ACTIVE SHIMMING OF DYNAMIC MULTIPOLES OF AN APLLE II UNDULATOR IN THE DIAMOND STORAGE RING

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Abstract

Diamond has recently installed a 5 m long, APPLE undulator in a long insertion straight section. Theoretical investigations showed a severe impact on machine dynamics especially when the device is operated in vertical polarization mode. The use of local optics corrections and/or lowering of beta functions were initially investigated as possible solutions but with limited success. Active shimming of dynamic multipoles, following the approach at BESSY-II, proved more effective. The optimum shiming has been devised using kick map approach. In this paper we describe the theoretical analysis, the commissioning of the active shims and undulator, and the net effect of the undulator after compensation.

INTRODUCTION

Diamond is a 3GeV low emittance ring which has been operational since 2007. It has six long and eighteen short insertions straights. The long straight has large horizontal (~10m) and vertical (~6m) beta functions. An APPLE II undulator with long period length (λ=140mm number of periods N=34 and minimum gap of 23.5mm) is operational in the long insertion straight I05. Its effect on linear tunes and beta beat were simulated using kick map. It produced significantly large linear tunes and beta beatings which could not be suppressed by lowering beta functions in both planes and feed forward corrections using the triplets on either side of the ID.

An active shim system, based on an array of current carrying wires, was used to compensate the dynamic multi-pole fields generated in the ~5 meter long device. This particular scheme was selected as at appears to be simple and has more flexibility. It is based on a similar scheme used at BESSY II [1]. The beam dynamics in the IDs and wires system was modelled with the kickmap approach [2] rather than the symplectic integrator used at BESSY-II. Optimum shim wire currents were set to minimise the linear optics distortion and dynamics multipoles

The wires shim consists of 28 copper wires mounted in a ribbon on the vacuum chamber. 14 wires will be on the top and the remaining 14 will be fitted on the bottom of the vacuum chamber. This set of wires will produce a field map over the aperture required for injection and good beam lifetime.

ACTIVE SHIM SETUP

Fourteen power supplies control the currents in these wires. Figure 1 shows the wire configuration. The top and the bottom wires will be connected in series to one power supply and will carry current in the same direction. A maximum current of about 20 amperes can flow through the four central wires, while 10 Amps can flow in the remaining ones. A water cooled vacuum chamber takes care of the heat load of these wires. The cross-section of the wires is 3 mm x 0.3 mm. The effective length of these wires is ~5m. The return sections of all the wires is assembled together and routed in such a way that it does not produce any disturbing field on the electron beam.

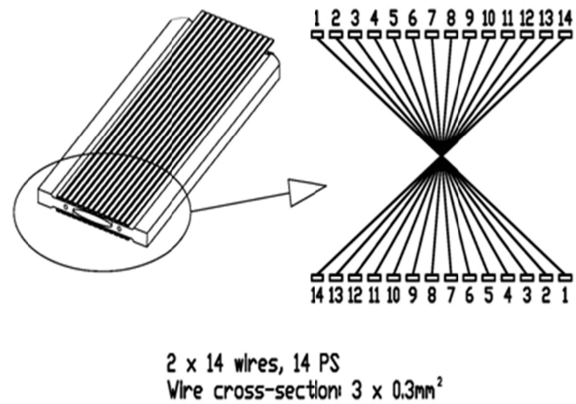

Figure 1: Shim wires set up.

COMPUTATION OF KICKMAP

RADIA and MATHEMATICA programs were used to do the calculations. KICKMAP [2] program was used to calculate kickmap for the device. In the map file, the undulator is replaced by the integrated horizontal and vertical angular kick $\theta_x(x,z,\gamma)$ and $\theta_z(x,z,\gamma)$. The kick values depend on the transverse coordinates x and z and the normalized electron energy γ = Total energy / m_0c^2.

The kick values obtained from the kickmap were used to calculate the equivalent field integrals corresponding to the dynamic multipoles generated by the device. The RADIA [3] program was used to calculate the interaction matrix for the active shim wire setup. A program was written in Mathamatica to calculate currents that will generate the same field pattern with opposite sign. The kickmap due to the active shims was calculated using this program. This kickmap was added to the original kickmap from the device to get the total kickmap. This total kickmap was used to see the effect of the device with active shim on the beam dynamics.

