Polarized Beam: Spin Rotator for SuperKEKB

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Motivation

Spin is an intrinsic angular momentum of particles and is purely quantum mechanical. Having spin-polarized beam in collision experiments serves many physics purposes. Polarization can increase the cross-section of some rare event and thus the luminosity. Other studies concern the polarization dependence or asymmetry between identical process. In this project, we aim to design a spin rotator for SuperKEKB in Japan.

Theory

The precession of polarization around electric and magnetic field is given by Thomas-BMT equation [2]: $\frac{d\mathbf{P}}{dt} = \mathbf{\Omega} \times \mathbf{P}$

$$\Omega = -\frac{e}{m\gamma}\left[(1+G\gamma)\vec{B}_\perp + (1+G)\vec{B}_\| + (G\gamma + \frac{\gamma}{\gamma+1})\frac{\vec{E}\times\vec{v}}{c^2}\right]$$

The stable spin direction $\hat{n}$ is the closed orbit solution for spin motion around the ring. A polarization vector parallel to $\hat{n}$ remains stationary after turns. $\hat{n}$ is usually close to vertical due to the vertical guide field. The polarization needs to be vertical in the ring and longitudinal at the interaction point (IP), which will be achieved by installing the spin rotator on both sides of the IP.

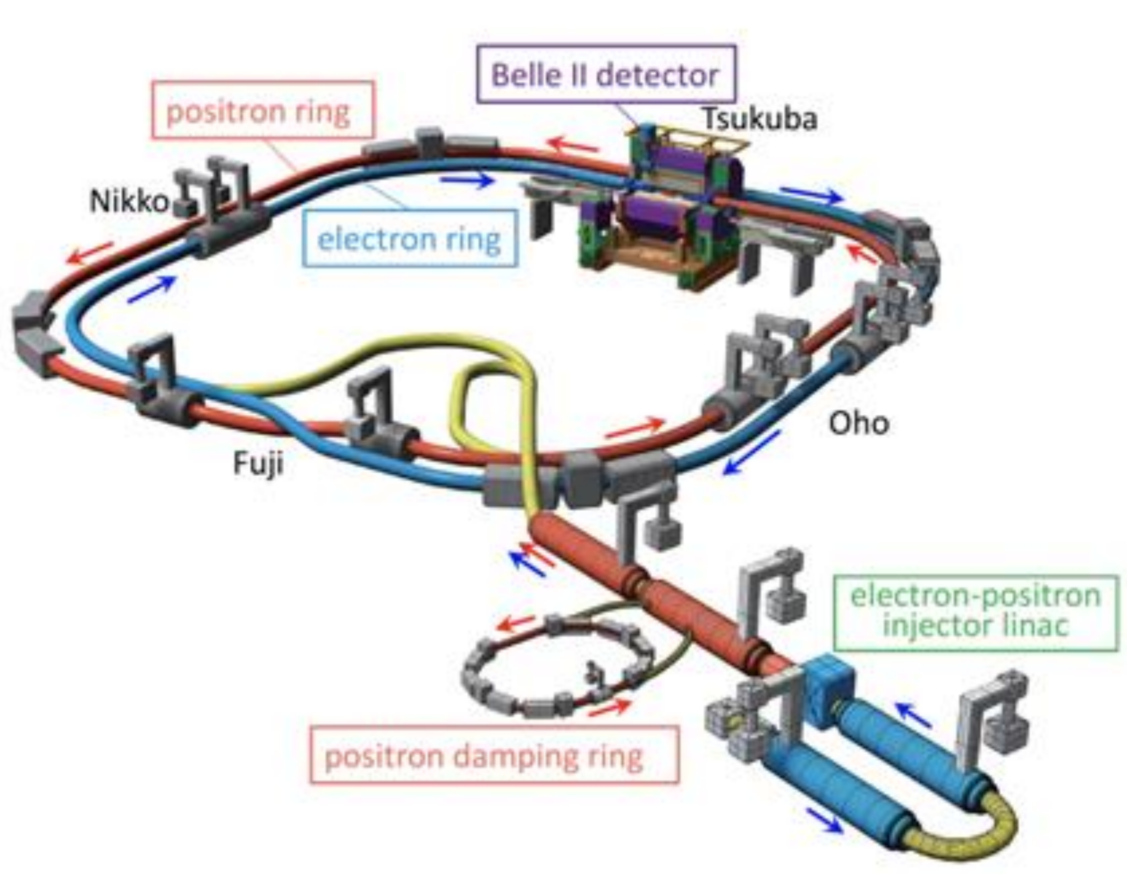

Figure 1: Schematic view of SuperKEKB. [1]

