ID MODELING AT THE ALS*

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Abstract

At the Advanced Light Source there are several projects being proposed that will require high field insertion devices. It is important that these devices do not significantly impact the performance of the machine. In particular they should not degrade the beam lifetime or injection efficiency. It is known that high field devices with large field roll off can impact the beam lifetime. It is therefore important to model the effect of the insertion devices including both transverse and longitudinal field roll off. In this paper we present the result of tracking studies using an explicit symplectic integrator with both transverse and longitudinal field roll off. The simulations show where sufficiently large field roll off will impact the beam lifetime.

INTRODUCTION

Due to the ever increasing number of insertion devices used in light sources, the impact of their presence on the beam dynamics becomes more and more of an issue. The problem is made more pronounced by the higher magnetic field and smaller gap of the up coming devices. Most existing insertion devices affect the beam mainly through linear focusing in the vertical plane. The change of phase advance between nonlinear elements (primarily sextupoles) causes change in the strengths of resonances excited. As a result, both injection efficiency and beam lifetime can be affected. Recent experience at SSRL shows that the octupole like component generated by the horizontal roll off of the field can have dramatic effects on the beam dynamics [1]. Since then the issue of horizontal field roll off has attracted more attention both from accelerator physicists and magnet designers.

The Femtoslicing project, currently under construction at the Advanced Light Source (ALS), requires two new insertion devices to be incorporated into the storage ring [2]. One of the design criteria is that the device should be ”transparent” from the point of view of the beam. With no exception, the effect of the horizontal field roll off is the main question to be answered. The most economical way to answer this question and optimize the design is to develop simulation tools that takes into account all important effects of the insertion device on the beam dynamics. To this end, a symplectic integrator developed recently is adopted [3]. Together with an adequate field model and existing tools such as frequency map analysis, the designs of both insertion devices have been validated by the simulation results. Furthermore, a case that horizontal significantly reduced dynamic aperture has been identified.

Following the introduction, we outline the setup of the simulation tools and the approach we take to study beam dynamics at the ALS. The simulation results are shown in the following section. Summary and acknowledgment are presented in the last section.

SIMULATION TOOLS

Over the years, frequency map analysis has been applied to the ALS and hence been verified by experimental data [4, 5]. As a result, frequency map analysis has become one of the standard tools for simulations on single particle dynamics. Until recently, the insertion devices has been modeled as a sequence of alternating dipole magnets, where the effect of the horizontal field roll off is not taken into account. As mentioned in the previous section, it is necessary to include this effect in the model if the design of an insertion device is to be validated before procurement order is placed. The newly developed symplectic integrator for insertion devices meets the demand perfectly [3]. The main assumption of the model is the paraxial approximation, which leads to a Hamiltonian that can be separated into solvable parts. It has been implemented in the code PTC [6] using the harmonic representation of the field.

In order to take advantage of the existing model quickly, the lattice of the ALS storage ring was imported into the code PTC and the frequency map analysis was performed separately. Since most of the simulation tools are integrated in the MATLAB environment, the symplectic integrator in PTC was soon rewritten in C and incorporated into the MATLAB based code Accelerator Toolbox [7]. This allowed us to add the new model of insertion devices directly to the existing infrastructure that does the tracking and the frequency map analysis in a integrated way. Comparison between the two versions of the model showed agreement up to the machine precision.

SIMULATION RESULTS

As mentioned in the introduction, two new insertion devices will be built for the Femtoslicing project. One is a wiggler with the period of 11.4 cm and the peak field of 1.9 T (named W11), placing an existing wiggler with the period of 16 cm (W16). The other one is an undulator whose period is 3 cm and peak field is 1.5 T (U3). Based on the success of W16 at the ALS and the lesson of the BL11 wiggler at SPEAR, the designers of these new insertion devices sought to keep the horizontal roll off small, as shown in Figure 1. The goal of the simulation is to de-

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cide whether these insertion devices significantly affect the beam dynamics and, if not, what is the safety margin of the designs.

