SLIA Beam Line Design

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Abstract

The design of the beam line for the Spiral-Line Induction Accelerator (SLIA), a 10 kA recirculating induction electron accelerator that uses stellarator windings to provide strong focussing on the recirculator bends, is described. A SLIA proof-of-concept experiment is in process at Pulse Sciences, Inc., and the design calculations presented are primarily of relevance to that device — a three-bend, two-pass accelerator. Beam matching techniques are described to take the beam from a field-free diode, through the three-turn accelerator, while minimizing beam envelope oscillations and beam centroid excursions. Simulations of the beam dynamics with ABBY, an envelope code for X-Y coupled, linear focusing systems[1], are displayed.

BEAM LINE EQUILIBRIA

The energy in the planned Proof-of-Concept Experiment (PoCE) is 2.5 MeV (input), which will be accelerated to 4.0 MeV by the first bend, 5.5 MeV by the second bend, 7.0 MeV by the third bend, and 8.5 MeV (output). The major and minor radii of the bends have been chosen at 80 cm and 3 cm, respectively. The transport system is a spiral configuration, having solenoidal focusing in the straight sections that pass through the induction accelerator modules, and stellarator windings on the bends to reduce the momentum compaction factor.

Pitch lengths corresponding to m = -8, -12, and -16 have been examined in an effort to identify equilibria which are identity transformations and which offer good chromatic properties. Identity transformations are equilibria in which the beam centroid undergoes an integer number of betatron oscillations while traversing the 180° bend.

A code which searches the SLIA identity transformations on each of the three bends in the PoCE, and accepts those which display beam parameters within specified constraints, has been exercised to obtain the results given in Table 1. The rows marked in bold type are the specific equilibria used in the three-turn simulation described below.

SOLENOID-STELLARATOR MATCHING

The beam matching strategy illustrated in Figure 1 was suggested by M. Tiefenbach at PSI and developed at SAIC. It has been generalized to allow thick focusing elements, to include the fringe fields of the stellarator and vertical field coils, and to permit the matching section to be displaced from the mouth of the bend. Using this technique, it is now possible to match any solenoid-stellarator transition in SLIA.

FIELD ERRORS AND CORRECTION COILS

Beam offset occurs in straight solenoidal sections of the beam line due to fringe fields from coils in other sections of the transport system. Correction dipoles are used to force the beam centroid back on axis. A schematic of the correction coil configuration is shown in Figure 2.

Table 1. Equilibrium Code Results for PoCE

Bend #	m	ν_+	ν_-	B_{long} [G]	$B'_\perp(0)$ [G/cm]	L_{quad} [cm]	r_{maj} [cm]	r_{min} [cm]	δ_{GC}* [cm]	ρ_L* [cm]
1	-16	20	6	5095.	227.7	62.8	.899	.583	.150	.0625
1	**-16**	**22**	**6**	**5481.**	**254.5**	**62.8**	**.866**	**.559**	**.129**	**.0531**
1	-12	20	4	4759.	200.4	83.8	1.04	.585	.152	.0482
1	-12	22	4	5142.	222.3	83.8	.999	.560	.128	.0433
2	-16	12	6	4676.	148.5	62.8	.874	.619	.209	.240
2	-16	14	6	5225.	190.8	62.8	.842	.580	.243	.112
2	-12	14	4	4802.	177.8	83.8	.982	.589	.277	.0794
2	**-12**	**16**	**4**	**5327.**	**208.4**	**83.8**	**.934**	**.556**	**.225**	**.0560**
3	-16	10	4	4731.	162.0	62.8	.985	.597	.338	.300
3	-16	10	6	5132.	124.2	62.8	.786	.597	.254	.465
3	-12	10	4	4652.	140.7	83.8	.947	.606	.322	.318
3	-12	12	4	5340.	182.8	83.8	.900	.560	.329	.152
3	**-8**	**14**	**2**	**5476.**	**183.1**	**126.**	**1.12**	**.525**	**.370**	**.0725**

