ISBN: 978-3-95450-231-8 ISSN: 2673-5490 doi: 10.18429/JACoW-IPAC2023-WEPL094

THE EFFECT OF INSERTION DEVICES ON BEAM DYNAMICS FOR ELETTRA 2.0

K. Manukyan*, B. Diviacco, E. Karantzoulis, S. Dastan, S. Di Mitri, S. Krecic
Elettra Sincrotrone Trieste, Basovizza, Italy

Abstract

The effect of both existing and the planned insertion devices on linear optics, dynamic and momentum aperture was modeled using the kick map approach. Cross check for some IDs have been done with different tracking codes. Mitigation strategy for avoiding the crossing of a 4th order resonance line, excited by some of the IDs, is proposed.

INTRODUCTION

Elettra 2.0 is a 259.2 meter long 4th generation light source project that will replace the existing Elettra light source. The basic block of the new storage ring is a 6-band achromat cell with a short dispersive straight in the middle [1]. In total, there are 12 long and 12 short straights. Two long straights are reserved for injection and transverse deflecting cavities [2]. The rest of the long straights will host insertion devices of different types. In addition to this, 5 short straights will be used for IDs. The new machine will reuse some of the IDs from Elettra, and in addition, new IDs will be built [3]. Table 1 summarizes the ID parameters. Elettra 2.0 will also host a superconducting wiggler with a 2.5 T central field and 3 superconducting bending magnets [4]. The impact of these devices is out of the scope of this paper.

Table 1: Specification of the IDs for Elettra 2.0. For EPUs 3 values of B_0 corresponds to horizontal and vertical polarization modes respectively.

ID	L(m)	B_0 (T)	λ(mm)
EPU10.0	2.0	1.02/0.78	100
Figure-8	2*2.2	0.75/0.14	140
EPU13.2	2.6	0.39/0.63	132
EPU5.0	1.5	0.85/0.62	50
EPU4.4	2.0	0.59/0.56	44
EPU7.7	2.1	0.92/0.64	77
EPU4.8	2.0	0.58/0.34	48
EPU12.5	2.1	0.77/0.60	125
EPU6.0	2.2	0.78/0.51	60
EPU3.2	0.8	0.83/0.49	32
APU3.6	0.8	0.67	36
W9.6	0.7	1.82	96
IVU	2.0	1.17	20

The effect of these IDs on the linear and nonlinear dynamics of Elettra 2.0 was systematically studied.

* koryun.manukyan@elettra.eu

ID EFFECTS

The effects of ideal ID can be conditionally divided into three categories:

- Beta beat and linear tune shift. This effect will depend on the undulator parameters and beta functions in the location of the ID. For EPUs this effect will impact both planes.
- In addition, IDs will introduce a higher-order magnetic field. Due to the symmetry of magnetic poles, these will be odd multipoles. These fields will affect the amplitude-dependent tune shift and excite fourth-order resonances, which in turn can reduce dynamic apertures and affect energy acceptance of the ring.
- IDs modify the radiation (quantum excitation and damping) equilibrium, resulting in a change of the beam emittance, energy spread, and damping times. Depending on the dispersion function in the location of the ID, this will increase or reduce the emittance. For Elettra 2.0, short straights have a non-zero dispersion while long straights are dispersion-free.

In addition, due to construction tolerances, real IDs will have non-zero first and second field integrals. Magnetic measurements of existing and newly-built IDs for Elettra show that the principal components of these integrals are dipole fields. These can be easily corrected with orbit correctors installed at the beginning and end of the straight section. Higher-order field components are much smaller than ”dynamic multipoles.” Nevertheless, these components were also taken into account for IDs for which field integrals were measured. To study the linear and nonlinear effects of IDs, a kick map approach was used [5]. For all IDs from Table 1, nonlinear kick maps were generated using RADIA [6]. For EPUs, kick maps were generated at the minimum gap and for different polarization modes.

TRACKING CODE CHOISE

Before starting the systematic study, the kick map of the short wiggler (W9.6) was used to compare the results of ELEGANT [7] and AT [8]. Figure 1 shows the effect of the short wiggler on vertical beta beat and dynamic aperture as computed with AT and ELEGANT. As can be seen, these codes agree very well with each other. The small difference in dynamic aperture results is due to modeling differences in the bare lattice. Simulation results were also compared for amplitude-dependent tune shift and momentum aperture, and no significant difference was observed in either case. Comparison was also done for a much stronger ID (EPU13.2) in the long straight where dispersion is zero, and again no

ISBN: 978-3-95450-231-8 ISSN: 2673-5490 doi: 10.18429/JACoW-IPAC2023-WEPL094

significant difference was observed. The study was done using ELEGANT for the rest of the IDs.

