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IMPACT OF INSERTION DEVICES ON THE SLS 2.0 DYNAMIC APERTURE

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Abstract

Insertion devices may be also very detrimental for the dynamic aperture of storage rings, since they introduce linear and higher order perturbations on the optics of synchrotrons. It is essential to study these effects to adjust the lattice to compensate for these terms when possible (high order multipole magnets are present in the lattice of the machine), or optimize the design of the IDs to minimize the higher order effects. We applied our analysis to SLS 2.0, the upgrade of the presently running Swiss Light Source (SLS) facility at Paul Scherrer Institut. In particular, we compared the results using an approach based on the calculation of the multipoles computed on the beam reference trajectory and on the kick map calculation.

SLS 2.0 AND DYNAMIC APERTURE

SLS 2.0 will have a seven bend achromat lattice with longitudinal and reverse bends, an increased electron energy of 2.7 GeV and an close to on-axis injection scheme. New undulators with complex magnetic fields for magnetic force compensation in hard x-ray in-vacuum undulators respectively on-axis heat load reduction in APPLE X undulators for soft x-ray will be installed as well [1]. These devices may introduce high order multipoles, which may be detrimental for the performance of the machine. In this proceeding we will focus ourselves on the UE36kn APPLE X undulator in linearly horizontal polarization mode. A key figure quite used in rings to determine the "quality" of the lattice is the dynamic aperture (DA). It defines the region in the transverse plane (x,y) at a given location (typically the injection) where the particles may be injected without being lost during their motion in the following turns in the ring, because they cross a resonance or hit a restriction of the beam aperture, in case the physical aperture is included in the computation. To verify the ring performance in case of an energy error in the injection, the calculations are typically performed not only for the on-energy beam, but also for off-energy bunches to verify the ring performance in case of an energy error in the injection. In this case another mechanism may cause losses: the mismatch of the optics, and tune shift, which may provoke the crossing of a resonance.

DYNAMIC APERTURE COMPUTATION

Any tracking code may be used to determine the DA. In this proceeding we concentrate on Elegant [2], after a verification that the results without the IDs is consistent with Tracy [3]. We studied the impact of the IDs using the first tracking code following two different approaches: the first one based on the calculation of multipoles computed on the beam reference trajectory, and the second one giving to the code the output from the magnetic model useful to compute the kick imparted to the beam by the IDs.

The SLS 2.0 DA was extensively optimized in the latest years using genetic algorithm-based optimization [4], and re-optimized all the times that the lattice was changed to accommodate new elements, or to take into account high order magnetic moments computed using the most realistic field maps [5] of the different magnets. All this effort resulted in a very large DA, shown in Fig. 1.

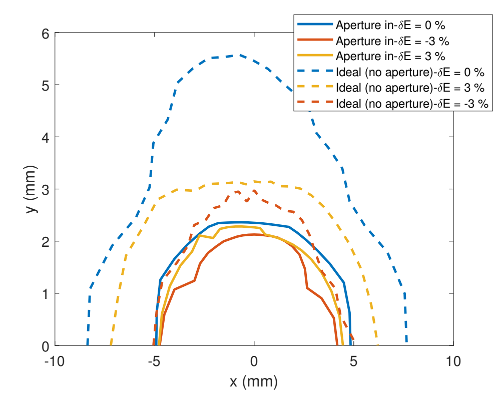

Figure 1: Comparison of the IDA and the DA computed at the SLS 2.0 injection kicker.

We computed it using both Tracy and Elegant. We verified the stability of the solution varying the number of turns, obtaining a stable solution already for a modest number of turns (few hundreds) for Tracy, and up to 5000 for Elegant. We obtained quite a good agreement between the two codes for the on-energy and the -3 % off-energy configurations. The agreement was worse (slightly less than 30 % in the vertical and 15 % in the vertical plane, respectively) for the -3 % off-energy case. Elegant reproduced the same behavior observed using a third code, AT. We decided to perform our computations using Elegant, which gave the most pessimistic result.

The DA may be computed without putting any physical aperture, or assuming the beam pipe aperture during the tracking. We refer to the first as the Ideal Dynamic Aperture (IDA), and to the latter as simply with Physical Dynamic Aperture (PDA). The IDA represents only an idealized case, especially in SLS 2.0 where the dynamic aperture is much larger than the physical beam pipe. In the following we will use both these results as the reference cases to evaluate the impact of the IDs in the dynamic of the ring.