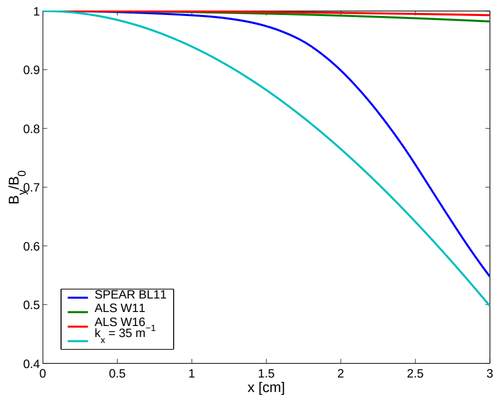

Figure 1: Horizontal field roll off of various insertion devices

The simulations are done using a lattice that is close to normal operating conditions. Random gradient errors are introduced to mimic errors in the real machine. Random skew quadrupole errors are used to reproduce ∼2% coupling which is the way to maintain desired beam lifetime during user operations. Physical apertures, ±30 mm horizontally and ±4 mm vertically, are placed at the center of the injection straight and those of the insertion devices. Beta beating induced by the insertion devices is largely compensated by two families of quadrupoles nearby. In case of U3, two families of skew quadrupoles are adjusted to produce the vertical dispersion bump required during the operation of the Femtosciling beamline [2]. The horizontal and vertical tunes are 14.25 and 8.20, respectively; the horizontal and vertical chromaticities are 0.4 and 1.4. In order to perform frequency map analysis, both synchrotron radiation and synchrotron oscillations are off.

Both longitudinal and horizontal roll off are modeled by a Fourier series with only one harmonic (Fig. 2). It is also clear that the vertical roll off is more severe than the real field which makes the simulation more pessimistic than reality. Since $k_y^2 = k_x^2 + k_z^2$ and $k_z \gg k_x$, the vertical roll off is dominated by the longitudinal roll off. When 8 harmonics are used to model the longitudinal roll off, relative error of the vertical roll off is below 3E-4 up to 4 mm. As a benchmark, this model of 8 harmonics (fitted to the data of W11) was used once in the simulation and no appreciable difference in the beam dynamics was found. Since U3 has a much shorter period, the difference should be even smaller. Figure 3 and 4 show the effect of W11 on the beam dynamics. On-momentum frequency map analysis shows the dynamic aperture, which is important for injection. In case of ALS, injection orbit is about 8 mm off the design orbit horizontally. Figure 3 shows that the presence of W11 will not affect injection efficiency. Off-momentum frequency map analysis shows the momentum acceptance, hence the beam lifetime, because beam lifetime is mainly determined by Touschek scattering [2]. Figure 4 shows that momentum aperture is slightly worse with W11 on. Simulation of W11 with no horizontal roll off shows the same reduction in momentum.

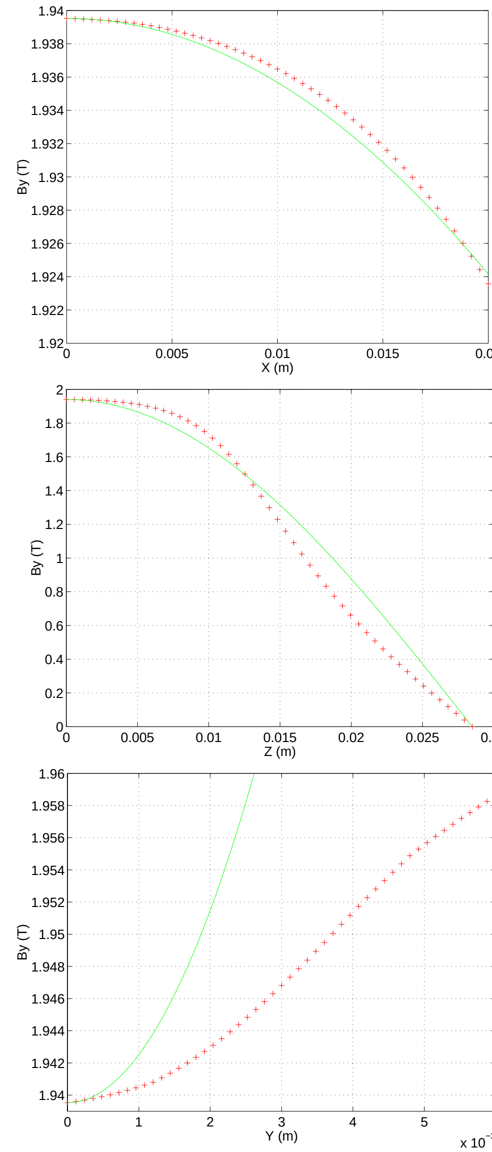

Figure 2: One harmonic field model for W11. The model for U3 looks qualitatively the same.

In order to decide the safety margin of the horizontal roll off, several cases were studied with different k_x. No difference was found between the nominal case which k_x = 6.3 m^{-1} and the ones that k_x = 7 m^{-1} and 8 m^{-1}, respectively. When k_x is set to be 35 m^{-1}, comparable to that of BL11 (Fig. 1), dynamic aperture is reduced to about 6 mm (see Fig. 5).

