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CESR-c Optics

1 5.3 GeV

1.1 BMAD_I9A10A300.FD94E_4S_15KG

These are Phase III optics with:

- 3 sections of permanent magnet IR quad
- The permanent magnet quad is erect
- CLEO solenoid at 1.5T
- As for all phase III optics, the 3 degrees of freedom for constraining all 4 elements of the C-matrix at L3 and C_{12} at the IP to be zero are the skew quads superimposed on Q1 and Q2 (named SK1 and SK2) and the skew quad adjacent to the soft bend, (named SK3).
- G-line wiggler

Essential parameters of the lattice are summarized in the table.

β_v^*	10mm
β_h^*	103cm
$\theta{*}_c$	2.3mrad
ϵ_h	0.19mm-mrad
β_h(at G-line wiggler)	14.6m
β_v(at G-line wiggler)	21.2m
Trains	9
Bunches	5

The BMAD_I9A10A300.FD94E_4S_15KG lattice is based on a layout that is not up to date. In particular, it needs to be corrected between 7W and 10W. Since the lattice was created, there has been some rearrangement of quads and sextupoles.

The lattice is an existence proof that $\beta_v^* = 10$mm optics exist but otherwise not terribly useful. We do not anticipate running for HEP on the 4s, and in any event, given the available RF accelerating voltage, bunch length is limited to no less than 18mm, so we should design for β_v^* =18mm.

1.2 startup optics

Because the superconducting quads are so strong, any misalignement will result in a large orbit error. It would be easiest to start up with a lattice in which the IR quads were relatively weak, and the β-functions in the quads were modest. Specifications for such a startup lattice would include:

- Q_v =0.6
- Q_h =0.56
- Solenoid compensation. Unless the coupling is compensated it will be very difficult to make sense of phase measurements
- β_h <40m in IR
- β_v <40m in IR
- ϵ_h <0.2mm-mrad

The lattice need not support bunch trains so requires no pretzel constraints. A low emittance will simplify injection. Once we have stored a beam in the startup optics, measured and corrected IR quad misalignment and phase errors, we can switch to an HEP type lattice.

1.3 4s HEP optics

BMAD_I9A10A300.FD94E_4S_15KG should be reworked to include:

- The proper machine layout

- Realistic final focus parameters ike β_v^* =18mm
- The 4.5° rotation of the permanent magnet quad.

2 5.175GeV Υ_{3s}

The Υ_{3s} lattice is the one in which we will spend some time tuning and running for HEP. Design constraints are:

β_v^*	18mm
β_h^*	~1m
Q_h	10.53
Q_v	9.58
Trains	9
Bunches	5
β_v(g-wig)	$<$ 23m
ϵ_h	$<$ 0.2mm-mrad

Emittance has typically been near 0.2mm-mrad in 4s running in the Phase II configuration. With the replacement of the west wiggler with the g-line wiggler it will be possible to make it somewhat smaller and at the lower energy, smaller still. We should try to make it as small as possible, perhaps with 0.1mm-mrad as a lower limit. Since our current limit has in the past been due to parasitic beam-beam interactions and not horizontal tune shift from the collision, a smaller emittance will improve the clearance without otherwise limiting bunch current. Presumably this lattice will evolve from the 4s optics described previously.

3 4.7GeV Υ_{1s}

Energy spread and bunch length scale with beam energy so we can expect that the bunch length will be 16mm (vs 18mm at 5.3GeV) and we can design for $\beta_v^* = 16$mm. Emittance scales as the square of the energy. The lower emittance may prove an advantage in increasing the pretzel related beam current limit. Assuming that the RF voltage has not been reduced to maintain the same synchrotron tune (and bunch length) as at higher energy, the tune plane will look different and our operating point may need to change. Meanwhile, let's create a 4.7GeV lattice with the same constraints as for the 5.27GeV case.