Kickmap Computation for Vertical Polarization (VP) Mode

Figure 2 shows the horizontal kick values obtained from the kickmap due to the device at different transverse

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horizontal positions from the beam axis A good field region of ±20 mm was required for good injection efficiency and Touschek lifetime. Figure 3 shows the vertical kick values obtained from the kickmap at different transverse vertical positions

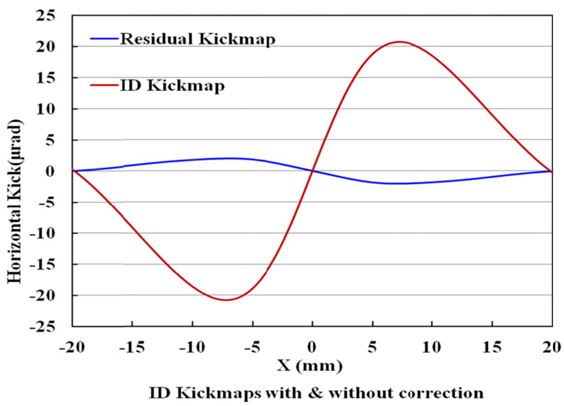

Figure 2: Horizontal kicks versus horizontal position with and without active shim.

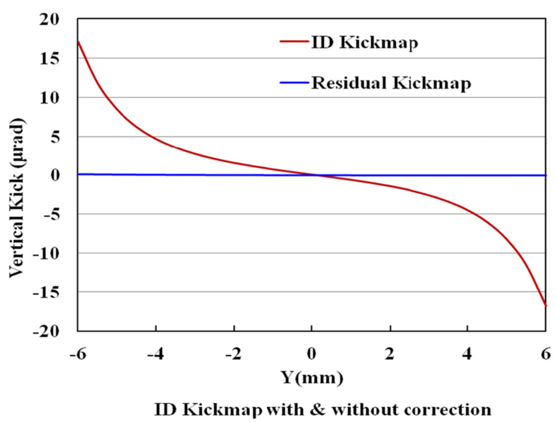

Figure 3: Vertical kicks versus vertical position with and without active shim.

Initially, the currents were calculated to compensate the horizontal kicks in the midplane. Vertical kicks at different locations in the beam aperture are not fully compensated for this current configuration. These currents were then multiplied by a correction factor such that linear tune-shifts in both planes and beta-beating were minimised.

Optimum Shim Wires Currents

The correction factor of 1.125 and 1.2 were found to give the best overall compensation for circular (CP) and vertical polarization (VP) modes respectively. Figure 4 shows the current values that give the best overall compensation VP and CP modes. The application of the same procedure to the case of the horizontal polarization mode (HP) was not as successful. The scaling factor was established experimentally. This discrepancy is under investigation.

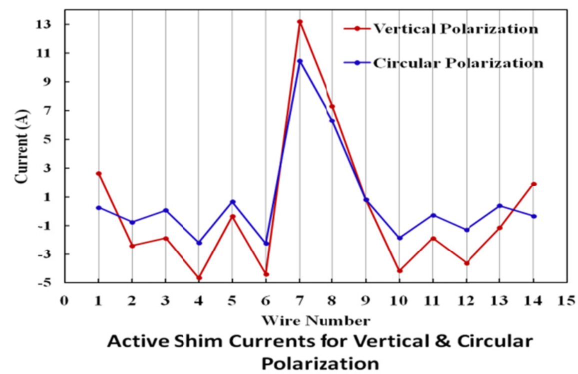

Figure 4: The current values of shim wires which produced optimal correction in VP and CP mode.

OPTIMIZATION OF ACTIVE SHIMS

The total kickmaps computed as described above were used to calculate linear optic perturbations such as linear tune-shifts and beta beating and to study the effect on injection efficiency and Touschek lifetime for VP, CP and HP modes.. Linear optics perturbations were computed using optic codes AT and TRACY II and results are shown in table 1.

Table 1: Linear tune-shifts and relative beta beatings with ID and ID+shims

Mode (phase)	$\Delta Q_x/\Delta Q_y$ ID (10^{-2})	$\Delta Q_x/\Delta Q_y$ ID+ shims (10^{-2})	Relative beta-beatings ID/ID+shims (x, y) (%)
VP (0.5)	-4.3/3.2	0.3/0.3	(33,32)/(2,3)
CP (0.35)	-3/2.6	0.5/0.4	(22,25)/(3,3)
HP (0.0)	0/1.5	0.8/0.7	(2,13)/(5,6)

As stated before the HP mode tune-shifts were not compensated by shims but transferred from vertical to horizontal (see table 1). Therefore it was decided to compensate linear optics perturbations using feed forward (ff) table of 4-quadrupole families including one quad from the achromat on either side of the ID. Residual beta beat is reduced to less than 1% except in the ID neighbourhood.

Nonlinear Beam Dynamics Studies

The dynamic aperture (DA) was simulated using AT with the total kickmaps of different modes of polarization. Figure 5 shows the DA of VP mode with shims on. A chaotic region appears around x=9mm which is absent when no ID and shims are present. this region is within the injected beam oscillations and therefore it could impact the injection efficiency. Therefore further studies have been carried out to simulate its effect on injection efficiency and Touschek lifetime using model developed at Diamond [4].

