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Study of Low β_y Straight Section in SPEAR 3 [1]

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Abstract

The SPEAR 3 light source [1] has two 7.6 m straight sections one of which is available for new insertion devices (ID). By reducing the vertical β_y function at the center of the straight from 9.8 m to 1.5 m, the beam size can be decreased from 44 μm to 17 μm to reduce the ID gap, but the ID length may be limited by the increased β_y variation in the ID. Alternatively, a "double waist" optics with two symmetric low β_y locations and a chicane may be considered to implement two IDs. In this paper, we discuss the low β_y optics, effects on the beam dynamic aperture, and the ID parameters needed to maximize photon flux density and brightness while maintaining electron beam lifetime.

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The SPEAR 3 light source [1] has two 7.6 m straight sections one of which is available for new insertion devices (ID). By reducing the vertical β_y function at the center of the straight from 9.8 m to 1.5 m, the beam size can be decreased from 44 μm to 17 μm to reduce the ID gap, but the ID length may be limited by the increased β_y variation in the ID. Alternatively, a "double waist" optics with two symmetric low β_y locations and a chicane may be considered to implement two IDs. In this paper, we discuss the low β_y optics, effects on the beam dynamic aperture, and the ID parameters needed to maximize photon flux density and brightness while maintaining electron beam lifetime.

1 INTRODUCTION

The SPEAR 3 design optics consists of two periodic arcs separated by the East and West matching cells [2]. Intended locations for the insertion devices in the arcs are the twelve 3.1 m drift sections between the 14 arc cells and four 4.8 m drifts at the arc ends. At present, the matching cells (MC) have identical symmetric optics with a 7.6 m drift at the center of MC and phase advance $\mu_x/\mu_y = 1.6/0.8$ [2π] per cell. The East 7.6 m drift is available for the new IDs, and the West MC will contain the RF accelerating cavities.

The photon flux density and brightness in the insertion devices depend on the electron beam size and, hence, β functions at the IDs. At present, the β_x/β_y values are $10.2/4.7$ m at the arc drift sections, and $5.0/9.8$ m at the center of 7.6 m drifts. For the SPEAR 3 design vertical emittance of 0.2 nm at 3 GeV, the vertical beam size is 31 and 44 μm at the ID locations in the arcs and MCs, respectively. The beam size and the ID gap can be reduced by decreasing the β_y at ID, but this will increase the beam divergence and variation of β_y in the ID. For a better ID performance, a large β_y variation in the insertion device should be avoided by limiting the ID length or the minimum value of β_y. The β_y value is also limited by the acceptable size of dynamic aperture and beam lifetime.

In this report, we discuss the low β_y options for the 7.6 m drift in the East MC. The West MC was maintained close to nominal in most of this study. The optics and dynamic aperture calculations were done using MAD [3] and LEGO [4] codes, respectively.

The present SPEAR 3 optics has been well optimized for a maximum dynamic aperture. To maintain the current lattice properties, the following requirements were used for the low beta modifications:

- Matched optics using local quadrupoles.

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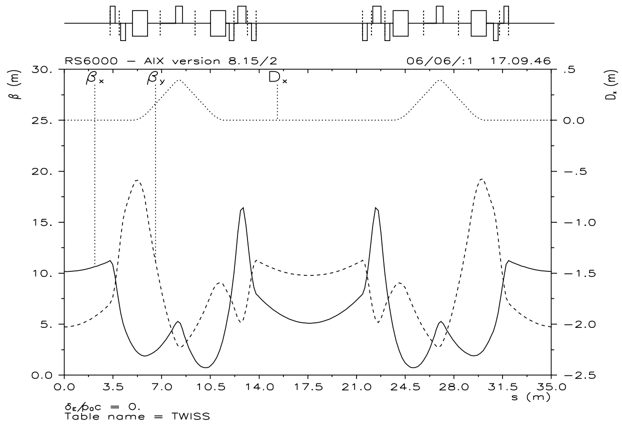

Figure 1: Nominal lattice functions in the MC.

- Minimal change of the local phase advance.
- Minimal increase of maximum β functions.
- Realistic quadrupole strengths.

In addition, we tried to keep equal or close phase advance in the East and West MCs and limit the sextupole strengths, since the stronger sextupoles and ring optical asymmetry may enhance resonance effects and reduce dynamic aperture.

