EFFECTS OF PHASE 1 INSERTION DEVICES AT THE ALBA PROJECT

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Abstract

ALBA is the new third generation light source being constructed in Barcelona (Spain). The facility will offer a large number of straight sections, 4 of 8 m, 12 of 4.2 m and 8 of 2.6 m. The compact lattice of a 268 m circumference ring is now mature and its main components are already fixed. The lattice has been designed such as most of the vertical focusing is mainly controlled by the gradients in the dipole magnets. We discuss here the beam dynamics studies performed for Phase 1 Insertion Devices (IDs) where a helical device EU71, a 2T-superconducting wiggler (SC-W31) and two in-vacuum undulators IVU-21 have been modeled using the kick map approach. A suitable compensation scheme has been defined for these devices when considered first independently then grouped according to their phase 1 configuration. In addition, the 6D- Touschek lifetime computations and the identification of the limiting resonances using Frequency Map Analysis showed how strong the working point is in presence of these IDs.

INTRODUCTION

Third generation light sources are optimized in order to accommodate a large number of IDs of different types for the use of photon beams with different polarizations from linear to circular and of different helicity. This constantly increasing demand has resulted in a number of advances in the technology of IDs as well as in the 3D magnetic codes necessary for their design [1]. In-vacuum undulators, APPLE II-type devices, multipole and superconducting wigglers are nowadays typical devices foreseen from day one of the operation of a storage ring. However, when installed in the ring, IDs induce additional linear and non linear effects to the electron beam and thus may limit the dynamic aperture (DA). Moreover, in-vacuum undulators can be operated at rather small gaps and so limit considerably the physical aperture. These effects can affect the beam lifetime and injection efficiency of the machine. It is therefore very important to understand the beam dynamics with IDs, even at the early stage of their design, if one would like to reach optimum performances.

IDS MAGNETIC FIELD DESCRIPTION

When dealing with the dynamics of an electron in the magnetic field of an ID, the usual approach consists in the approximation made by replacing the real magnetic field by the analytical one [2]. This description gives quite a good insight into the 3-dimentional field of a periodic device. However, the sinusoidal magnetic field of the ID does not only contain the spatial fundamental period but also some harmonics which may make appreciable contributions if the electron propagates close to the surface of the magnet block as it is clearly the case for in-vacuum undulators. Also, the magnetic field of exotic undulators such as helical or elliptical devices is poorly or even not at all described by such approach. One of the solutions was proposed by P. Elleaume [2] where the Lorentz force has been integrated up to the second order of the inverse of the electron energy. The angular kicks *(Δx', Δz')* (1) experienced by any electron injected close or far away from the symmetry axis of the ID have then been computed from a potential function *U(x, z)*:

$$\Delta x' = -\frac{1}{2(p/e)^2}\frac{\partial U}{\partial x}(x,z)$$
$$\Delta z' = -\frac{1}{2(p/e)^2}\frac{\partial U}{\partial z}(x,z) \quad (1)$$

where:
$$U(x,z) = \int_{1\ period} \phi(x,z,s)\,ds$$

and
$$\phi = \left(\int_{-\infty}^{s} B_x\,ds'\right)^2 + \left(\int_{-\infty}^{s} B_z\,ds'\right)^2$$

U(x, z) can be deduced from the 3D magnetostatic computations or even measured then can be tabled or fitted in order to be incorporated in tracking codes.

BEAM DYNAMICS WITH IDS

It is known that the linear and non-linear effects induced by IDs on the beam dynamics are proportional to $(B/E)^2*<\beta>$ and $(B/\lambda E)^2*<\beta>$ respectively where *B*, *E*, *λ* and <β> are the magnetic field, the e-beam energy, the undulator's period and the average of the beta functions at the ID location [3]. The linear effects are therefore more dominant for high field devices such as wigglers and high field undulators while the non-linear effects are more dominant for small period devices such as undulators. Nevertheless, ALBA will offer low beta straight sections in order to accommodate the IDs [4] which will significantly reduce both effects. The linear perturbation (quadrupole-like terms) produces linear tune shifts which can bring the working point close to a resonance but also β-beating which leads to the loss of the symmetry of the ring and may excite additional resonances [5]. The non-linear fields (sextupole and octupole-like terms) will induce amplitude-dependant tune shifts and again play a role in the proximity of the working point to dangerous resonances but also excite intrinsic ones. The octupole-like fields are for instance responsible for the excitation of the well known 4th order resonances such as $4\nu_x$, $4\nu_z$ and $2\nu_x \pm 2\nu_z$.

