INSERTION DEVICES AND BEAM DYNAMICS IN THE PLS-II STORAGE RING

S. Chunjarean[#] and S. Shin, Pohang Accelerator Laboratory (PAL), Pohang, Korea

Abstract

Effects of insertion devices like a superconducting multipole wiggler or an in-vacuum undulator on the beam dynamics of tghe upgraded Pohang Light Source (PLS-II) storage ring have been investigated. The narrow gap related to a short period length of the in-vacuum undulator or a transverse magnetic field roll off can impact the dynamic aperture or Touschek lifetime or injection efficiency. A three dimensional magnetic field model has been developed based on numerical data consisting of several coefficients in the Taylor expansion to accurately represent the actual field. In this paper, the magnetic field model has been produced with the differential algebraic code COSY INFINITY to formulate the Taylor transfer map for the wiggler and undulator. Frequency map analysis (FMA) and full 6D tracking has been performed to investigate resonances which may affect the particle stability and causing a reduction in injection efficiency.

INTRODUCTION

Insertion devices (ID) like wiggler and undulator magnets are most efficient to produce high brightness synchrotron radiation. The PLSII storage ring has just been upgraded to allow installation of twice as many IDs up to 22. While they greatly enhance the utility of a synchrotron radiation source, they also cause problems for beam dynamics, which must be solved before utilization.

During operation, the strengths of IDs will be changed arbitrarily as required by the research objectives. Such changes can cause a shift in the orbit for all users which would impact the quality of experiments if not compensated. We will discuss these compensations one by one as implemented in PLSII IDs.

BEAM OPTICS FOR PLS-II STORAGE RING

PLS-II is replacement of the original PLS and provides twice as many (24) straight sections for IDs in additional to a smaller beam emittance at a beam energy of 3 GeV. A diffusion map for the bare lattice for the beam region within the vacuum chamber. There is sufficient stability with some weak influence of a quarter resonance at about 13 mm in horizontal axis. Implementation of the ID strengthens this resonance leading to a reduction of dynamic aperture. We choose therefore to change the storage ring tunes from υ_x/υ_y 15.28/9.18 to 15.245/9.18 which is used for linear and non-linear perturbation studies and corrections. The frequency map in Fig.2 shows a greatly improve beam stability. The beam optics for the new tunes are shown in Fig.3.

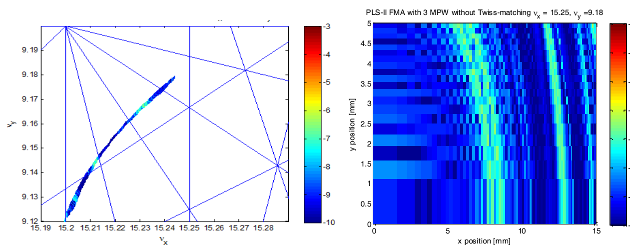

Figure 1: Diffusion map for the PLSII lattice with horizontal and vertical tunes of 15.245 and 9.18, respectively.

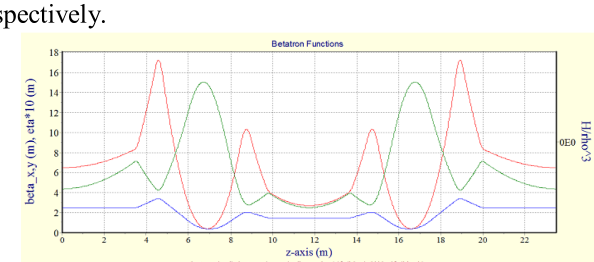

Figure 2: Betatron functions in horizontal (red solid line), vertical (green solid line) planes and dispersion function (blue solid line).

INSERTION DEVICES AND BEAM DYNAMICS IN THE PLS-II

To obtain high brightness for the PLS-II ring, insertion devices as wigglers, in-vacuum undulators (IVU) and EPU are required with parameters listed in Table.1. There are three high field wiggler magnets, eight in-vacuum unduators and EPU. To ensure beam stability for all users, independent of the field in individual IDs, a series of corrections must be implemented.

Table.1: Insertion devices parameters

ID	Period [cm]	No# of period	Min Pole gap [mm]	By [T]	Bx=By (circular mode) [T]	Bx [T]
2A EPU	7.20	34	18.00	0.793	0.482	0.608
IVU20C (SFA)	2.00	67	5.00	0.970		
MPW10 (2 m)	10.00	20	12.00	1.800		
MPW10 (1 m)	10.00	11	12.00	1.800		
MPW14 (1 m)	14.00	8	14.00	2.020		

Linear and non-linear fields of these magnets impact on beam dynamics not on the orbit therefore to correct first and second field integrals are required to preserve orbit for users. The linear perturbation can be corrected by adjusting adjacent quadrupoles called Twiss matching.

