

The nonlinear effect is estimated with the variation of dynamical aperture. It is simulated by accelerator toolbox (AT) [4] with 1000 turns tracking. The horizontal dynamical aperture is reduced significantly in vertical polarization mode, which would be a problem for injection. In horizontal and circular polarization mode, the reduction of horizontal dynamical aperture is much small. On the other hand, the vertical dynamical aperture is found to be reduced severely, especially in vertical polarization mode.

NORMAL CORRECTION SCHEME

Adjacent quadrupoles are used to match the linear optics. The RMS of global beta beating could be suppressed to a level of 0.01% for both horizontal and vertical plane in each polarization mode. However, it brings a further reduction in dynamical aperture. The sextupoles are optimized, and the dynamical aperture is enlarged a little. However, nonlinear optimization is time consuming, especially for the sextupoles are in families, which means a global compensation to a local disturbance.

In the normal correction scheme, it involves 6 quadrupoles and all the 8 families of sextupoles. And it is inefficient to obtain the feedforward table for various polarization modes. On the other hand, the accuracy of power supply would also be a challenge, because the current of feedforward is very small comparing to the original current of quadrupoles and sextupoles. It is better to establish a dedicated correction system to compensate the disturbance of Knot-APPLE in the local area, and the active correction scheme of current strips is considered.

ACTIVE CORRECTION SCHEME

The current strips correction scheme was firstly proposed by I. Blomqvist for APPLE undulator in BESSY [5]. The strips are stuck along the vacuum chamber, and supplied with current independently. So it is possible to generate a magnetic field consisting of dipole, quadrupole sextupole and even higher mode multipoles. The magnetic field distribution depends on the current for each strip, and could be calculate precisely. Practically, we measure the multipole integrals of Knot-APPLE first, and then work out a solution of current for the strips. Combining the contributions from Knot-APPLE and the current strips, the kicks are depressed.

The layout of current strip correction scheme is shown in Fig. 3. There are 12 independent current strips on the upper surface of vacuum chamber, and another 12 on the lower. The cross section of current strips is 4mm in width and 1.8mm in height, and the maximum current is about 10A. The interval between strips is 1mm.

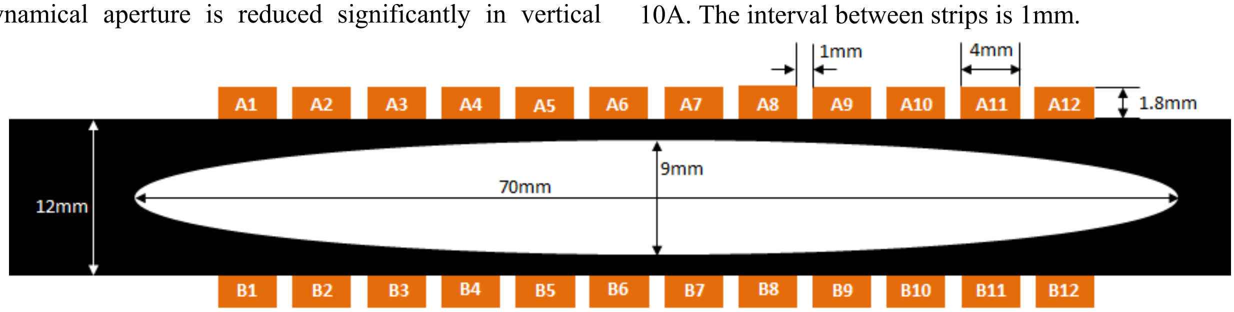

Figure 3: Layout of current strip correction scheme for Knot-APPLE.

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Preliminary simulation has been done. Kicks near the longitudinal axis could be depressed to one order smaller. A solution to correct horizontal kick for vertical polarization mode is shown in Fig. 4.