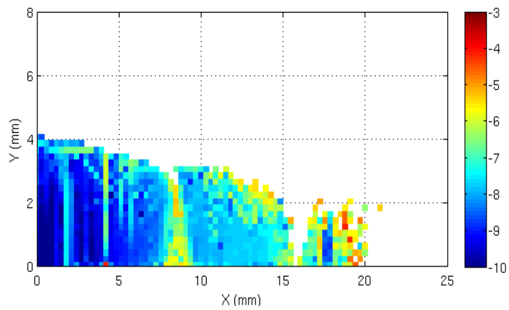

Figure 5: DA calculated using residual kickmap of VP mode (ID+shims) + 5mm apertures in one of 5mm gap in-vac ID.

Injection Efficiency

The injection efficiency was simulated in presence of random multipolar errors of magnetic elements in presence of the full engineering apertures. The results are listed in table 2. For some seeds the injection efficiency can decrease below 80% for VP and CP mode, and below 70% in HP mode. Therefore ff table is preferable in this mode.

Table 2: Injection efficiency simulated for different seeds.

seed	VP+ shims (%)	CP+ shims (%)	HP+ shims (%)	HP+ ff (%)	Without ID (%)
101	79.0	79.0	69.3	78.0	87.6
85	99.3	99.3	96.1	99.0	99.3
3	99.6	99.6	96.2	98.9	99.6

Touschek Lifetime

The Touschek lifetime simulated are shown in table 3 and it can be reduced by 0.9h in HP mode with shims.

Table 3: Computed 6D Touschek lifetimes for different polarization modes.
(bunch length σ_l=2.8mm, 500mA, 2/3 fill pattern)

Mode	Touschek Lifetime (h)
VP	10.0
CP	10.3
HP	10.7
HP +feed forward	10.8
I0913+i05 aperture	10.9

COMMISIONING OF ID

The ID chamber with active shims was installed much before installation of the ID which provided us an opportunity to experiment effect of the active shims on e^- beam. During the experiments it was found that design shim currents generated large orbit distortions in machine, while ideally design shim currents should not generate orbit errors.

Alignment of shims

In order to align the shim wires, currents configuration were set in such a way as to generate the highest gradient of vertical field to produce maximum orbit distortion due to misalignment. Then we generated orbit bumps in x and y to produce the minimum orbit distortion in order to assess the misalignment of the centre of the wires. The vessel was then moved by x=0.9mm and y=0.2mm leaving only few tens of microns or residual orbit distortion. When the ID was installed then it was aligned with vessel. The effect on the orbit was finally checked with the ID closed to minimum gap and the shim currents powered for the respective polarisation modes and it was found that in all cases the effect on the orbit was reduced to 10-20μm.

Experiment with ID

The ID was closed to minimum gap at 300mA beam current in different polarization modes. The linear tune-shifts were measured and are listed in table 4. They are smaller than the theoretical values predicted in table 1. We then set the theoretically calculated shims currents for the respective polarization mode. These currents were scaled down by a scaling factor to minimise tune-shifts. The residual tune-shifts are listed in table 4. Then LOCO was used to measure the residual beta-beat (table 4). The residual beta-beat is less than 6% showing a good correction of the optics. in all mode of polarization of the ID.

No effect on injection efficiency was noticed when the ID was closed minimum gap with optimum shims in CP, VP and even in HP mode though theoretical predictions (table 2) indicated so. This could be due to a better than expected field quality of the ID. Further work is in progress to test feed forward and shim wires for different polarization mode and ID gaps.

Table 4: Linear tune-shifts and residual beta-beat with optimum shim wire currents and ID closed to minimum gap (VP: 23.5mm, CP: 27mm, HP: 27mm).

mode	$\Delta Q_x/\Delta Q_y$ Shims off (10^{-2})	$\Delta Q_x/\Delta Q_y$ Shims on to optimum (10^{-2})	Resi. beta-beat (%) (x, y)
VP	-3.6/2.5	0.1/0.2	2, 5
CP	-2.7/1.9	0.2/0.2	3, 5
HP	-0.3/1.0	0.4/0.4	6, 6

CONCLUSIONS

The kickmap approach developed at Diamond to study and optimize the ID with active shim wires has been tested and it successfully corrected the linear and nonlinear optics effect of the ID.. The shims were aligned very well using novel method described in paper. Further tests are in progress to operate the ID in any phase and gap with top up operation. The authors would like to thank members of operation team of Diamond ring.

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