LATTICE TRANSLATION BETWEEN ACCELERATOR SIMULATION CODES FOR SuperKEKB

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Abstract

To improve collaborative studies on beam dynamics for SuperKEKB between several labs, efforts have been made to translate the SAD lattices of SuperKEKB rings to the versions for other codes: AT, Bmad, MAD-X, and PTC. It turns out that lattice translations between these codes are not straightforward because of the complexity of the SuperKEKB lattices. In this paper, we describe our experiences of lattice translations, and present some results of benchmarks for the case of SuperKEKB.

INTRODUCTION

Many simulation codes have been developed over the years for studying the various aspects of beam physics in particle accelerators. Though they may have common objectives such as optics design and optimization, each code has its own features. On one hand, cross checks for the same study are very useful in bug detection for a new code developed from scratch, or for a well-developed code applied to a next-generation project. On the other hand, every code holds its particular merits and makes it outstanding from other existing ones. Therefore, a full investigation of every topics in an accelerator motivates collaborative studies using different codes from different research groups. Accordingly, translating lattice models between these codes is naturally the first step for the accelerator physicists who want to work together on problems of common interest.

For the case of SuperKEKB [1], as an example, the lattice translations from SAD code [2] to several other codes, Accelerator Toolbox (AT) [3], Bmad [4], MAD-X [5] and PTC [6], have been tried, but it is non-trivial because of the overall complexity of the lattice design. Firstly, the fringe fields of magnetic components, both the hard-edge and soft-edge, are not implemented in all codes. Usually, the impact of fringe fields may become non-negligible in small storage rings with large acceptance. But for SuperKEKB, we are pushing the limit to achieve very high luminosity with low emittances and extremely small beta functions at the interaction point (IP). It is found that linear fringe effect of dipoles, quadrupoles and wigglers modifies the beta functions and tunes. And the nonlinearity originated from the drift space near IP and the fringe fields of the final focus quadrupoles become very important. In addition, the tilted strong solenoids for particle detection and relevant adjustments in the design of the interaction region (IR) are other important sources of lattice nonlinearity [7]. In lattice modelling of SAD, all these effects have been taken into account by carefully constructing the transfer maps for each kind of lattice components. But the relevant modelling may not be equivalent in other codes, and that becomes the main obstacle in our efforts of lattice translations.

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TRANSLATION BETWEEN CODES

Translation to Bmad

Initially, the two main impediments with translation between SAD and Bmad were the SAD *MULT* element and SAD fringe field effects in dipoles and other elements [2]. The SAD *MULT* element is a general element that can include solenoid, multipole, and RF fields. Additionally, a *MULT* element can define a bending angle which bends the reference orbit just like a bend element in other languages.

In terms of the SAD *MULT* element, the solution was to implement an element in Bmad that corresponds to the SAD *MULT* element. This element was named *sad_mult*. To keep things simple, the *sad_mult* does not have RF or bend attributes. In practice, this has not been a problem for the translation of SuperKEKB lattice.

In terms of the fringe fields, Bmad already had an element attribute called *fringe_type* which could be set to toggle various fringe models. The possible settings of *fringe_type* were extended to cases that corresponded to the SAD fringe models and the appropriate code was implemented for tracking.

The final hurdle was creating a translator to translate between SAD and Bmad. The translator was written in Python. SAD to Bmad translation has been implemented and Bmad to SAD translation is in development. For the SAD to Bmad translation, there were a couple of issues that were encountered. One issue was that in a SAD lattice, if the *GEO* element attribute is set for a *SOL* (solenoid) element at the ends of a solenoid, the reference orbit is shifted to keep the reference orbit on top of the closed orbit. This was dealt with by adding to the translated Bmad lattice a *patch* element, which is an element that shifts the reference orbit, at the ends of a solenoid as needed.

Another translation issue was due to a feature in SAD where, during tracking, the longitudinal z coordinate of a particle is shifted in every element to counteract a difference between the length of the reference orbit and the length of the closed orbit. For example, the SuperKEKB lattice has

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the reference orbit through the center of the interaction region solenoid which makes the closed orbit length slightly longer since there is a crossing angle. This correction, called *FSHIFT*, makes particles traveling on the closed orbit encounter the RF cavities at nearly zero z. That is, the effect of *FSHIFT* is to nearly cancel energy and orbit shifts due to shifts in z due to differences between reference and closed orbit lengths. The *FSHIFT* effect could have been mimicked on the Bmad side by putting patch elements after every regular element. This was unacceptable since it would have doubled the number of elements in the lattice. Rather, patch elements where put just before and after every RF cavity. Thus being the case, the z coordinate as computed by SAD and Bmad will not agree except at an RF cavity. However, this difference does not lead to any differences in physically computed quantities like dynamic aperture (DA), etc.