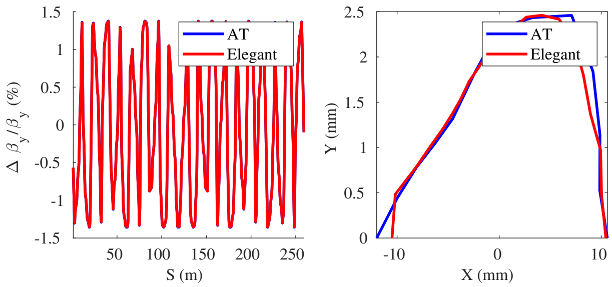

Figure 1: Comparison of the results of AT and ELEGANT. Left: Vertical beta beat. Right: Dynamic aperture.

ANALYSES

Mini IDs

As previously mentioned, five short straight sections will host IDs in Elettra 2.0. Initial concerns included the absence of quadrupoles nearby for beta correction, but simulations demonstrated that the optics distortion for these IDs is less than 2 percent, which is easily tolerable. Since these IDs are in dispersive straights, they will increase the equilibrium emittance. The most significant effect is due to two mini wigglers (W9.6), which will be installed in the short straights of cells 5 and 11. The field of these devices was carefully chosen to avoid increasing the emittance beyond the tolerance limit. Tracking studies revealed no significant reduction of dynamic or momentum apertures due to IDs in the short straights.

An interesting case study involved the mini wiggler, which is a fixed gap device that needs to move horizontally approximately 80 mm to reach the zero field configuration. We investigated the possibility of moving the wiggler while there is a beam in the storage ring, which is considered a fast enough process to not require an injection. The main concern in this case is the reduction of lifetime. To model the process, the measured field integrals were fitted piecewise with a 10 mm step since it was not possible to fit a polynomial to the full range. The coefficients, together with the kick map from RADIA, were inserted into the model, and the orbit and tunes were corrected for each step. The momentum aperture was calculated for each step, and Fig. 2 shows the resulting lifetime reduction due to the movement of the short wiggler. The asymmetric behavior is due to the fact that the field integrals are slightly different on opposite sides of the wiggler. Based on the simulation results, it will be possible to "switch off" this device while keeping the beam.

IDs in the Long Straight

Out of the 10 available long straight sections, one will be allocated for a superconducting wiggler and a 3rd harmonic cavity, while three will host two different IDs for low energy and high energy photon beam production. Only one of these

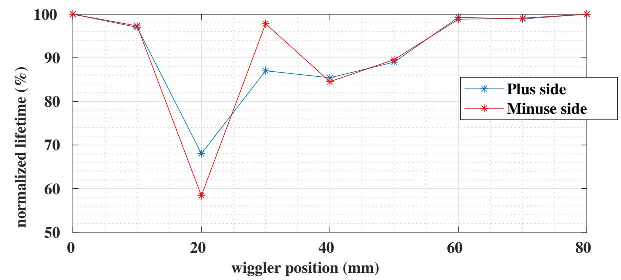

Figure 2: Normalized lifetime calculated for the different position of mini wiggler.

three sections will have two beamlines operating simultaneously. The layout of this straight section is different from the others. A chicane separates the cones of emission of the two undulators by 2 mrad, thus allowing two beamlines to be operated simultaneously. Although a correction scheme which includes both IDs is possible, simulation results suggest that it is not necessary. The beta beat produced by the high-energy undulator (EPU6.0) in this straight is less than 3%, so it does not require correction. Quadrupole triplets at both sides will follow only the low-energy counterpart (EPU12.5).