Spin Rotator

The spin rotator magnets are modeled as 6 sections of solenoid-dipole combined function magnets that control the spin. A skew quadrupole is added to each section to compensate the plane coupling introduced by the solenoid [3]. The spin rotator consists of three such magnets that together rotates the spin to the horizontal plane. The lattice dipoles between the spin rotator and the IP will rotate the spin to the longitudinal direction. These magnets are buildable using "Direct Wind" superconducting magnet developed at Brookhaven. [4]

Modeling

We used Bmad&Tao [5] to create a computer model of the rotators and optimize the parameters. The solenoid strength for BLA4LE and B2E are respectively ks = 0.19363, 0.03417 m^{-1} or 4.5, 0.798 T. The minimized maximum quadrupole strength is k1 = 1.5 m^{-1}, which requires a 2.8 T magnetic field at r = 8 cm. These strengths are realistic and buildable. At the end of rotators, x-y planes are fully decoupled and the vertical dispersion is minimal to avoid increasing vertical emittance.

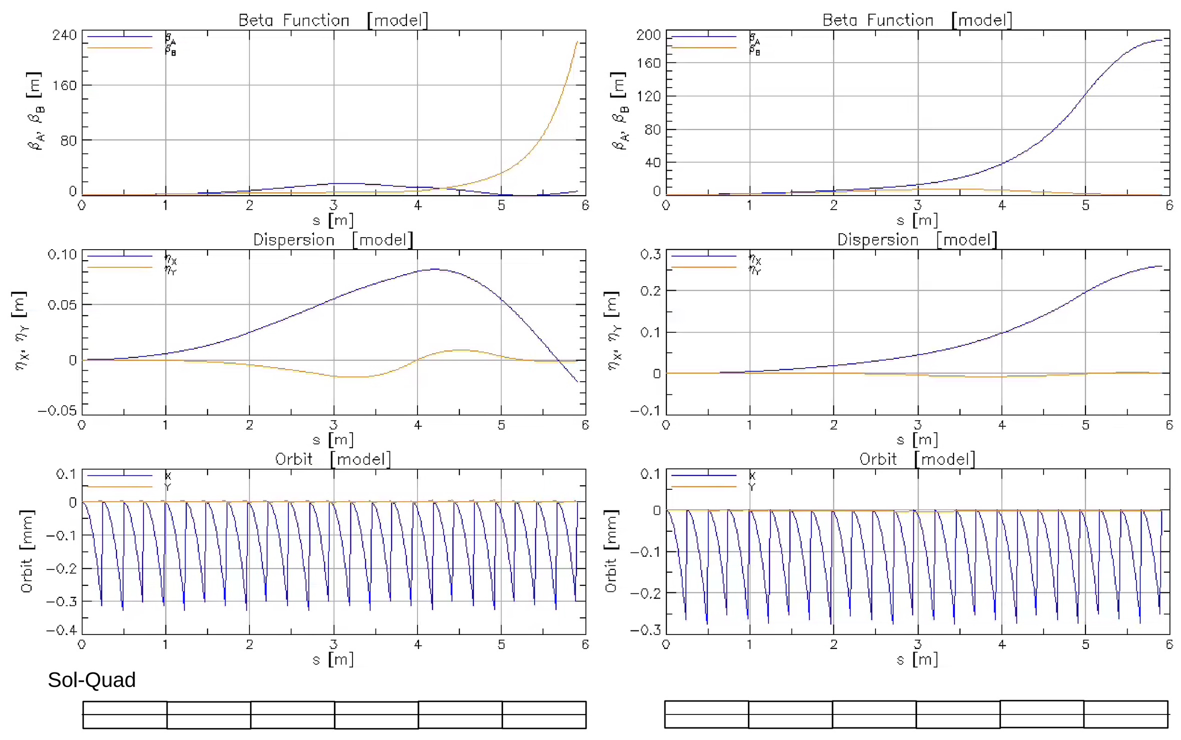

Figure 2: Stand-alone model of spin rotator magnets, BLA4LE (left) and B2E (right).

Matching to Lattice

We plugged the stand-alone model into the existing lattice, and alter the quadrupoles in the region to match Twiss parameters and dispersion such that the spin rotator is transparent to the system. The overall R matrix shows that the off-diagonal coupling terms are reasonably small. The beta functions and horizontal dispersion are matched to the original lattice, as shown in figure 3&4.