Translation to PTC

Implementation of SAD to PTC translation was fairly straight forward once the SAD to Bmad translation was implemented since PTC could already handle a combination solenoid/multipole element. Lattice translation is handled by first translating a lattice from SAD to Bmad and then using Bmad's Bmad-to-PTC translation software.

Translation to MAD-X

Translation to MAD-X, like translation to PTC was done either a direct translation or a two step process via Bmad. The direct translation was done based a dedicated SAD script, but was only confined to simple lattices which do not contain solenoids and fringe fields.

For the realistic lattices of SuperKEKB, the translation to MAD-X is problematical since MAD-X does not have element equivalent to a SAD *MULT* with Maxwellian fringe models, nor tilted solenoid with fringe field. Thus at present it is not possible to fully translate SAD to MAD-X. However, it is possible to construct an approximated MAD-X lattice that has the same linear Twiss parameters. This is done by first translating to Bmad and then constructing equivalent MAD-X *MATRIX* element which, despite the name, are elements with a nonlinear map in second order of phase space coordinates. The terms of the map were computed by constructing the equivalent map in PTC. In terms of the fringe fields, extra *MATRIX* elements representing the fringes are placed just before and just after the element in question.

In the translation via Bmad, extra elements were needed for a number of reasons. One case is when an element is not a kicker type of element but has a dipole kick. For example, a quadrupole with steering coils. In this case, kick element are inserted just before and just after the element. Additionally, a *MATRIX* element is added, if needed, after a kick element to get the correct z shift through the element. Even drifts can need an extra *MATRIX* element when the angle of the closed orbit is large so that MAD-X's second order drift map is not accurate enough. The representation by such a *MATRIX* element has limitations for large amplitude particles.

Translation to AT

AT [3,8] is a Matlab [9] lattice design toolbox used mainly for synchrotron light sources. We would like to apply the low emittance tuning procedures and the nonlinear optics optimizations developed at ESRF to the SuperKEKB lattices. For this reason we implemented a Matlab function to translate a SAD lattice into AT[1].

The translation of the SuperKEKB Phase-1 lattice [10], which has no IR, to AT presented two main issues: the presence of linear soft-edge fringe field in quadrupoles and the modelling of the wigglers. The map for the soft-edge fringe field in quadrupoles has been introduced in AT using the Elegant code [11] that uses the formalism described in [12]. To implement the trapezoidal model of SAD, the SAD parameter *F1* is set in AT as $I_{1+} = I_{1-} = F1^2/48$. Figure 1 shows the improvement of the optics of LER when using this effect in quadrupoles.

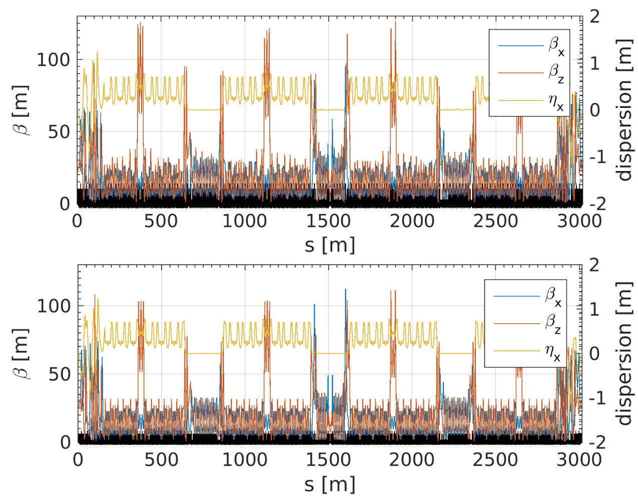

Figure 1: Optics functions for a Phase-1 lattice of LER without wiggler, modeled in AT with (top) and without (bottom) linear soft-edge fringe fields.

Table 1: Lattice Parameters for a Phase-1 Lattice of SuperKEKB LER in SAD and AT

	Without Wiggler		With Wiggler	
	SAD	AT	SAD	AT
ν_x	.5300	.5300	.5300	.5293
ν_y	.5700	.5700	.5700	.5701
ξ_x	2.3	1.72	2.5	2.02
ξ_y	0.828	-0.425	1.67	-0.0057
Nat. ξ_x	-61.67	-62.23	-61.45	-61.99
Nat. ξ_y	-87.53	-88.85	-86.75	-88.53
ϵ_x (nm)	6.30	6.57	1.77	1.96
U_0 (MeV)	0.367	0.377	1.86	2.08

[1] It is already possible to translate files, with some limitations, from AT to MAD-X, MAD8, Elegant and OPA and from MAD-X, MAD8 and Elegant to AT.

