EFFECT OF INSERTION DEVICES ON BEAM DYNAMICS OF THE DIAMOND STORAGE RING USING KICK MAPS

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Abstract

The effect of the Phase I Insertion Devices (IDs) on the beam dynamics of the Diamond storage ring has been investigated using the kick map modelisation of the IDs. Kick maps have been produced with high accuracy using the computer code RADIA, considering many longitudinal harmonics. The effect of IDs on the dynamic aperture, Touschek lifetime and injection efficiency in the low emittance lattice, was investigated considering both coupling errors and physical engineering apertures. Harmful resonances have been identified using Frequency Map Analysis and full 6D tracking was performed to estimate the Touschek lifetime and the injection efficiency. Additionally, the kick maps have been used to generate feed-forward tables for compensation of linear optics distortion.

INTRODUCTION

The Diamond storage ring [1] is a 24 cell DBA lattice with a nominal emittance of 2.7 nm, obtained by breaking the achromatic condition in the straight sections. The storage ring has 6 long straight sections (β_x =10 m, β_y=5.8: at middle of straight) and 10 standard straight section (β_x = 4.7 m, β_y= 1.5 m). Overall, 22 straight sections are free for installation of IDs. For the so called Phase I operation, 7 IDs are currently under installation in the storage ring: these include a high field wiggler MPW60 (B_0=3.5T, λ=60mm, N=25), two APPLE-II undulators: 2xHU64 (B_{x0}=0.8T, B_{y0}=0.9T, λ=64 mm, N=33) and 5 in-vacuum undulators with full gap of 5 mm (two U23 (B_0 = 0.7T, λ=23 mm, N= 73), two U27 (B_0 = 0.8T, λ=27 mm, N= 73) and one U21 (B_0 = 0.64T, λ=21 mm)). All of these devices will be located in standard straights. For the present investigation, five U23 in-vacuum devices have been considered.

The effect of the IDs on the ring dynamics have been extensively studied with numerical tracking codes. The kick map approach [3] has been used to model effects of the IDs using computer codes TRACY-II [4] and BETA-LNS [5]. The effect on Touschek lifetime, momentum acceptance, DA (dynamic aperture), FM (Frequency Map) analysis and injection efficiency has been computed in the presence of coupling errors and realistic engineering aperture.

COMPUTATION OF KICK MAPS

The kick map modelling of an ID is an alternative approach to symplectic integration and was used to study the effect on beam dynamics of APPLE II undulators in the ESRF lattice [6]. The RADIA version of the code to produce kick map from 3D field simulations has been further modified to increase the accuracy of the map by taking a higher number of longitudinal harmonics. The kick maps for MPW60, HU64 and U23 are calculated considering 3, 5 and 5 harmonics and for transverse dimensions of x = ±30 mm and y=±5 mm, ±6 mm and ±2.5 mm respectively.

The 3D kick map (z, x, y: z = kick angle (unit arbitrary), x or y = transverse position in m) of U23 are graphically shown in Fig. 1: the horizontal kick map is shown as a function of the physical aperture and clearly shows the effect of transverse roll off of the magnetic field at |x| ≥ 18 mm.

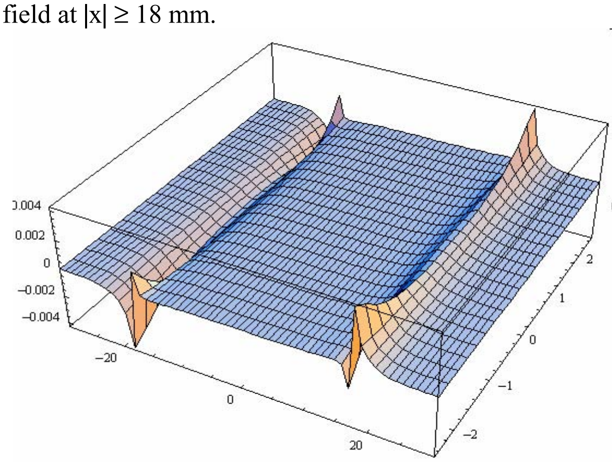

Figure 1: 3D horizontal kick map for undulator U23.