Similar studies were done on the impact of U3. Even more so, the effect of the insertion device on the beam dynamics is hardly detectable.

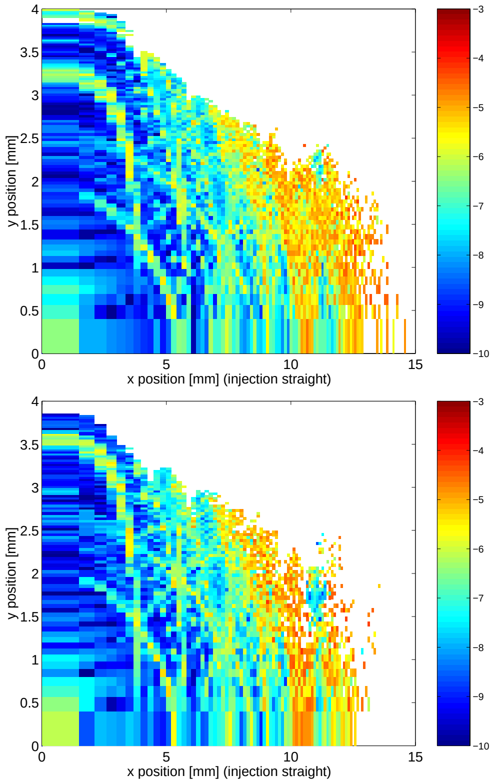

Figure 3: On-momentum frequency map analysis with the wiggler on (top plot) or off (bottom plot)

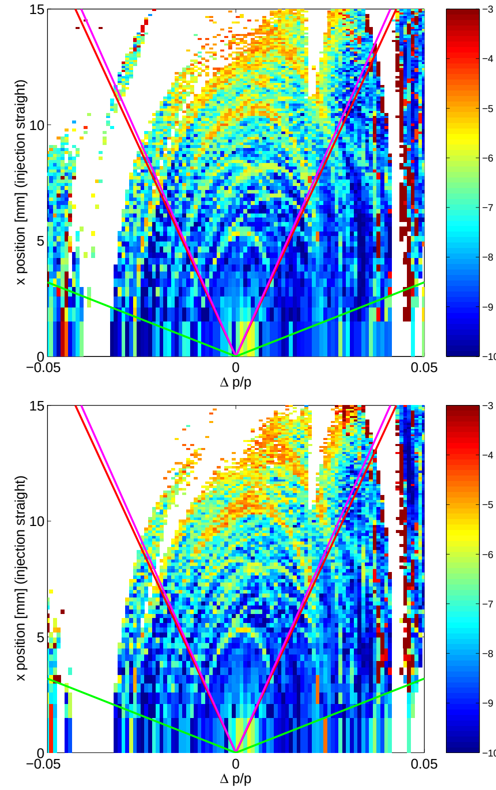

Figure 4: Off-momentum frequency map analysis with the wiggler on (top plot) or off (bottom plot)

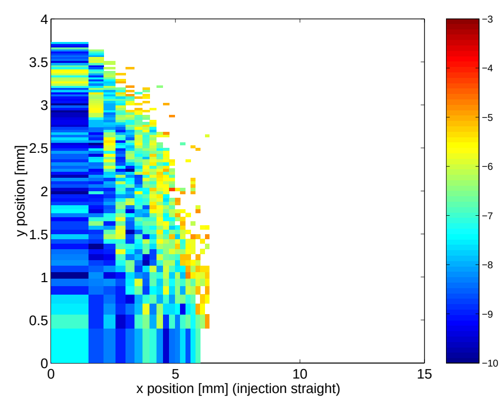

Figure 5: On-momentum frequency map analysis with the wiggler on and with vere horizontal roll off

SUMMARY

A newly developed symplectic model for insertion devices has been used in studying beam dynamics issues. This model was successfully rewritten in C and integrated into the existing MATLAB based simulation tools. Design of two upcoming insertion devices were evaluated and validated from the beam dynamics point of view. A by-product of the study is that a rather straightforward way of modeling the field of planer insertion devices was found. Both the longitudinal and the horizontal roll off are fitted by a Fourier series. The product of the two serieses represents the field in the midplane. Using the standard harmonic representation, the off-plane expansion is done through the relation $k_{yij}^2 = k_{xi}^2 + k_{zj}^2$. The result is that, for W11, the error is below 30 Gauss at $x = 2$ cm and $y = 4$ mm.

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