The nominal lattice functions in the MC are shown in Fig. 1, where the 7.6 m drift is at center. The corresponding dynamic aperture without ID effects is shown in Fig. 2, where the solid and dash lines are for the nominal and 3% off-energy particles, respectively. The dynamic aperture simulations included a full set of magnet errors and machine correction for six random error settings.

2 SINGLE LOW β_Y IN THE MC

Several options for a matching cell with single low β_y were analyzed as listed in Table 1, where $\beta_{x,y}$ is at the MC center, $\mu_{x,y}$ is the MC phase advance, $\xi_{x,y}$ the ring natural chromaticity, and $K_{SF,SD}$ the K-values of global sextupoles.

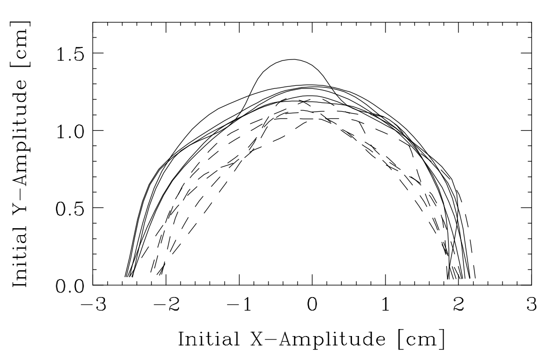

Figure 2: Nominal dynamic aperture for 6 error settings.

Table 1: Single low β_y options in the East MC.

	β_y/β_x [m]		μ_x/μ_y $[2\pi]$	
	East	West	East	West
1	1.0 / 4.41	9.78 / 5.08	1.60 / 0.90	1.60 / 0.80
2	1.0 / 3.77	9.78 / 6.49	1.56 / 0.96	1.56 / 0.96
3	1.0 / 4.35	9.77 / 5.04	1.60 / 0.90	1.60 / 0.90
4	1.5 / 5.25	9.00 / 5.09	1.60 / 0.87	1.60 / 0.87
5	2.0 / 6.04	9.17 / 5.09	1.60 / 0.84	1.60 / 0.84

	ξ_x/ξ_y	K_{SF}/K_{SD} $[m^{-3}]$
1	-22.20 / -15.35	31.43 / -37.96
2	-22.67 / -15.70	31.21 / -37.30
3	-22.26 / -15.51	31.46 / -37.79
4	-22.03 / -15.19	31.09 / -37.41
5	-21.90 / -15.03	30.85 / -37.26

The low β_y optics in the East MC was matched using five local quadrupole families while the West MC was maintained close to the nominal. For low β peaks and chromaticity, the MC phase advance was slightly varied. The arc phase was adjusted accordingly to keep the working tune at $\nu_x/\nu_y = 14.19/5.23$.

Comparison of the three $\beta_y = 1$ m options showed a larger dynamic aperture in case 3. It indicates that the preferred optical conditions are close to the nominal phase advance, equal phase advance in the two MCs, low chromaticity and weak sextupoles. Note that low β_y naturally increases the MC vertical phase advance since $\mu = \int \frac{ds}{\beta}$.

Cases 4,5 with $\beta_y = 1.5$ and 2 m were designed similar to case 3. In comparison, the lower β_y requires stronger focusing and larger quadrupole strengths as listed in Table 2. Consequently, the lower β_y leads to larger β peaks in the MC, higher chromaticity and stronger sextupoles, and reduced dynamic aperture. At present, the QDXE, QFXE design strengths are limited at $|K| \approx 2$, therefore optics with $\beta_y < 1$ m would require an upgrade of these magnets.

Maintaining sufficient aperture for horizontal injection and beam lifetime with Touschek effects requires a large horizontal dynamic aperture with up to 3% energy errors. LEGO simulations with machine errors, but without ID effects, estimate the horizontal dynamic aperture near 16 mm for $\beta_y = 1$ m, and 17 mm for $\beta_y = 1.5$ and 2 m, compared to the nominal 18-20 mm aperture. This aperture may be sufficient even with the ID effects included which will reduce it by $\sim$1-2 mm. For a conservative design, we consider an option with $\beta_y = 1.5$ m. The MC optics and dynamic aperture in this case are shown in Fig. 3 and 4.