SIMULATION RESULTS AT ALBA

We have estimated the linear and non linear effects of three types of Phase 1 IDs (EU71, IVU-21 and SC-W31) on the beam dynamics at ALBA. Their characteristics are summarized in Table 1. The IDs have been modelled using the kick maps generated from Radia [1] and linked to the TRACY II tacking code. Each map describes the angular kicks *(Δx', Δz')* (1) experienced by the e-beam in the transverse planes (*x* and *z*) and is split in the longitudinal direction (*s*) in a number of lenses which has been optimized in order to take into account the variation of the beta functions along the ID. No errors on the field integrals have been considered here and the original design for the IVU-21 has been used in order to optimize the transverse peak field homogeneity using realistic pole width.

Table 1: Characteristics of the "Day 1" Insertion Devices. The IVU-21 will be built twice

ID	Field	Period	Min.-gap	Length
SC-W-32	2.1 T	32 mm	11 mm	1.98 m
IVU-21	0.87 T	21 mm	5.5 mm	2.0 m
EU 62	0.88 T	62 mm	15.5 mm	1.5 m
EU 71	0.93 T	71 mm	15.5 mm	1.675 m
W 65	1.55 T	65 mm	11.5 mm	2.0 m

LINEAR EFFECTS

Table 2 shows the induced linear tune shifts when compared to the expected ones (using analytical formula [5]) as well as the maximum of the β-asymmetries. In the case of the helical device EU71, the in-homogeneity of the fields introduces additional focusing in both planes in all polarization modes. The largest contribution to the tune shifts is obtained in the vertical mode when this device is placed at 1.5 m downstream of one of the long straight sections. The maximum β_z-beat is obtained in this mode, at the ID location, and is comparable to the one generated by the superconducting wiggler. Figure 1 illustrates both the horizontal and vertical beta-beating obtained in this case. This device, together with a similar one which will be introduced in the same long straight, will possibly be used for helicity switching purposes. Figure 2 shows the change in the quadrupoles used for fully compensating

Table 2: Linear tune shifts and β-beating for three types of the ALBA Phase 1 IDs

ID	EU71 H-mode	EU71 V-mode	EU71 C-mode	IVU21	SCW31
B_x (T) B_z (T)	0. 0.93	0.71 0.	0.57 0.57	0. 0.87	0. 2.1
Straight section	Long	Long	Long	Medium	Medium
β_x(m) in the centre of the ID	11.6	11.6	11.6	2.0	2.0
β_z(m) in the centre of the ID	6.8	6.8	6.8	1.3	1.3
$\Delta\nu_x$ analytical	0.	$+3.64.10^{-3}$	$+2.35.10^{-3}$	0.	0.
$\Delta\nu_z$ analytical	$+3.70.10^{-3}$	0.	$+1.39.10^{-3}$	$+ 1.1.10^{-3}$	$+5.4.10^{-3}$
$\Delta\nu_x$ mapped ID	$+1.22.10^{-3}$	$-7.60.10^{-3}$	$-4.34.10^{-4}$	0.	0.
$\Delta\nu_z$ mapped ID	$+3.17.10^{-3}$	$+7.02.10^{-3}$	$+5.50.10^{-3}$	$+0.9.10^{-3}$	$^{+}5.0.10^{-3}$
Max β_x-beat	1.75 %	6.25 %	2.63 %	0.	0.4%
Max β_z-beat	9.98 %	12.67 %	11.6 %	0.9%	15%