The correction strategy is based on local correction of phase advance and beta function. Since there is a quadrupole triplet at both sides of the straight, the correction is mostly successful. Tunes are corrected globally whenever there is a small tune shift. Figure 3 shows the beta beat for the uncorrected and corrected machine for one of the "strong" undulators. The initial tracking results revealed a significant reduction in

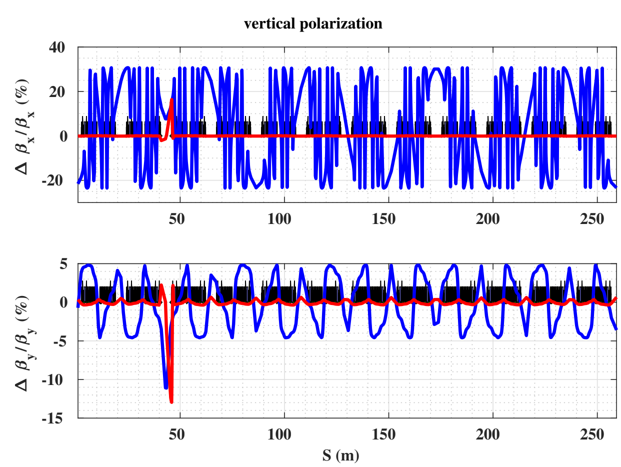

Figure 3: Horizontal-top and vertical-bottom beta beat with EPU10.0 in vertical polarization mode. Blue: uncorrected machine. Red: with local correction.

on-energy dynamic aperture when using the EPU10.0 in vertical polarization mode, despite the corrected optics. More detailed studies using frequency map analyses indicated that the reduction was caused by the excitation of the 4th order resonance line ($4\nu_x$). Figure 4 shows the DA and frequency map for this particular case. It is worth noting that several other IDs in long straights, such as the EPU5.0, EPU7.7,

ISBN: 978-3-95450-231-8 ISSN: 2673-5490 doi: 10.18429/JACoW-IPAC2023-WEPL094

EPU12.5, and EPU6.0, demonstrated similar behavior. This was traced back to the comparably high horizontal octupolar component in kick maps at vertical polarization mode. After trying two different approaches to solve the problem

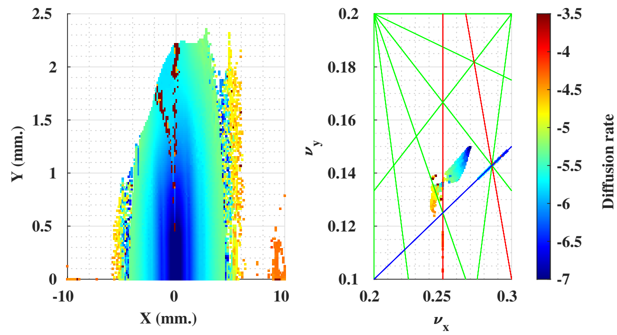

Figure 4: Dynamic aperture and frequency map for the ideal lattice including EPU10.0 after optics correction (ν_x=32.27). Calculations are done at the centre of injection straight.

of reduction in on energy dynamic aperture with EPU10.0 in vertical polarization mode, it was decided to change the horizontal tune. The first approach involved optimizing resonance driving terms, which was able to minimize the effect. However, since the device would operate in different polarization modes, which have different nonlinear components, it was decided to proceed with the second approach. The horizontal tune was changed from 32.27 to 32.24, resulting in an improvement in the on energy dynamic aperture. Figure 5 shows the resulting dynamic aperture and frequency map for the new horizontal tune, with EPU10.0 in vertical polarization mode and corrected optics.

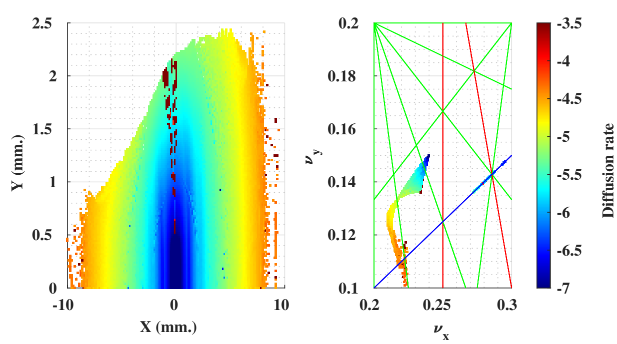

Figure 5: Dynamic aperture and frequency map for the ideal lattice including EPU10.0 after optics correction (ν_x=32.24). Calculations are done at the centre of injection straight.

A small impact on the momentum aperture from the long straight IDs was noticed, but the impact of any single ID is still within the tolerance of the machine.