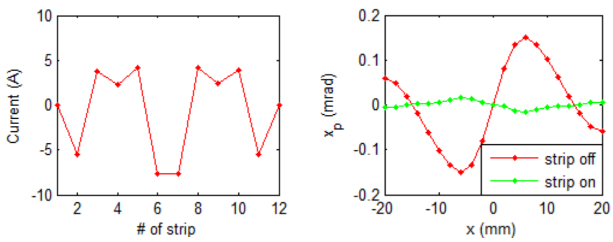

Figure 4: A solution to correct horizontal kick for vertical polarization mode. Left: the current of the strips. Right: the horizontal kicks before and after current strip correction.

The effect on the linear optics is reviewed after preliminary correction with current strips. The RMS of global beta beating is within 0.5% in both horizontal and vertical plane, which is acceptable for operation. Figure 5 illustrates the distribution of global beta beating before and after current strip correction for vertical polarization mode. The tune shift is also found one order less, no matter in horizontal or vertical plane.

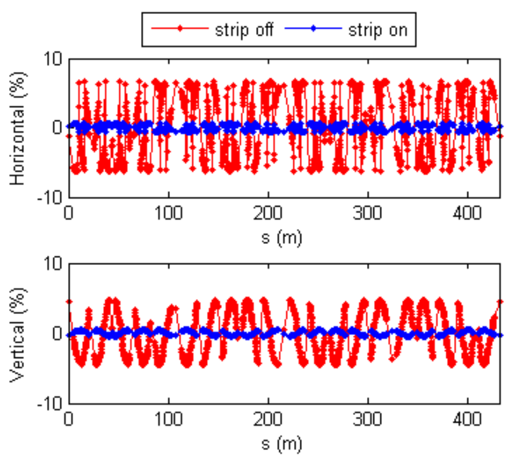

Figure 5: Global beta beating before and after current strip correction for vertical polarization mode.

The dynamical aperture is also optimized. Although dynamical aperture degrades worse in vertical plane, we pay more attention in the horizontal, which brings significant impact on injection efficiency. What is more, the height of the vacuum chamber is limited so as to save space for tuning Knot-APPLE, and the physical aperture is no more than 5mm. To be practical, the vertical dynamical aperture is only optimized to be as much as the physical aperture, while the horizontal dynamical aperture is almost restored, so as to keep the injection efficiency. The dynamical aperture of vertical polarization mode is illustrated in Fig. 6, including the degradation with Knot-APPLE and the correction with current strips.

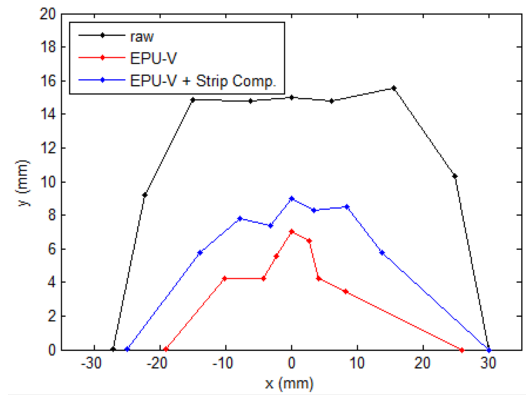

Figure 6: Dynamical aperture of vertical polarization mode: degradation with Knot-APPLE and correction with current strips.

CONCLUSION

A new type of undulator, Knot-APPLE, is proposed for PES-beamline in SSRF. The effects on beam dynamics are studied based on the 3D magnetic field model and kick map analysis. The major disturbance comes from the vertical polarization mode. The tune shift could reach up to 0.01/-0.007 (horizontal/vertical), while the RMS of global beta beating is 5%/3% (horizontal/vertical). Dynamical aperture is also reduced significantly, especially in the vertical plane. Normal correction scheme including quadrupole compensation and sextupole optimization is studied. The linear optics is retained very well. However, the nonlinear optimization is inefficient and difficult for operation. An active correction scheme of current strips is considered. With its ability to generate multipoles, the linear optics distortion is depressed by an order, and the nonlinear effect is also optimized to be tolerable in the preliminary solution. The tuning flexibility of current strip correction scheme also makes it practical for operation.

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