4 Pretzel constraints

A variety of constraints are applied to optimize the bunch separation, and minimize the aperture requirements. These are:

1. Pretzel efficiency. Let x^i_{pc} be the pretzel displacement at the i^{th} parasitic crossing point, and x^j_{pretz} the pretzel displacement at the j^{th} ring element. Then

$$\begin{aligned} A_{pc} &= \frac{x^i_{pc}}{\sqrt{\beta^i_h}} \\ A_{pretz} &= \frac{x^j_{pretz}}{\sqrt{\beta^j_h}} \end{aligned} \quad (1)$$

   and

$$\epsilon = \frac{MIN(A_{pc})}{MAX(A_{pretz})} \quad (2)$$

2. Bunch current. The bunch current (I_BUNCH) is a measure of the effectiveness of the pretzel separation. Let $(\Delta q^i_h)I_b$ and $(\Delta q^i_v)I_b$ be the long range tune shift at the i^{th} parasitic crossing. I_b is the bunch current. The parameter

$$B \propto \epsilon_h \Sigma_i \left(\sqrt{\Delta q^i_v \Delta q^i} \right) I_b \quad (3)$$

   includes the dependence on the horizontal beam size. Maximum tolerable values for ΔQ_h,ΔQ_v, and B are determined empirically and set in the constraint list as LRBBI_DEL_Q and WELCH_TEMNYKH. Then I_BUNCH is the bunch current such that the tune shifts and B parameter are not greater than the respective maxima. I_BUNCH is typically about 6mA for Phase II 9X5 optics.

3. Sigma separation. Let N_σ^i be the separation at the i^{th} parasitic crossing point in units of rms beam size. Then SIGMA_SEP is MIN(N_σ^i) for all i. In Phase II optics the minimum separation is about 7σ.

4. Displacement. The displacement constraint is simply the horizontal or vertical displacement of the closed orbit at the prescribed element or in the prescribed range. We have interpreted the observed degradation in specific luminosity with pretzel as a result of magnet nonlinearities at large amplitudes. We impose a limit of 18mm on the horizontal orbit.

5. Pretzel_aperture. The pretzel aperture $P_{aper}^i = x^i + 7.5\sigma_x^i$. x^i is the displacement at the i^{th} and σ_x^i the rms beam size at the i^{th} lattice element. That $7.5\sigma_x$ gives adequate clearance is determined empirically. The available arc aperture is 45mm.

6. Crossing angle. The Phase II crossing angle was close to 2.5mrad. It is limited from below by the constraints on tune shift and B-parameter. It will be limited from above by an aperture constraint. But it is not clear how much aperture is required in the IR. Presumable it is more than the 7.5σ that seems to work in the arcs. It may be more difficult to maintain high specific luminosity with a large crossing angle because of some beam-beam effect and the crossing angle tends to be somewhat larger with the Phase III IR than the Phase II. We may want to constrain it but just where has yet to be determined.

And then there are all of the other requirements:

1. Twiss parameters at the IP

2. Tunes

3. Coupling (C-matrix)

4. Energy dependence of β

5. Injection

4.1 Injection

. The acceptance for the injected bunch is maximized if the β_h at the injection point (Q34) is greater than β_h anywhere else in the arcs. On the other hand, we do not want a high value of β_h^{34} to limit the pretzel amplitude or an increased sensitivity to field errors. So we usually constrain β_h at 34 to be 40m and β_h every else to be less than 40m.

The amplitude of the pulsed bump is limited by the beam size at the injection point. Since β is constrained to be relatively large, only the η-function is at our disposal. Minimize η to minimize beam size. If we want to take advantage of off energy injection, that is where the injected bunch has an energy that is a bit below the energy of the stored beam, then the dispersion at the injection point must be finite. The injected bunch oscillates with an amplitude that is determined by its displacement from the orbit of the stored beam when it enters CESR. If the injected bunch has the same energy as the stored beam than the local displacement of the bunch is proportional to $\sqrt{\beta_h}$. But if the injected bunch has an energy offset the displacement is a linear combination of betatron and energy oscillation with the amplitude of the energy oscillation proportional to η. Typically we constrain η at the injection point to be between 1 and 2m.