All IDs

All IDs from Table 1 were included in the machine model. Measured field integrals for EPU5.0, EPU13.2, and W9.6 were added, in addition to the kick maps. The kick maps for the vertical polarization mode of EPUs were used since this was the mode that affected the dynamic aperture most. For IDs that produced more than 5% beta beat, a correction was calculated and applied. The resulting beta beat is 3% for the horizontal plane and 6% for the vertical plane. The emittance and energy spread were reduced from 226 pm and 9.3e-4 to 218 pm and 8.9e-4, respectively. The dynamic and momentum apertures for this case are shown in Figs. 6 and 7, respectively. Since the beam is injected at -4 mm, the resulting dynamic aperture is considered sufficient. However, the momentum aperture shows approximately a 1% reduction. Further investigation is currently being conducted to understand the cause of the predicted reduction in momentum aperture and to find ways to minimize it.

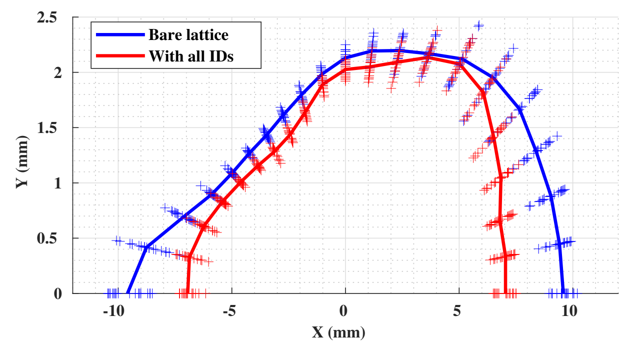

Figure 6: Dynamic aperture with and without IDs. Machine with 20 seeds of typical errors are simulated.

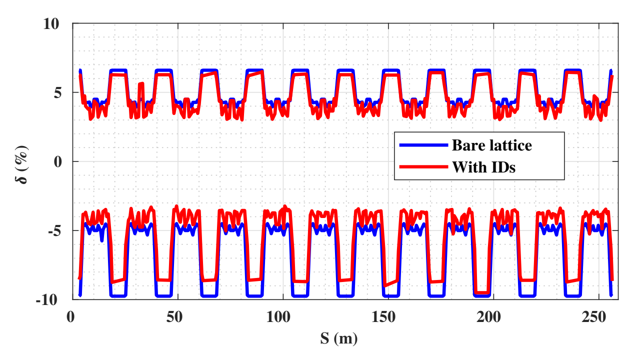

Figure 7: Momentum aperture with and without IDs.

CONCLUSION

The study examined the impact of IDs on both linear and nonlinear dynamics. The most significant effect was the reduction of dynamic aperture due to the excitation of 4th order resonance by several IDs. This issue was resolved by shifting the working point away from the harmful resonance. Another effect observed was a small reduction in momentum aperture in the case of all IDs in vertical polarization mode, which is currently under investigation.

REFERENCES

[1] E. Karantzoulis, A. Fabris, and S. Krecic, “The Elettra 2.0 Project”, in *Proc. IPAC’22*, Bangkok, Thailand, Jun. 2022, pp. 1459–1462. doi:10.18429/JACoW-IPAC2022-TUPOMS023

ISBN: 978-3-95450-231-8 ISSN: 2673-5490 doi: 10.18429/JACoW-IPAC2023-WEPL094

[2] S. Di Mitri, A. Bianco, L. Raimondi, M. Altissimo, S. Lizzit, E. Karantzoulis, S. Krecic, K. Manukyan, “Transverse deflecting cavities for short X-ray pulses at Elettra 2.0”, presented at IPAC’23, Venice, Italy, May 2023, paper MOPA163, this conference.

[3] B. Diviacco, “Insertion device developments for Elettra 2.0”, presented at IPAC’23, Venice, Italy, May 2023, paper MOPM097, this conference.

[4] M. Modica, *et al.*, “Superbend magnet for Elettra 2.0”, presented at IPAC’23, Venice, Italy, May 2023, paper WEPM056, this conference.

[5] P. Elleaume, “A New Approach to the Electron Beam Dynamics in Undulators and Wigglers”, in *Proc. EPAC’92*, Berlin, Germany, Mar. 1992, pp. 661–664.

[6] P. Elleaume, O. Chubar, and J. Chavanne, “Computing 3D Magnetic Fields from Insertion Devices”, in *Proc. PAC’97*, Vancouver, Canada, May 1997, paper 9P027.

[7] M. Borland, “elegant: A Flexible SDDS-Compliant Code for Accelerator Simulation”, Advanced Photon Source, LS-287, Sep. 2000.

[8] A. Terebilo, “Accelerator toolbox for MATLAB”, SLAC, CA, USA, SLAC-PUB-8732, 2001.