The second issue is related to the wiggler model. In particular the description of the bending magnets that do not impact the reference trajectory is not equivalent in AT and SAD. The edge focusing effects are available in AT only for dipoles that change the reference trajectory, while in SAD are present for any dipole. These effects will be introduced also in AT. Table 1 shows the comparison of some relevant parameters with the introduction of quadrupole linear fringe decay in AT, in the lattice with and without the wigglers.

More efforts are needed to translate the SuperKEKB lattices with complicated IR.

BENCHMARK RESULTS

In this section, we present some benchmark results comparing SAD, Bmad and PTC. We use a baseline lattice of SuperKEKB LER on which the details of design can be found in [1]. After translating the lattice file from SAD to Bmad and PTC, the first check is to compare the optics functions. Figure 2 shows that the overall agreements between beta functions are very good, with difference in the calculated tunes less than 0.01. Thus we confirm that the three codes have great agreements in linear optics.

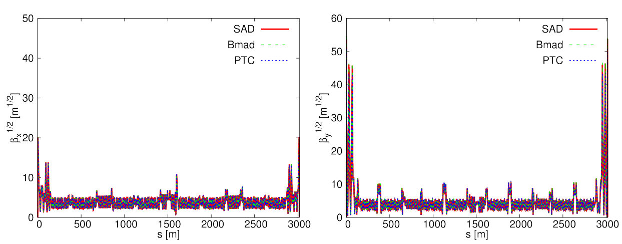

Figure 2: Horizontal (left) and vertical (right) beta functions for a baseline lattice of SuperKEKB LER.

Having verified that the lattice models agree to first order, next we perform the standard frequency map analysis (FMA), and compare the results of SAD and Bmad. These are shown in Figs. 3 and 4. It is seen that both SAD and Bmad estimate similar DA for the LER lattice. Besides the difference in resolutions, they also show similar resonance lines of the phase space lying in the dynamic aperture. With very large amplitudes close to the boundary of DA, discrepancy is seen in the stability of particle trajectories. This indicates that the nonlinear maps implemented in Bmad and SAD are somehow different from each other.

SUMMARY

The translation of SuperKEKB lattices between SAD, Bmad, and PTC is now straight forward. The translation to MAD-X for the linear part of the lattice is possible by adding a number of *MATRIX* elements. This is useful for computing the closed orbit and Twiss parameters but cannot be used for studies where non-linearities are important like dynamic aperture or chromaticity calculations. The translation to AT is successful for the lattices without complicated IR. Further improvements in the translations are foreseen, while some investigations for SuperKEKB, such as nonlinear lattice analysis using PTC and emittance tuning using AT, have also started.

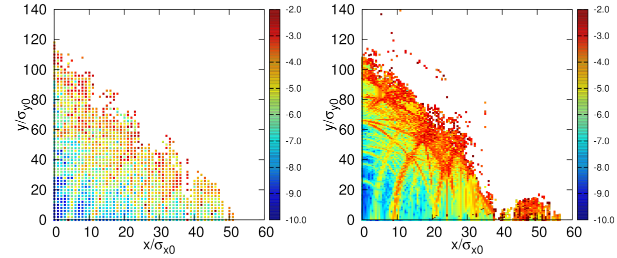

Figure 3: Amplitude-dependent diffusion for a baseline lattice of SuperKEKB LER using SAD (left) and Bmad (right).

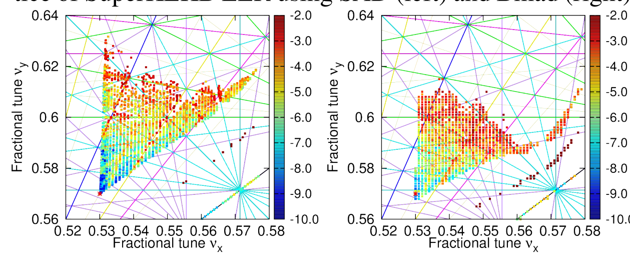

Figure 4: Frequency maps for a baseline lattice of SuperKEKB LER using SAD (left) and Bmad (right). The colored lines indicate various resonance lines.

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