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"Multipoles" Approach

This method is based on the determination of the multipoles computed on a reference co-propagating with the beam and perpendicular to its reference trajectory. The analysis is performed in four steps:

- Reading the 3D field map generated by Radia [6];
- Determination of the beam reference trajectory, $(z, z_{TR}(z), x_{TR}(z))$;
- Determination of the multipoles on segments perpendicular to the reference trajectory;
- Tracking of the beam along the lattice using the *FMULT* element in Elegant.

As a first case we approximated the *FMULT* element as a single device whose length is that of the ID, and the integrals of the multipoles over the ID full length are used.

Critical aspects of this approach are the choice of the algorithm to perform the 2D interpolations used to determine the beam trajectory (less critical), and to compute the coefficients of the field expansion (more critical), and the choice of the degree of the polynomial fit applied to the magnetic field. We selected the interpolation algorithm comparing the periodicity of the coefficients of the fit with that expected from the ID magnetic model. Among the tested linear, nearest, cubic, spline, and makima algorithms, we selected the cubic for the consideration just described. For completeness, we verified that the dynamic aperture determined in this case is not strongly affected by the octupole, since a cubic interpolation may add this artifact to the model. We have also verified that the residuals of the fourth and fifth order fits differ by less than 1 % to further demonstrate that the fourth order well suit our analysis.

An advantage of this method is that it straightforward determines the multipole order or orders responsible for an eventual reduction of the dynamic aperture. This may be done removing the one of the other multipolar order (we did it for the octupole as aforementioned). Another advantage of this kind of DA calculations that we may do include or not the physical aperture to compare the results with the IDA or the PDA. This is an important difference with the "kick-based" method, which does not make much sense to compute the IDA, because the map of the ID will introduce a restriction of the space where the particles move.

We generated a magnetic field map of the ID model from Radia (field determined per requested point, no interpolation involved) along the longitudinal coordinate z. For the horizontal plane x at each z we then computed the angle of the beam trajectory, $\theta(s)$:

$$\theta(z) = \frac{1}{B\rho}\int_0^{L_{ID}} B_y(z)dz \quad (1)$$

where $B\rho$ is the beam magnetic rigidity, B_y the vertical component of the magnetic field along z, and L_{ID} the length of the insertion device. We determined then the position $x(z)$ as the integral of the angle over z. Similar considerations apply to the vertical plane y. Figure 2 shows the beam horizontal orbit and angle along the ID obtained from the field map of the UE36-LH. We added a small correction,

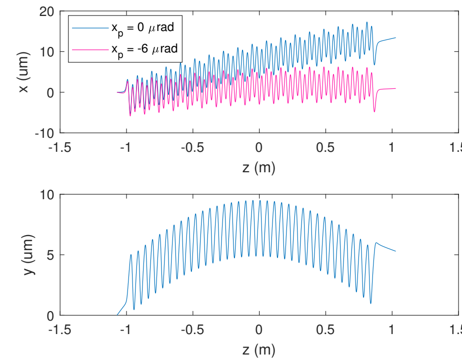

Figure 2: Horizontal and vertical beam reference trajectories along the ID.

equivalent to use a corrector of moderate strength (6 μrad), to the entrance angle to minimize the exit position and angle in the x plane. For the presented calculations we used the multipoles computed around the beam reference trajectory, but the difference between this and the multipoles computed around the z axis is more critical in other cases, where the beam excursion compared to the field flatness is larger than in our case. In our case the multipoles computed on z or along the beam reference trajectory differ much less than a percent in the worst case.

We determined the coefficients of the field expansion, $c_n(s)$, applying a 4^{th} polynomial fit to B_y as described before:

$$c_n(s) = \frac{1}{n!}\frac{\partial^n B_y(s)}{\partial x^n} \quad (2)$$

From the $c_n(s)$ we computed the integrals of the multipolar order in the Elegant convention, known the beam magnetic rigidity and the factorial of each order. Table 1 shows the results.

Table 1: Integrated multipoles in the Elegant convention determined from a 4^{th} order polynomial fit of B_y. The range for the fit is ±3.5 mm, and the step for the fit is 50 μm and 1 mm in x and z, respectively.

I_d	**Value**
I_1 (T)	0.0001588
I_2 (T/m)	0.53415
I_3 (T/m^2)	-61.8774
I_4 (T/m^3)	157385.87

We used the element defined by these integrated high order terms for all the seven UE36 devices along the ring, and we determined the DA performing both an on-energy and off-energy (±3 %) beams. Figure 3 shows the comparison of the obtained dynamic aperture with the IDA. Figure 4 shows instead the result of the calculations assuming the physical aperture of the machine. In both cases we observed a very moderate impact of the UE36 on the DA. This is valid modeling the UE36 devices as a single element where the effect is the integrated one over the full length of the ID. In the future we plan to split longitudinally the model, and repeat the analysis to confirm this result.

