NON LINEAR BEAM DYNAMICS AND BEAM LIFETIME ON THE SOLEIL STORAGE RING

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Abstract

The impact of several non-linear effects on energy acceptance and beam lifetime has been investigated, using the BETA and TRACY II tracking codes. The effect of all magnets multipolar components has been checked on the working point (18.20; 10.30), especially the decapolar component induced by the H-corrector. The dipolar field, which is created by additional coils in the sextupoles, generates a significant decapolar component which, together with the large distributed dispersion, can reduce significantly the dynamic acceptance at large energy deviations. This effect depends on the natural closed orbit to be corrected: corrector strengths and cross talk between the different decapolar components. The sensitivity to the number of correctors has also been evaluated. The effect of insertion devices has also been studied, integrating field maps generated by the RADIA code into the tracking codes. With undulators, such as an in-vacuum U20 and an Apple II type HU80 (with different polarization modes), it was shown that the transverse field in-homogeneity and the focusing effects generating beta-beat can affect severely the energy acceptance and the beam lifetime because of resonance excitation.

INTRODUCTION

The nominal working point (18.20-10.30) has been optimised for the SOLEIL storage ring, in terms of energy acceptance and beam lifetime, taking into account the vacuum chamber dimensions (including the 5.5 mm in-vacuum undulator gap) and coupling errors [1]. Regarding 4D dynamics, the particle motion remains stable up to ±6% energy deviations. The physical aperture of the vacuum chamber then limits the Touschek lifetime. Taking into account the non-linear synchrotron motion (which limits the energy acceptance to about –6/+4%), the lifetime, computed in 6D, is 35 h for a 1.2 mA bunch current, 12 ps natural bunch length, 1% transverse coupling and ±6% RF energy acceptance (note that all the Touschek lifetime values presented here are calculated with the same parameters). In order to check the sensitivity of the dynamics to higher order field components and insertion devices, both BETA SOLEIL [2] and TRACY II [3] codes have been modified to include multipolar field components and undulator field maps generated by the 3D RADIA code [4]. A very good agreement between the two codes was found for linear and non-linear, on- and off-momentum dynamics. The TRACY II code was then used to perform Frequency Map Analysis (FMA) [5] in the presence of multipolar field errors and insertion devices. All the frequency maps presented in this paper are calculated in the presence of and coupling errors (random quadrupole rotations lead to a 1% coupling between projected emittances), and with the vacuum chamber limitations.

EFFECT OF MULTIPOLAR ERRORS

The effect of multipolar field components has been tested in parallel with the magnet design in order to define the tolerances. This led to the choice of chamfers and pole profiles for quadrupoles and sextupoles. The calculated values are given in [6]. For the dipole, the components have been calculated around the real curved trajectory, leading to an additional gradient that generates a vertical tune shift $\Delta\nu_z$=–0.07. The fringing field adds $\Delta\nu_z$=–0.076. Both tune shifts are compensated using the 10 quadrupole families in order to restore tunes and symmetry. The chromaticity variation induced by the sextupolar component of the dipoles is small and can be compensated with two sextupole families. The non-linear dynamics is not perturbed by the multipolar components except by the decapolar component created by the H-corrector field (non-linear effects due to longitudinal dependence of the fringing field are under study).

Effect of the decapolar component

Simulations have been done for the nominal working point. A set of 40 random natural horizontal closed orbits has been generated using misalignment errors and corrected with the 56 H-corrector scheme described in [7]. The 6D Touschek lifetime is reduced from 35h to below 25h for 4 seeds over 40, due to a strong reduction of the energy acceptance: the off momentum dynamic aperture is drastically affected and becomes smaller than the physical one. The decapolar component acts as an octupole modifying the amplitude dependent tune shift [6] and exciting the 4th order resonance $4\nu_x$=73 as shown on Fig. 1. As the decapolar component is proportional to the corrector strength, an orbit correction scheme using 120 H-correctors was tested. Then only one seed leads to a reduction of the lifetime below 25h, but this seed corresponds to a good lifetime for the 56 corrector mode. In fact we have demonstrated that the effect of decapolar components depends on corrector strengths but also on the distribution of random errors and on the correction scheme. An attempt to compensate the decapolar spill down effect with octupoles was tested with a local (one octupole proportional to each decapolar component) and a global compensation (one or two octupoles in the ring). The lifetime can be restored with the 3 methods by adjusting octupole strengths and further studies are needed in order to find the best compromise between on- and off-momentum dynamics in the presence of these additional octupoles.