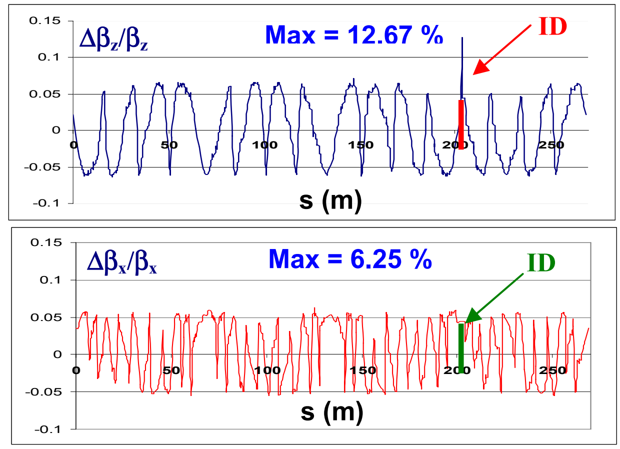

Figure 1: β-beat induced by the EU71, placed at 1.5 m off-centre of one of the long straight sections (β_x = 11.6 m, β_z = 6.82 m), when operated in the vertical mode.

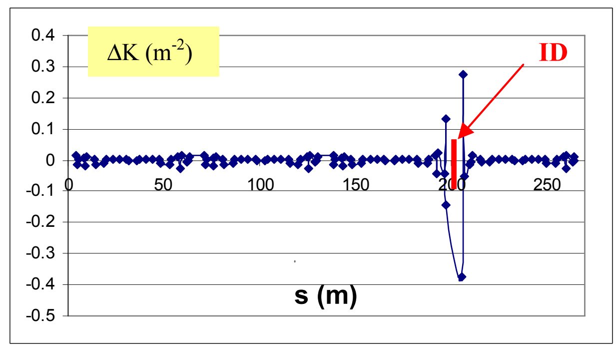

Figure 2: Transverse tunes and ring symmetry globally recovered in the case of the EU71 operated in the vertical polarization mode. The triplet of quadrupoles downstream the ID is the most effective.

the tune shifts and β-beating in both planes. This represents a global compensation scheme, based on an SVD method, which has been developed in TRACY II in house [6]. One has to note that because most of our vertical focusing is generated by the dipole magnets and the helical device is not centred in the long straight section, the local scheme tested earlier has failed. But, both schemes are now available to deal with the different configurations of IDs.

NON LINEAR EFFECTS

Frequency map analysis and 6D Touschek lifetime computations have been performed in order to estimate the non linear effects induced by the IDs specified above. These IDs have been first studied separately then grouped according to their Phase 1 configuration. A realistic vacuum chamber has been adopted where all Phase 1 IDs apertures are considered as well as a septum magnet of 1.5 m long at its nominal position (-16 mm). In addition, and in order to test the sensitivity of the working point to linear and non linear coupling resonances, 1% coupling errors have been generated by rotating randomly the 112 quadrupoles of the ring. Figures 3–a) and 3-b) show the