It had been shown that the SPEAR 3 horizontal emittance can be reduced by allowing a small dispersion $\eta_x \sim 10$ cm in the arc drifts [5]. The required dispersion was obtained by slightly mismatching the arc achromats and appropriate adjustment of the matching cells. In this low β_y study, we verified dynamic aperture for $\eta_x = 5$ and 10 cm in the arc drifts. LEGO simulations without ID effects showed that at $\beta_y = 1.5$ m the horizontal dynamic aperture is 15-16 mm at $\eta_x = 5$ cm, and $\sim$13 mm at 10 cm dispersion. We conclude that dispersion up to 5 cm may be used to reduce the horizontal emittance from 18.5 to 14.6 nm.

Table 2: Quadrupole K-values in the East MC $[m^{-2}]$.

β_y [m]	1.0 (c.3)	1.5	2.0
QDXE	-1.9269	-1.6027	-1.3254
QFXE	1.8308	1.7695	1.6880
QDYE	-0.8003	-0.9760	-1.0481
QDZE	-0.6667	-0.7032	-0.7245
QFZE	1.3458	1.4110	1.4512

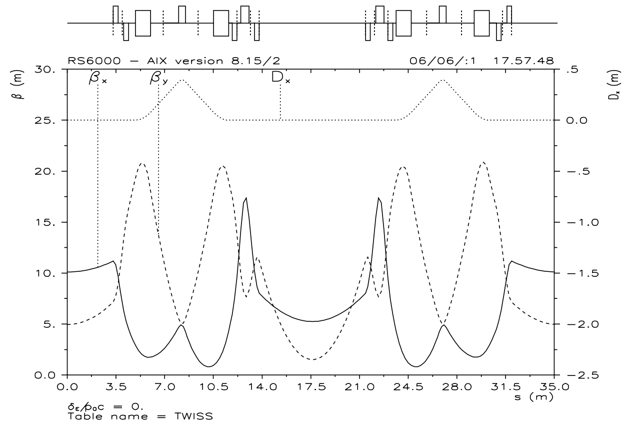

Figure 3: Matching cell with a single $\beta_y = 1.5$ m .

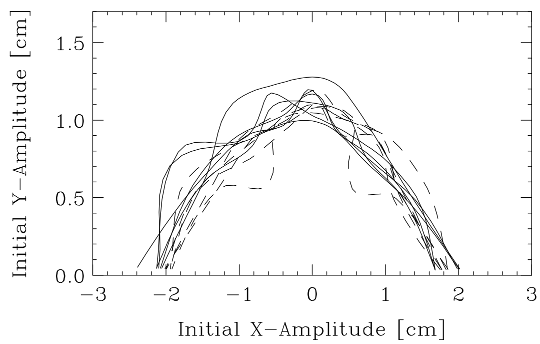

Figure 4: Dynamic aperture for a single $\beta_y = 1.5$ m.

The low β_y function increases beam divergence and β_y variation in the ID and may limit the ID length. At distance s from the waist: $\beta_y(s) = \beta_y + \frac{s^2}{\beta_y}$, where β_y is at the waist. For example, for $\beta_y(s)$ variation below 100% and the waist at ID center, the half ID length has to be less than β_y.

3 DOUBLE LOW β_Y IN THE MC

The 7.6 m straight section in the matching cell can be upgraded to have two low β_y locations for two IDs. A double waist optics can be obtained using an extra quadrupole triplet at center of the straight. An example of such optics with two symmetric $\beta_y = 2$ m locations is shown in Fig. 5, where the space available for each ID is about 2 m and the six local quadrupole families are adjusted to keep the MC matched.

The separation of the two ID beam lines can be done using a four bend horizontal chicane. We investigated symmetric and anti-symmetric chicane schemes with 25 cm

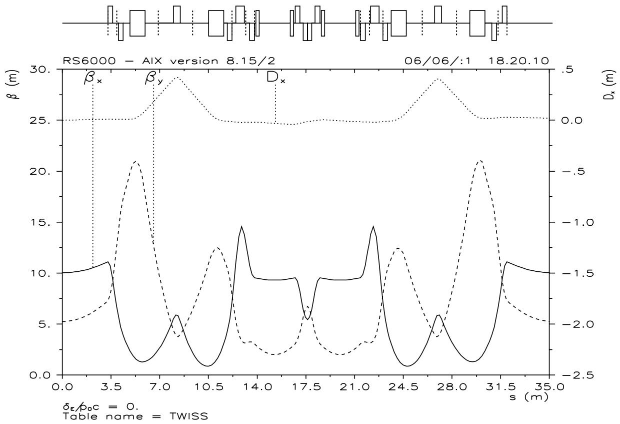

Figure 5: Matching cell with a double $\beta_y = 2$ m .

dipoles placed symmetrically around the β_y waists as shown in Fig. 5. In the symmetric scheme, the bending angles in the four dipoles were [-10,+10,+10,-10] mrad which produce 24.7 mm closed orbit bump and 20 mrad angle between the beam lines. In the anti-symmetric scheme, the bending angles were [-8,+25.7,-25.7,+8] mrad to generate two ± 19.8 mm bumps and parallel ID beam lines with horizontal separation of 57 mm.