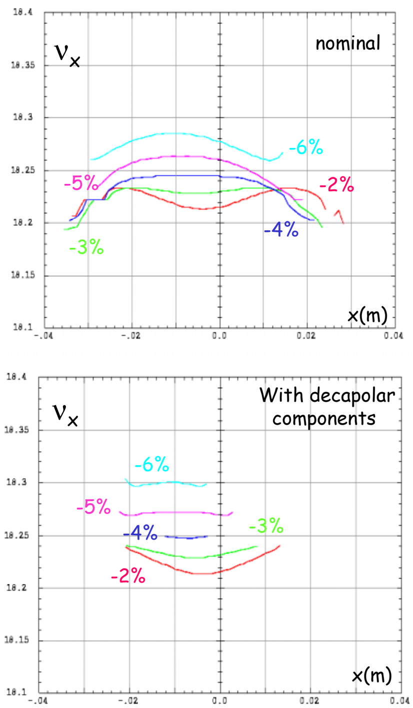

Figure 1: Off momentum amplitude dependent tune shift for (18.20-10.30).

EFFECT OF INSERTION DEVICES

The studies have been done for the first insertion devices (ID) to be installed: in-vacuum Undulators U20, Helical Undulators HU640, HU256 and HU80. Their main characteristics are given in Table 1.

Table 1: Insertion device characteristics.

Device	U20	HU640	HU256	HU80
Length (m)	1.80	8.96	3.328	1.52
Period (mm)	20	640	256	80
Max V-Field (T)	1.02	0.1	0.4	0.925
Max H-Field (T)	-	0.1	0.275	0.718

All the calculations are based on the use of field maps that describe the transverse field profiles in both horizontal (x) and vertical (z) directions. One map gives the integrated values of angular kicks and is split in several thin lenses in order to take into account the variation of the optical functions along the ID.

The effects of HU640 and HU256 have been studied in detail in terms of focusing and dynamics, for the main modes of polarization. For both undulators, the focusing effect remains small and no strong non-linear effects were observed.

U20 effect

As shown on Fig. 2, the magnet width of 50 mm leads to strong transverse field variation beyond x=10mm. The vertical focusing introduced by this undulator is small ($1.55\ 10^{-3}$), there is no additional horizontal focusing and the β-beating is negligible. The field in-homogeneity leads to strong non-linear effects. The limitation occurs at dp/p= - 4.4% where the $4\nu_x$=73 resonance becomes excited in the presence of U20. To cancel the resonance effect, one solution is to design a more than 100mm magnet width in order to improve the field homogeneity. This solution was not retained and a new optimization of the point was done so as to avoid this resonance for off momentum particles (see part 4).

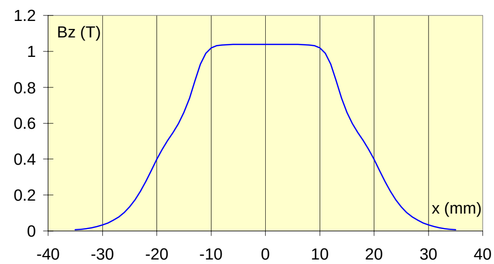

Figure 2: Transverse U20 field homogeneity.

HU80 effect

The effect of this undulator has been studied for 3 main modes of polarization (linear horizontal LH, linear vertical LV and helical HE). In all cases, the in-homogeneity of the fields leads to additional focusing in both planes as shown in Table 2. For the LV polarization mode, the β-beating has to be compensated. The compensation consists in restoring the symmetry of the β functions. As the HU80 undulators are not located at the centre of the straight section, 6 independent quadrupoles per device are needed for the compensation. FMA has shown that the restoring of the optics symmetry cancels the bad effect of the 3rd order $\nu_x+2\nu_z$=39 resonance, which is due to sextupoles and limits the positive energy acceptance. Nevertheless, the $4\nu_x$=73 resonance remains excited at negative energy deviations and the limitation of HU80 is comparable to the U20 one.

Table 2: Focusing effect of two HU80 undulators.

Mode	$\Delta\nu_x$ (Perfect)	$\Delta\nu_z$ (Perfect)	Maximum β-beating x / z
LH (Bz only)	+1.4 10-3 (0)	+3.510-3 (+4.3 10-3)	Negligible
LV (Bx only)	-1.1 10-2 (+3.6 10-3)	+1.1 10-2 (0)	5 / 6
HE (Bx = Bz)	-6.1 10-3 (+2.5 10-3)	+7.9 10-3 (+1.8 10-3)	3 / 4

The effect of the $4\nu_x$=73 resonance is confirmed by FMA. On Fig. 3, the maximum horizontal stable amplitude versus energy deviation is compared to induced amplitudes in straight sections (SDL, SDM, SDC) and achromats (black curves), and to physical aperture (red curve). The diffusion rate is increased by IDs (red color) and an unstable area (white hole) appears around – 4.4%.