Linear Perturbation Compensation

The periodic field of an undulator is given by

$$B_y = -\sum_{m,n} B_{0mn} \cos(k_{xm}x)\cosh(k_y y)\cos(k_{zn}z)$$

$$B_x = \sum_{m,n} B_{0mn} \sin(k_{xm}x)\sinh(k_y y)\cos(k_{zn}z)$$

$$B_z = \sum_{m,n} B_{0mn} \cos(k_{xm}x)\sinh(k_y y)\sin(k_{zn}z)$$

where k_i are wave number periods. Without any corrections, the IDs perturb the beam optics not only breaking a symmetry of the ring but also introduce variation on the vertical betatron function as shown in Fig. 3 with a vertical tune shift to +0.021. The frequency map in Fig.4 shows the detrimental effects as well.

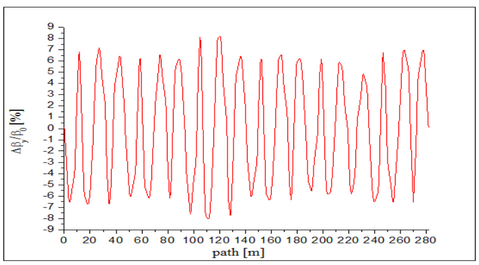

Figure 3: Change in the vertical betatron function caused by Ids without corrections.

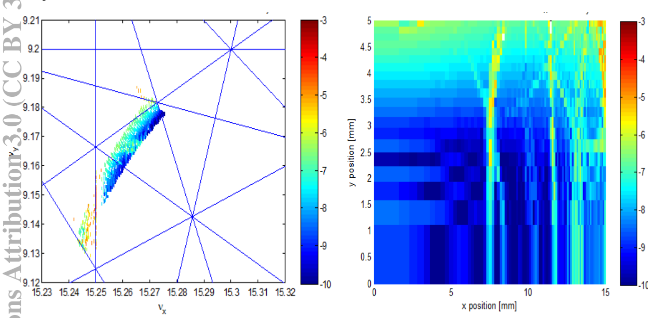

Figure 4: Frequency map for implementation of all IDs into PLSII without corrections.

First, we assume wide magnet poles which make Bx =0 in the beam area. The linear term Bz give rise to vertical focusing which can be corrected by adjusting adjacent quadrupole. Starting from unperturbed Twiss function, we use three of the closest quadrupoles (Fig.5) to create a symmetry plane in the middle of the ID.

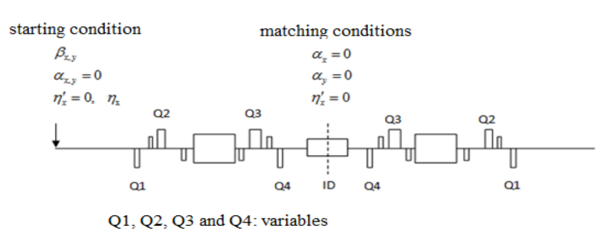

Figure 5: PLS-II cell (schematic) with an ID for betatron function matching.

This matching together with the ID tune shift, unfortunately causes a shift in both tunes. Figure 6 shows a flow chart for an iterative approach, which matches the Twiss function while keeping the tunes constant.

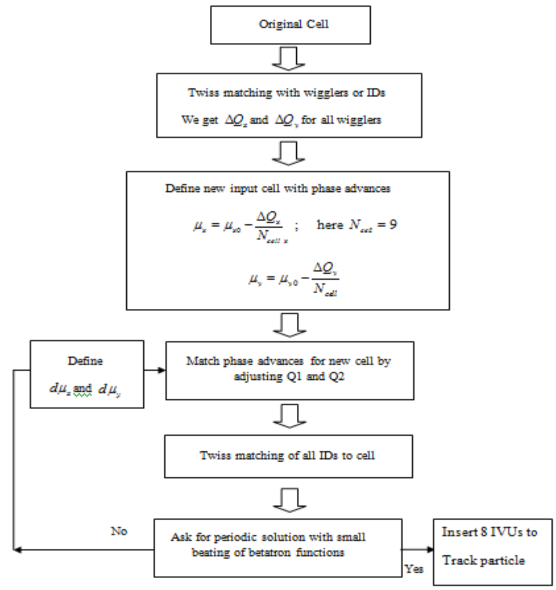

Figure 6: Flow diagram for iterative Twiss while keeping the tunes close to design values.

Applying this matching and tune iteration for the 11 IDs in PLSII with quadrupole strengths listed in Table 2, we are able to confine the ID perturbations to their vicinity. The beta beating (variation of the betatron function at similar points of the lattice) is eliminated as shown in Fig. 7. The symmetry of the ring and beam stability is essentially restored as verified later with non-linear studies.

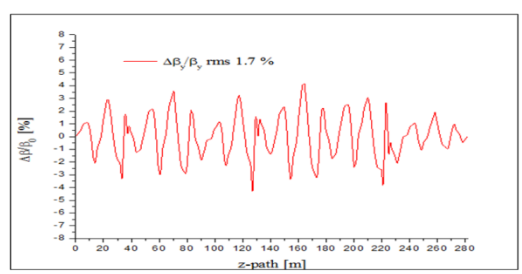

Figure 7: Variation of betatron function for Qx = 15.243 and Qy = 9.181 with three wigglers and eight in-vacuum undulators after Twiss matching and storing tunes.