11.33	-0.3086	-3.098E-5	-4.25E-6	0	0.2377
1.096	0.05839	-2.69E-6	-4.4E-7	0	-0.04210
-6.65E-6	7.01E-6	-18.82	-0.08484	0	-0.06507
4.50E-6	-5.07E-6	13.24	6.549E-3	0	0.00378
0.7377	8.929E-4	-0.7904	-1.057E-4	1	-0.05413
0	0	0	0	0	1

Table 1: R matrix of the spin rotator.

Future Work

This project demonstrates the possibility of building a compact spin rotator using dipole and solenoid decoupled by skew quadrupoles. The model could be applied to upgrade SuperKEKB without changing the geometry of the ring, or provide alternative design for future polarized machines such as Electron-Ion Collider (EIC).

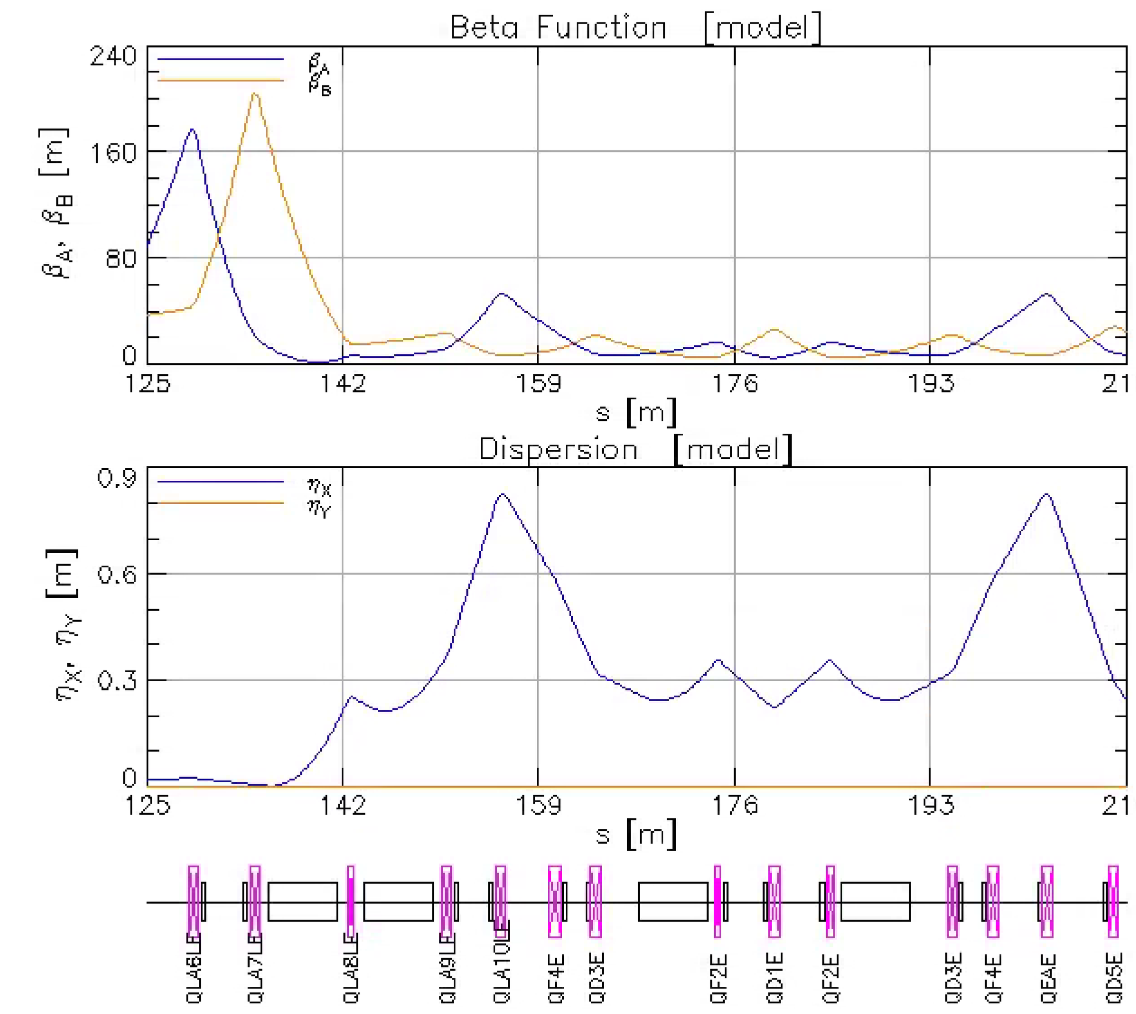

Figure 3: Original lattice of SuperKEKB.