LINEAR OPTIC DISTORTIONS

The effects of the IDs on the linear optics are computed using BETA-LNS first for each individual ID and then for all the Phase I IDs (MPW60+2xHU64+5U23) at the same time. The HU64 is considered separately in its 3 modes (h, v and c corresponding to horizontal, vertical and circular polarizations).

Linear tune-shift and β-beating generated by the IDs are reported in Table 1. The strongest linear optic distortion is caused by the MPW60 in vertical plane. The effects of HU64 are small and those of the U23 are negligible. Two compensation schemes for the MPW60 wiggler were studied: the LOCO algorithm [7] and the alpha-matching with global tunes compensation. In both cases the β-beating was reduced to less than 1%. The quadrupole variation required to compensate the optic distortion is 9% for LOCO and 1% for the alpha matching. Feed forward table have been extracted using kick maps computed at different levels of excitation of MPW60, from the alpha matching scheme.

Table 1: Linear distortions produced by different IDs

ID type	$\Delta\nu_x$	$\Delta\nu_y$	$\delta\beta_x/\beta_x$ (%)	$\delta\beta_y/\beta_y$ (%)
MPW60	0.0	0.013	~0	11
2xHU64 (c)	-0.005	0.007	3	3
2xHU64 (v)	-0.009	0.007	5	4
2xHU64 (h)	0.002	0.005	~0	2
U23	0.0	0.001	~0	~0
All IDs [HU64 (c)]	-0.005	0.023	3	14
All IDs [HU64 (v)]	-0.009	0.024	5	15
All IDs [HU64 (h)]	0.002	0.020	~0	13

FREQUENCY MAP ANALYSIS

DA plots and FMs were computed with TRACY-II to examine the stability of the on-momentum and off-momentum dynamics. The effect of each individual ID was considered separately and then in combination with all the Phase I IDs (MPW60+2xHU64+5U23). Again, the HU64 is considered separately in its 3 modes. Twenty kicks per ID are used in the simulations to include the effect of beta function variations over the ID length. The kick map automatically takes into account the physical limitation of the vacuum chamber of the ID. The simulations include misalignment errors with orbit correction providing a residual coupling of 1%.

The linear tune-shift generated by the MPW60 moves the FM vertically towards three potentially dangerous nodes located at the intersection of the following resonances a): ($3\nu_x$-$2\nu_y$, $3\nu_x$+ν_y, $3\nu_y$), b): ($2\nu_x$-$4\nu_y$, $3\nu_x$+ν_y, ν_x+$5\nu_y$) and c): (ν_x+$2\nu_y$, $2\nu_x$-$4\nu_y$, $4\nu_x$). The corresponding resonances, in particular the $3\nu_y$, reduce the vertical DA from 7 mm to 5 mm while the horizontal DA appears to be unaffected. It is interesting to note that the $3\nu_y$ resonance is a skew resonance excited in first order only by skew sextupoles or by normal sextupoles in the presence of coupling errors. The enhancement of its excitation is therefore a higher-order non-linear effect of the ID. The alpha-matching and global tune compensation restores the vertical DA to 7 mm albeit with more chaotic borders (see Fig.2). The excitation of the $3\nu_y$ resonance is still visible.

The analysis of DA and FMs with HU64 show no significant impact on the stability of betatron motion. In the case of the U23, the vertical dynamic aperture is reduced to 4 mm in the vertical plane, however, this effect is mainly due to the restricted vertical aperture (±2.5 mm) of the ID. In the horizontal plane, tiny holes in the dynamic apertures appear around x=±17 mm as shown in Fig. 3.

A detailed analysis reveals that particles are lost at the $3\nu_x$+ν_y resonance. However, also this effect is due to the vertical aperture limitation of the ID and to the coupling errors since it appears also in the bare lattice with the same vertical aperture limitations imposed by the kick map No explicit effect of transverse roll-off error of the U23 is noted on the DA, despite the U23 field roll off at x=±18 mm.