**Guiding-center displacement and Larmor radius are computed for an assumed mismatch of* $\frac{\delta p}{p}$ *= 10%.*

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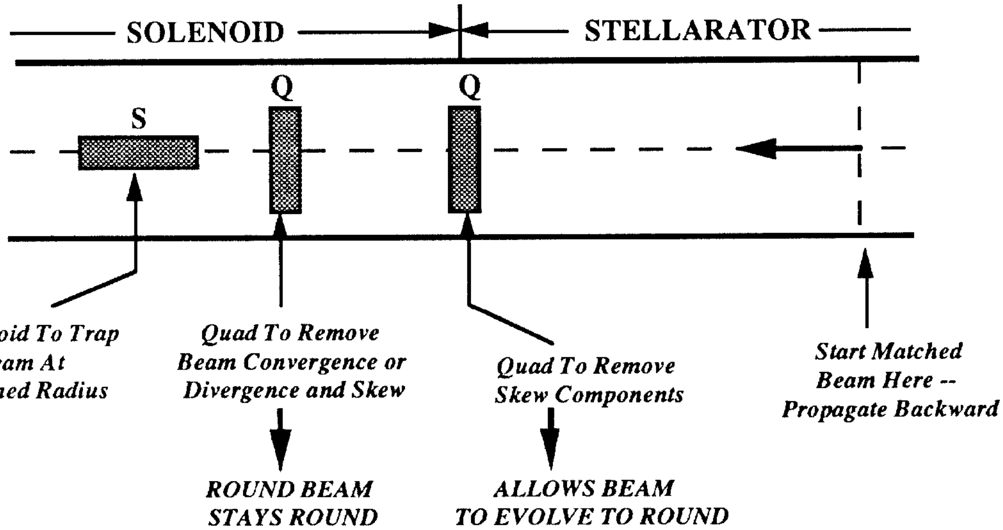

Figure 1. Beam Matching Scheme

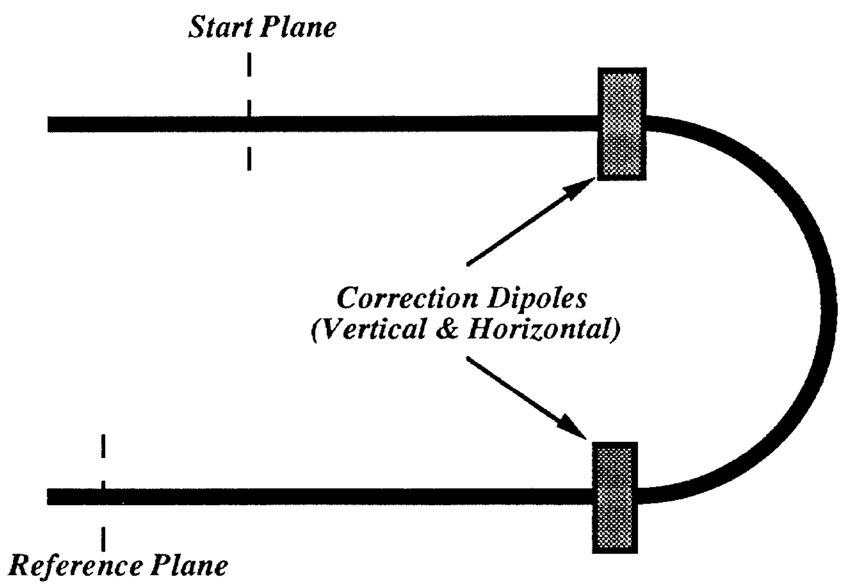

Figure 2. Centroid Orbit Correction Coil Scheme

The vertical and horizontal correction coils are adjusted so that the centroid trajectory meets the axis with zero slope at the reference plane. First, the location of the centroid trajectory $\{x_0, y_0, x_0', y_0'\}$ at the reference plane with no correction coils is computed. Then, a current of 1 A is introduced in the jth correction coil with no current in the other correction coils, and the centroid orbit crossing at the reference plane $\{x_j, y_j, x_j', y_j'\}$ is computed. This step is repeated with each of the correction coils energized in turn. The centroid trajectory at the reference plane with currents $\{I_1, I_2, I_3, I_4\}$ in the four coils may then be written by linear superposition as

$$x-x_0 = \sum_{j=1}^{4} I_j\,(x_j-x_0),$$

with similar equations for $y-y_0$, $x'-x_0'$, and $y'-y_0'$. These equations can be solved for the I_j's that force $x=y=x'=y'=0$ at the reference plane. This procedure generalizes easily to a correction system that corrects the centroid trajectory over multiple bends, using four correction coils per bend.

THREE-TURN SIMULATION FOR THE PoCE

To carry out the three-turn simulation for the PoCE, the individual bends were first matched and corrected, as described above, in three separate simulations. The ABBY code, including the acceleration (γ'/γ) term, was used to compute the beam envelope and centroid over the entire length of the PoCE. The magnetic fields were computed from coil specifications using the SPIRAL magnetostatic code. Analytically computed axial and radial electric field components in the accelerating gaps were included in the envelope model. Also, since the longitudinal magnetic field is slightly different in the three bends (see Table 1), that field component was ramped in the straight sections, and the radial magnetic field component associated with the ramped axial component in the straight sections was included in the simulation.