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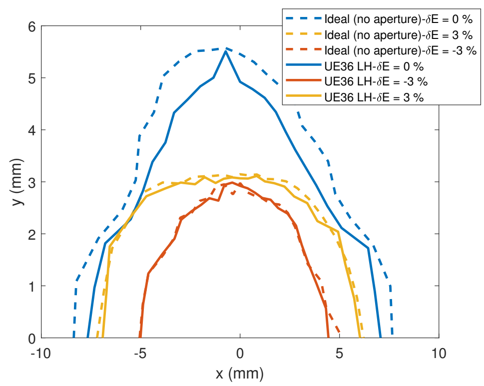

Figure 3: Impact of the UE36 on the IDA. The calculations for figures 3 to 6 consider 5000 turns and use 25 lines in the (x,y) plane.

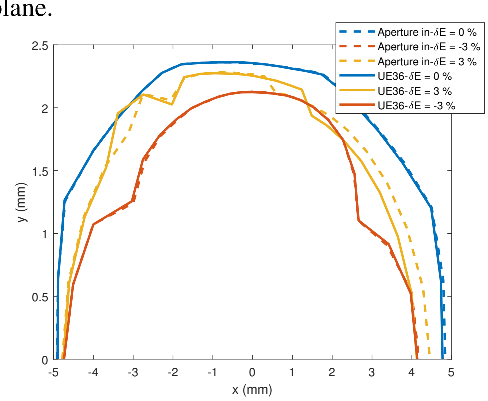

Figure 4: Impact of the UE36 on the PDA.

"Kick Map" Approach

In Elegant there is a dedicated element, *UKICKMAP*, which may be used to simulate the impact of the ID in a ring. Elegant, following the treatment reported in [7], uses this element to compute the kick imparted to the beam passing through the ID as a function of the x and y coordinates of the beam. We computed the input file necessary for Elegant using a function very kindly provided by the Elettra colleagues. The advantage of this routine is that we can avoid any field interpolation, being the elements directly computed in our Radia model.

Figure 5 shows the strength of the element used in Elegant for the UE36 ID.

Differently from the previous approach it makes sense to compute only the PDA, otherwise the presence of the *UKICKMAP* element in the lattice will cause a reduction of the dynamics aperture, simply due to the fact that the particle outside will be considered lost. Figure 6 shows the comparison of the obtained DA with the PDA. Also in this case we observed only a marginal reduction of the DA.

CONCLUSIONS

We presented two approaches to compute the impact of the IDs on the SLS 2.0 dynamic aperture: using the mulitpolar expansion of the ID magnetic field, and the kick imparted to the beam by the ID. In both cases we obtained a negligible impact on the SLS 2.0 dynamic aperture.

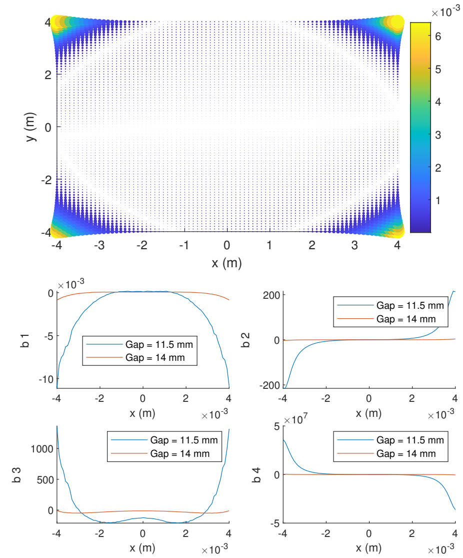

Figure 5: Top: Input for the Elegant tracking in the "kick-based" approach. Bottom: Polynomial coefficients of the elements used in the *UKICKMAP* at a constant y for 11.5 mm and 14 mm gap. These coefficients are proportional to the multipoles computed in the previous approach.

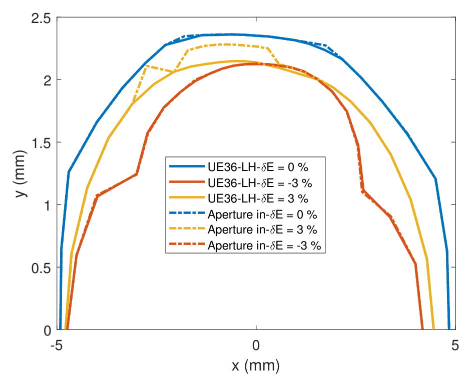

Figure 6: Impact of the UE36 on the PDA using the *UKICKMAP*.

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