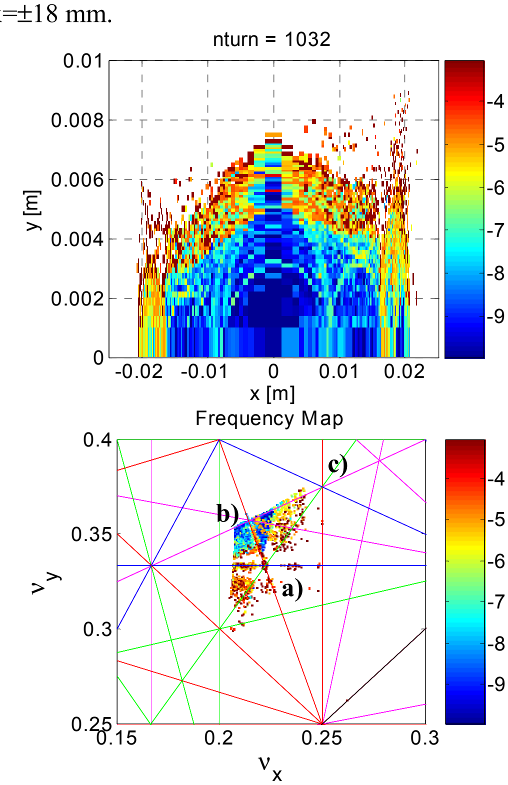

Figure 2: On-momentum DA and FM with MPW60 with alpha-matching/global tunes correction. The vertical aperture of the MPW60 is ±5 mm in the standard straight.

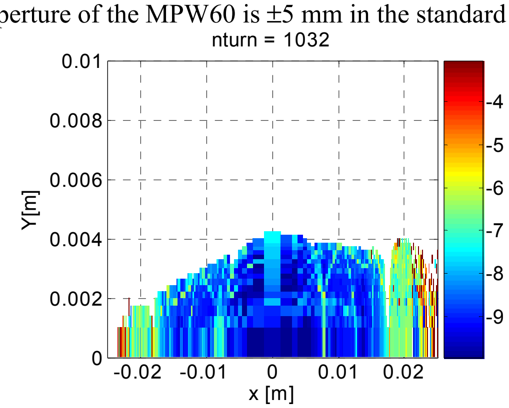

Figure 3: On-momentum DA with U23. The vertical aperture of the U23 is ±2.5 mm in the standard straight.

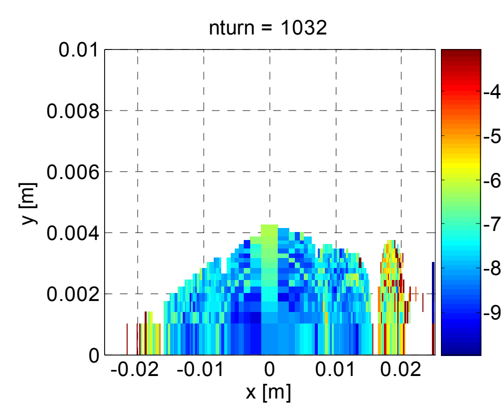

Figure 4: On-momentum DA with all Phase I IDs.

The on-momentum DA was then computed with all IDs and the HU64 in circular polarization mode which is expected to generate the worst coupling effects. The DA is shown in Fig. 4. The vertical dynamic aperture is similar to the one with U23. The hole in the dynamic aperture at 17 mm appears wider and significant losses appear only at very large horizontal amplitudes.

TOUSCHEK LIFETIME COMPUTATION

The Touschek lifetime was estimated with Tracy-II by computing the momentum acceptance for the whole ring instead of one super-period as customary, since the ring symmetry is broken due to linear optic distortions of the IDs. 6D tracking was performed with a residual coupling of 1 % and engineering apertures were included in the simulations. The results are summarized in Table 2. The explicit behaviour of the momentum aperture along the ring is reported in Fig. 5 for the case of the MPW60 with and without linear optic correction.