Non-Linear Perturbation by Insertion Device

Equation (1) shows many non-linear terms in the field equations. We still assume for now wide magnet pole leading to Bx =0. That leaves the nonlinear term for By and Bz. These intrinsic fields will be included during the particle tracking in the presence of all IDs. The frequency map in Fig.8 shows the appearance of reduced stability for large vertical betatron amplitudes. Fortunately, these effects do not yet lead to beam loss, but indicate an eventual limit of stability for IDs.

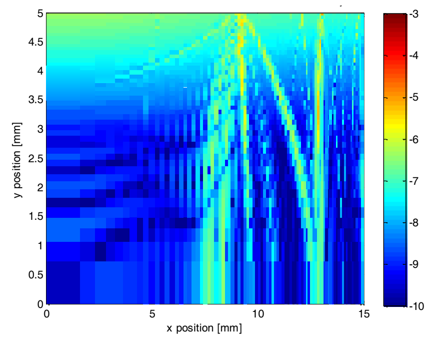

Figure 8: Diffusion map in coordinate space for the PLSII lattice (Qx =15.243 and Qy =9.181) with intrinsic nonlinear fields of three wigglers and eight IVU20.

Table2: Quadrupole Strengths for Iterative Twiss and Tunes Matching for PLS-II with 11 IDs

Quadrupole	Strength [1/m²]	Δk/k [%]
Q1	-1.691560	-0.54
Q2	2.359740	-0.15
Q3	2.014290	0
Q4	-1.961848	0
Q2W10	2.357302	-0.26
Q3W10	1.999296	-0.74
Q4W10	-1.920449	-2.11
Q2W102	2.355629	-0.33
Q3W102	1.988063	-1.3
Q4W102	-1.888302	-3.75
Q2W14	2.356657	-0.28
Q3W14	1.995059	-0.95
Q4W14	-1.908420	-2.72

NON-LINEAR FIELD ROLL-OFF

The finite width of undulator and wiggler poles cause a field "roll-off" [1]. This is especially often true for cost reasons in permanent magnet devices. This effect can be quite significant and need to be evaluated by modeling with a code like COSY INFINITY [2]. Transverse and longitudinal fields in one quadrant are used for both wiggler and IVU20. These fields are expanded in form of a 7th order Taylor series and a frequency map including both intrinsic nonlinear and horizontal roll-off is shown in Fig. 9. The effect of the field roll-off is very small and can be noticed only for large amplitudes (x = 15 mm and y = 5 mm) and is therefore not detrimental to the beam.

RESULTS AND DISCUSSION

Effect of the horizontal field roll-off of the wigglers and IVUs is slightly impact on resonances up to area 14.7 mm and 3.6 mm in horizontal and vertical planes, respectively. It means that this roll-off has no influence on stored beam however it is significantly effect on injection efficiency at large amplitude of oscillation. Installation of IDs into the ring lattice can perturb the beam optics period. By an iteration of Twiss matching we were able to restore the original tunes. The remaining beating of the betatron function has been reduced to 1.7 % rms in the vertical plane. A perturbation in horizontal betatron function appears only in the matching region of the IDs periods. A result of the frequency map we can see clearly that the 4th order of the resonance can be avoided for these tunes (Qx = 15.243 and Qy = 9.181). In addition the frequency map, we can get a good working point of tunes what governs dynamic aperture and helps to identify sources of the particle loss.

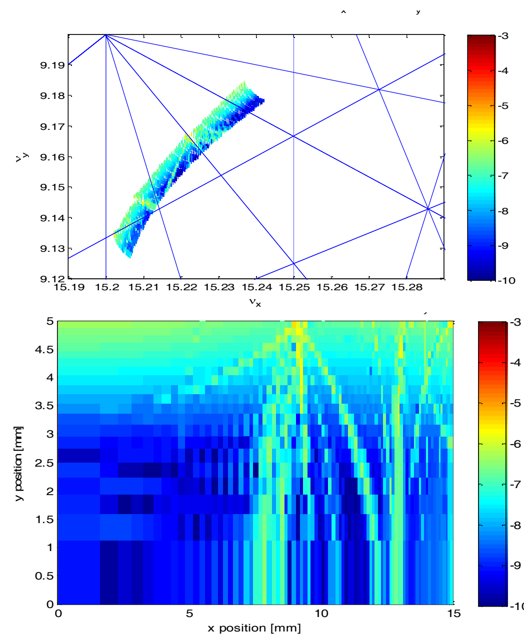

Figure 9: Frequency map in frequency (upper) and coordinate (bottom) spaces for Qx = 15.243 and Qy = 9.181 with non-linear intrinsic and horizontal field roll-off after the iterative Twiss and tunes matching.

ACKNOWLEDGEMENT

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[1] J. Safranek and *et. al,* Nonlinear dynamics in a SPEAR wiggler, Phys. Rev. ST Accel. Beams 5, 2002

[2] COSYINFINITY, Reference manual, LBL-28881, 1990.