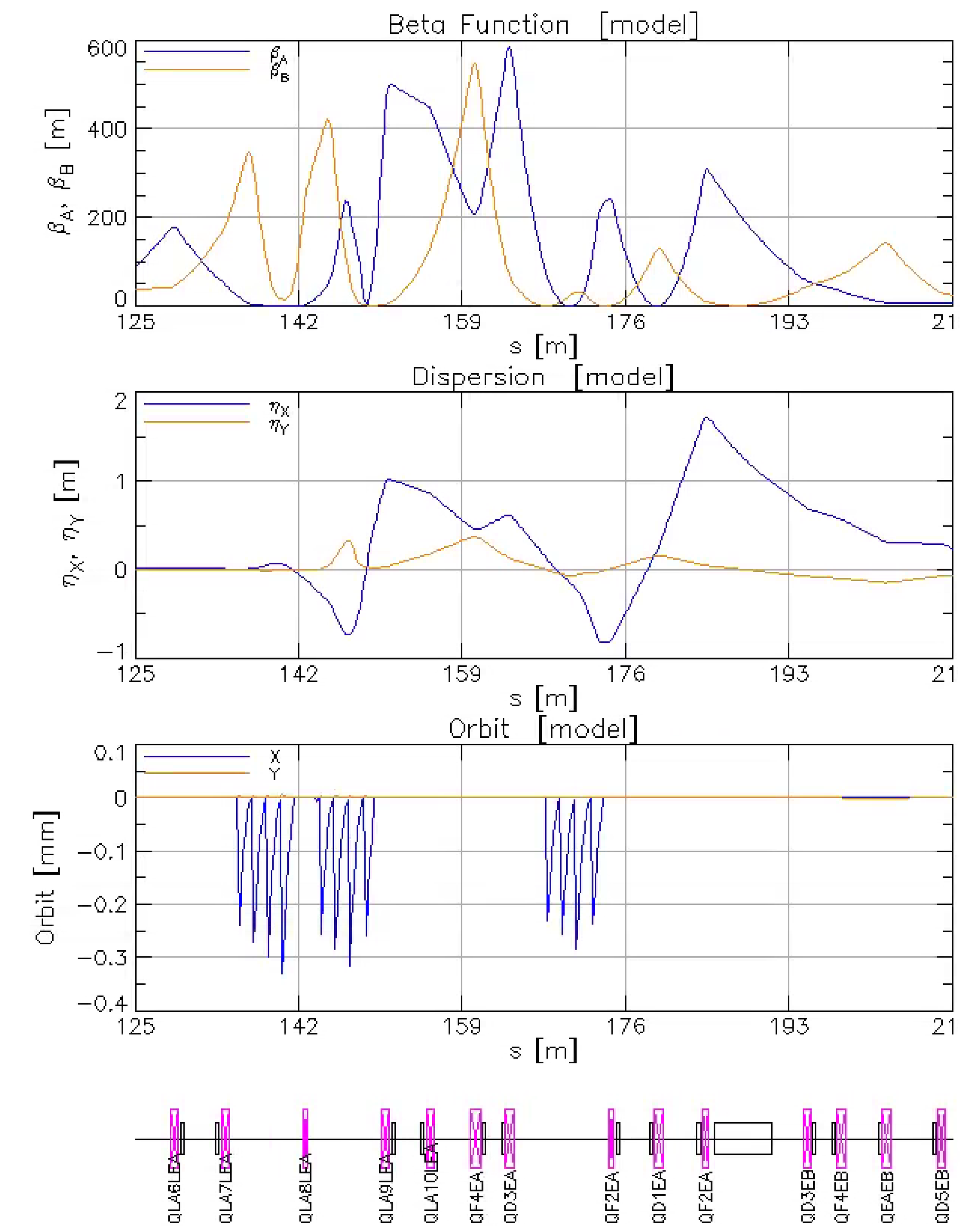

Figure 4: Lattice with spin rotators. The orbit excursions are an artifact of the modeling of combined functions in Bmad.

References

[1] https://arxiv.org/pdf/1809.01958.pdf
[2] N. Monseu, thesis, LPSC, Grenoble, France (September 20, 2013)
[3] A.A. Zholents, V.N. Litvinenko, *On the Compensation of Solenoid Field Effect by quadrupole Lenses* (I. Schulz-Dahlen, Trans.), BINP-81-80 (1984)
[4] B. Parker et al., BNL Direct Wind Superconducting Magnets, BNL-96547-2011-CP (2011)
[5] D. Sagan, *the Bmad reference manual* (July 2, 2019)

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