Table 2: Touschek lifetime computations with IDs (bunch length σ_l = 2.8 mm; 500mA, 2/3 fill pattern)

	6D Touschek lifetime (h)	
Bare lattice		12.7
2xHU64	h-mode	12.5
	v-mode	11.9
	c-mode	11.9
MPW60	no optic correction	11.8
	optic correction	12.8
	optic correction LOCO	12.1
U23		12.7
All IDs	no optic correction	11.8
All IDs with optic correction	HU64 h-mode	13.3
	HU64 v-mode	11.8
	HU64 c-mode	12.3
All IDs + multipolar errors	optic correction	10.7

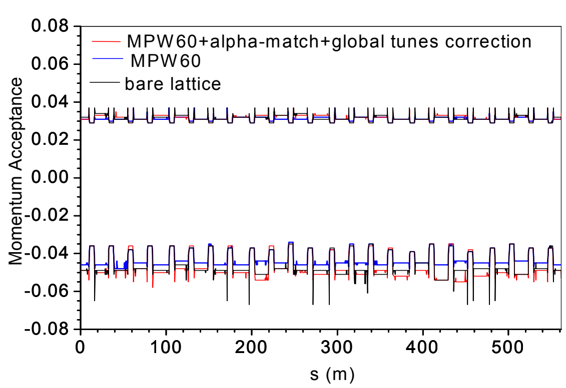

Figure 5: Comparison of 6D Momentum acceptance for the MPW60 with and without linear optic correction.

Without linear optic correction, the negative momentum acceptance is reduced by 0.4%, from -4.9% of the bare lattice to -4.5%. The linear optic correction restores the momentum aperture to the case of the bare lattice. The following conclusions can be made: no severe effect on Touschek lifetime was found as the maximum reduction in lifetime is only about 1 h; the Touschek lifetime is recovered with linear optics correction for MPW60 either in the individual case or with all IDs except HU64 in v-mode; no effect of U23 on lifetime and thus it can be concluded that transverse roll-off, has no effect on the lifetime; the Touschek lifetime with all Phase I IDs, including multipolar errors in the storage ring magnets and 1% coupling errors is 10.7 h.

INJECTION EFFICIENCY

The injection efficiency, computed using the method outlined in Ref. [2], drops from the 99% of the bare lattice to 88% in the case with all IDs without optic correction. However, linear optic corrections are sufficient to restore the injection efficiency to 99%. In Fig. 6 we report a (x, dp/p) FM which shows that off-momentum particles of dp/p=2% and -3% required for injection are stable [2]. Within this interval no particular resonance appears to be excited. Multipolar errors in the storage ring magnets reduce the injection efficiency to about 90%.

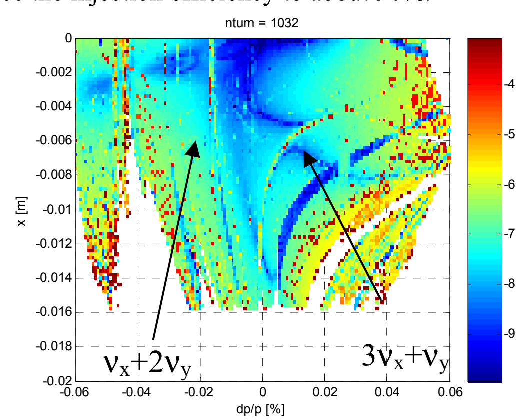

Figure 6: (x, dp/p) FM with all Phase I IDs.

CONCLUSION

The effects of Phase I IDs on the non-zero dispersion lattice of the Diamond storage ring have been investigated extensively. The kick map approach has allowed studying all IDs including APPLE II and the effect of roll-off errors of in-vacuum undulators on Touschek lifetime, DA, FM and injection efficiency. The effect of IDs on Touschek lifetime is small and compensated with linear optic correction only. Including multipolar errors reduces the lifetime to 10.7 h, still in excess of the original target minimum lifetime of 10 h (for 300 mA) and the injection efficiency is close to 90%.

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