The chicane bends generate additional dispersion in the MC. We found that with the symmetric chicane this dispersion can be locally compensated by slightly mismatching the MC achromats. In the anti-symmetric scheme, the dispersion could not be fully compensated using local quadrupoles, but the residual dispersion in the ring is below 4 cm which is not a problem for the IDs. This dispersion has only minor reduction effect on the emittance. The anti-symmetric double waist optics is shown in Fig. 5.

The double β_y optics further increases the vertical phase advance in the MC. Similar to the single β_y optics, the μ_y has to be kept close to the nominal value for a better dynamic aperture. For realistic magnet strengths and matched optics, the vertical phase advance was set at 1.1 [2π] as compared to the nominal 0.8 [2π]. The MC sextupole strengths were optimized for larger dynamic aperture.

LEGO simulations showed a larger dynamic aperture in the anti-symmetric scheme as shown in Fig. 6. This aperture may be sufficient for the beam operation, but more study is required for the design of ID beam lines.

4 UNDULATOR PERFORMANCE

The primary motivation for reducing β_y in the matching cells is to enhance hard x-ray brightness from small gap undulators. To evaluate the potential performance of small gap undulators in the MC, a rough examination of suitable undulator parameters was undertaken using the XTC routine of the XOP software suite [6]. Tuning curve simulations for hybrid, planar undulators in the absence of field errors are shown in Fig. 7 for the ID parameters listed in Table 3. The curves depict the fundamental and odd harmonics through the 9th order. For the high brightness hard x-ray beams, the undulator parameters were selected to provide

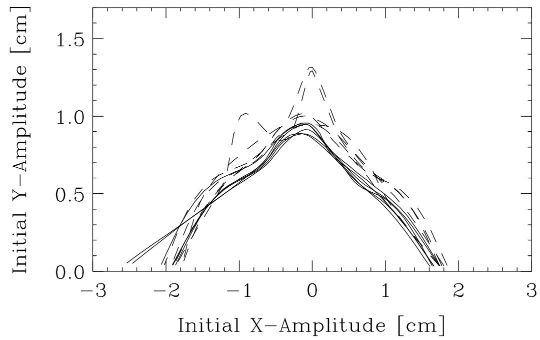

Figure 6: Dynamic aperture for a double $\beta_y = 2$ m.

reasonable tuning curve overlap in the $E > 6$ keV regime without concern for the coverage gap between the first and third harmonics for $E < 6$ keV. The magnet gaps used in the simulations preserve reasonable beam lifetime, though somewhat improved performance at high energies could be obtained using smaller gaps.

Table 3: Parameters of simulated IDs.

waist	β_x/β_y [m]	gap [mm]	period [mm]	length [m]
single	5.25 / 1.5	5.0	19.0	3.0
double	8.0 / 2.0	6.0	20.0	2.0

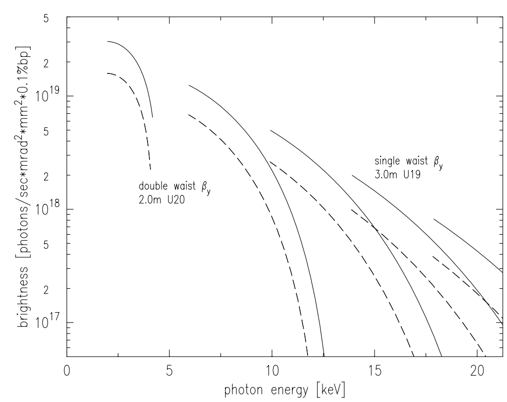

Figure 7: Undulator tuning curves for the single (solid line) and double (dash) waist low β_y optics.

5 CONCLUSION

We conclude that the SPEAR 3 design permits single or double low β_y optics in the matching cell 7.6 m drift with β_y as low as 1 m. Dynamic aperture for this optics seems to be acceptable for beam operation.

6 REFERENCES

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