The layout of the three-turn beam line was unfolded for this simulation to remove cross-talk between turns. In this model the SLIA is treated in a single plane. Figure 3 shows the beam centroid result from the three-turn simulation. The slight mismatch resulting from the ramped axial magnetic field leads to a small centroid oscillation by the third bend. This oscillation can be removed by adjusting the correction coils on each bend. Envelope oscillations also arise from this mismatch; these can be corrected by adjusting the matching coils.

FUTURE WORK

A higher-order moment model is being developed which will allow full time-dependent simulations that model emittance growth and nonlinear fields. This model is described in a companion paper presented at this conference[2].

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2. K. T. Tsang, C. Kostas, D. P. Chernin, J. J. Petillo, and A. A. Mondelli, *A High-Order Moment Simulation Model*, (published in these proceedings).

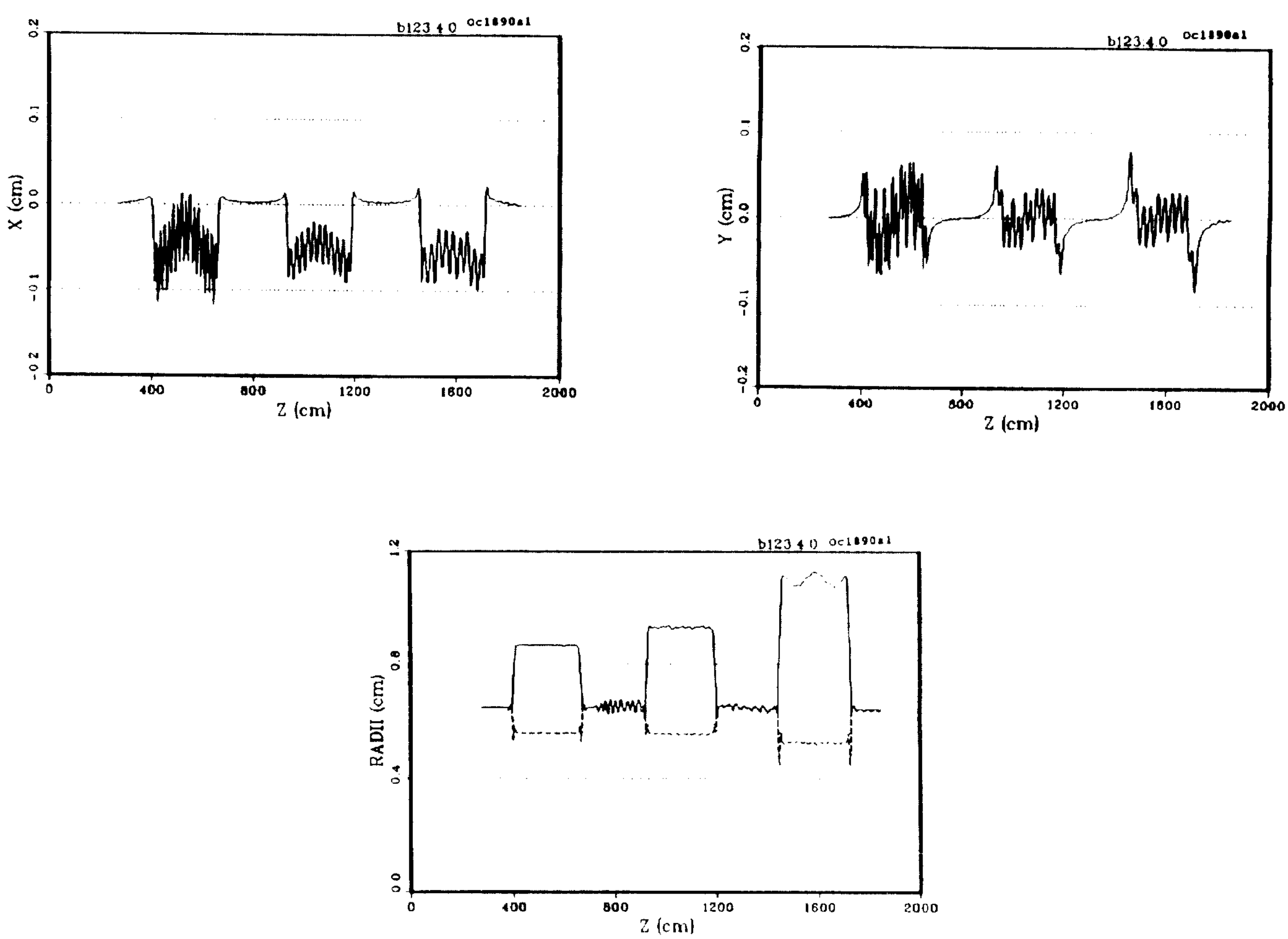

Figure 3. Three-Turn PoCE Simulation with matching coils adjusted to provide an end-to-end match.