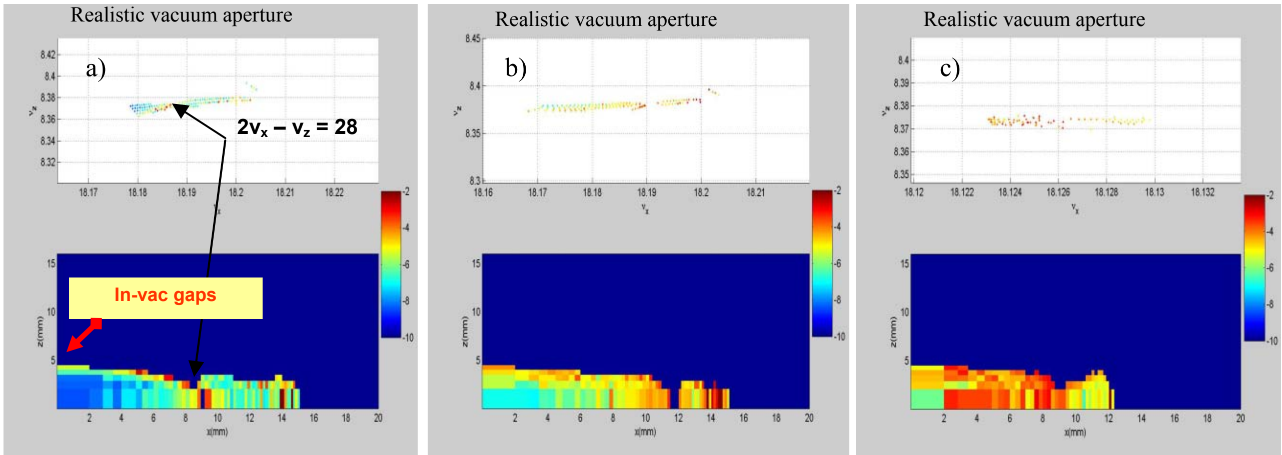

Figure 3: On-momentum dynamic aperture at the injection point for a) the bare lattice, b) the lattice including an EU71 in the vertical polarization mode and c) the lattice including four IDs (1×EU71, 2×U21 and 1×SC-W31). The linear tunes and β-beating are not yet compensated in cases b) and c). 1% coupling errors are also considered here.

on-momentum DA in the case of the EU71 operated in the vertical polarization mode (worst case) when compared to the nominal case. The extensions of the DA are comparable but the diffusion rate is clearly higher when the ID is present in the ring. One can also see the excitation of a third order resonance $2\nu_x - \nu_z = 28$, due to sextupoles, which limits this extension to less than 10 mm. The vertical aperture is limited by the in-vacuum undulators' gaps to about 4 mm. The situation is worse in terms of diffusion when four devices (1×EU71, 2×U21 and 1×SC-W31) are included in the ring (Fig. 3-c). Figure 4 shows how the 3rd order systematic resonance has been avoided by slightly moving the horizontal tune to ν_x = 18.19 which should improve the injection efficiency. The Touschek calculations showed no significant effects for all cases (IDs separated or grouped) and result in a lifetime of 41h (at 400 mA). This is mainly due to the fact that the working point has been optimized such as not to be sensitive to resonances which can be excited by coupling errors. All losses stay in the horizontal plane at the nominal position of the septum (-16 mm) [7]. In addition, the symmetry of the RF bucket, in the range of ±3.4% RF-acceptance, helps in reducing the non linear effects which could be due to the longitudinal motion.

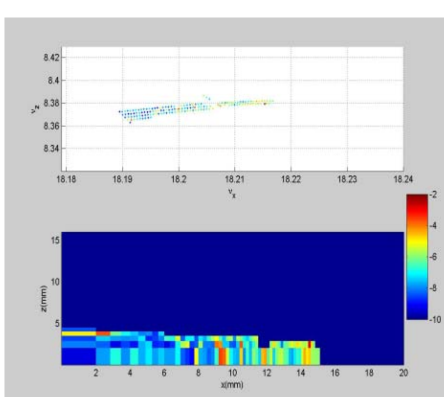

Figure 4: New optimization of the working point.

As a consequence, and in the case of the in-vacuum undulators, all modelled pole widths were equivalent from the on and off-momentum point of view and we decided that a width of ≥50 mm was safer to consider. The total lifetime at ALBA is 14h when considering both elastic (39h) and non elastic (48h) scatterings at 1.6 nTorr.

CONCLUSION

TRACY II simulations showed that Phase 1 Insertion Devices have no significant effects on the beam dynamics at ALBA where IDs straights offer low β-functions. The working point is optimized such as to be strong enough in presence of both coupling errors and IDs. The horizontal tune has been slightly displaced to ν_x = 18.19 in order to avoid the 3rd order structural resonance ($2\nu_x$-ν_z=28) which could limit the injection efficiency. Multipoles' effects due to the fields roll off are currently being examined and will allow defining reasonable tolerances for the ALBA IDs.

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