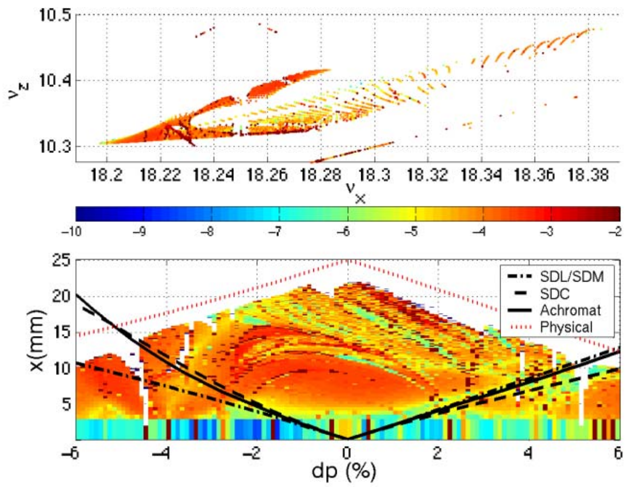

Figure 3: FMA for (18.20-10.30) with all IDs.

A NEW WORKING POINT

FMA has shown that the on momentum dynamics of the nominal point, in the presence of coupling errors, can be limited by the skew 4th order $3\nu_x+\nu_z=65$ resonance and can then affects the top-up operation [8] and the gas beam lifetime. This is due to the strong variation of the cross term $\nu_z(x)$. An optimization was done step by step, for on and off momentum dynamics, by controlling tunes, amplitude and energy dependent tune shifts, in order to avoid 4th order resonances. A new working point (18.19-10.29) was then chosen and offers a vertical dynamic aperture equal to the physical one (Fig. 4). The off momentum map is comparable to the nominal one. The effect of the $4\nu_x=73$ resonance has disappeared but another 4th order is now excited, $2\nu_x+2\nu_z=57$, and becomes a strong limitation with both U20 and HU80 undulators (Fig. 5). As a consequence, the 6D energy acceptance is reduced and the 6D Touschek lifetime is 27h with all IDs instead of 37h for the bare lattice.

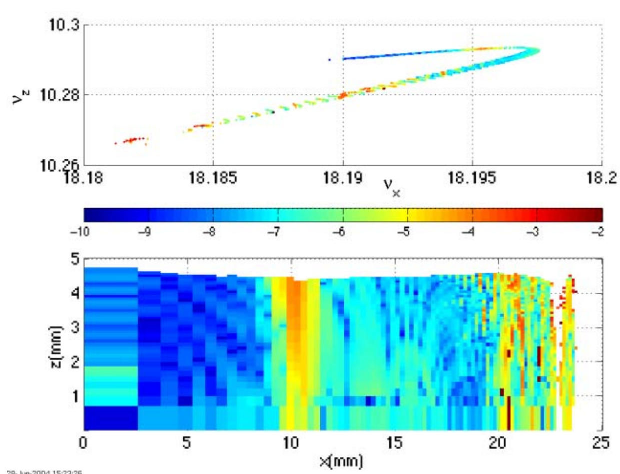

Figure 4: On momentum FMA for (18.19-10.29).

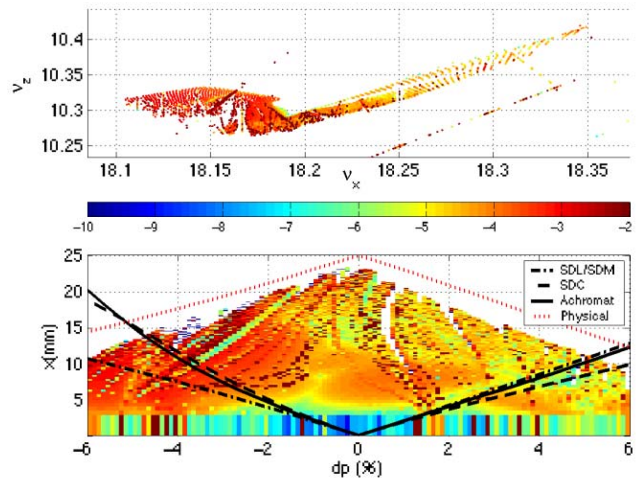

Figure 5: FMA for (18.19-10.29) with all IDs.

CONCLUSION

The study of the effect of the decapolar component created by the H-corrector field has shown that for several seeds, the energy acceptance could be significantly reduced. Even if the 120 H-corrector scheme is better for some particular cases, we do not plan to increase the number of dipolar correctors for the moment. Field maps connected to FMA are a very accurate way for revealing non-linear ID effects. After optimization, a new working point gives now a very good on momentum dynamics and is not sensitive to resonances excited by coupling errors. The off momentum dynamics still suffers from one 4th order resonances excited by IDs and will have to be further improved, including ID integrated field errors.

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