ANL/APS/LS-317

A Low-Emittance APS Lattice with Alternating Horizontal Beta Functions at Insertion Devices

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formerly OAG-TN-2004-057

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1 Introduction

Previously [1, 2] we looked at the possibility of reducing the horizontal beta function in a straight section in order to optimize the beam properties for certain uses. This is difficult to do as an insertion because of the many constraints on the APS lattice. In particular, the emittance inevitably increases, and it can only be done for one or two sectors. We noted in [1] that an ESRF-style lattice with alternating high- and low-β_x sectors might provide reasonably good emittance for the APS, while providing two types of beta function. In this note, we present such a lattice that not only provides alternating β_x, but also improved emittance.

2 Linear Optics

For the linear optics, we quickly realized that the horizontal tune would have to change. Making low-β_x in half the straight sections is not consistent with the present lattice's $\nu_x = 36.2$. Rather than risk a difficult working point closer to $\nu_x = 40$, we chose to jump to a tune of $\nu_x \approx 43.8$, which is the same distance from $\nu_x = 40$ as the present tune. Similarly, we chose $\nu_y \approx 20.77$, which is the same distance from $\nu_y = 20$ as the present tune of 19.3.

In addition to these tunes, we had the following constraints:

- Maximum beta functions of 35 m.
- Minimum effective emittance at the high- and low-β_x straight sections.
- Vertical beta function of $3.0 \pm 0.5m$ at the center of the straight sections.
- Horizontal beta function at the center of the high-β_x straight sections of $32.5 \pm 2.5m$.
- Horizontal beta function at the center of the low-β_x straight sections of $< 5m$.

The matching, which used `elegant`, proceeded fairly rapidly, though not all constraints were initially applied at these levels. Figure 1 shows the final lattice functions. Figure 2 shows the effective emittance. At the high-β_x straights, we have 2.5 nm, which is 20% lower than the present lattice value of 3.1 nm. At the low-β_x straights, we have $3.2nm$, which is only 3% larger than the present value.

Table 1 lists various lattice parameters. Perhaps the most interesting value listed is the natural chromaticity, which is quite large in the horizontal plane. This natural chromaticity is 40% larger than in the standard APS low-emittance lattice. Chromatic correction will obviously be a challenge. Table 2 lists quadrupole strengths. These are within the limits of $0.903m^{-2}$, although B:Q1 is right at the limit.

3 Chromatic Correction

Chromatic correction was performed using the `parallelOptimizer` script [3] running `elegant`. We started the optimizer with all sextupoles at zero. The penalty function included the tune spreads in the x and y plane due to chromaticity and amplitude. In addition, a chromaticity of 4 was sought in both planes. Tune spread calculations due to chromaticity assumed a ±2% momentum spread. Tune spread calculations due to amplitude used an amplitude of 3 mm in the vertical and, eventually, 7.5 mm in the horizontal. The most difficult constraint was the horizontal tune spread with amplitude.

Table 3 lists the sextupole strengths, which are quite high. We would need to upgrade most of the sextupoles by attaching "noses" to increase the field [5]. This would give a 20% increase in sextupole strength, allowing $K_2 \leq 25.91/mm^3$, which is sufficient for our purposes here.

The chromaticities achieved are $\xi_x = 4.48$ and $\xi_y = 4.64$. Figure 3 shows the tune variation with momentum deviation between -2% and $+2\%$. The tune footprint is fairly small. In particular, no integer or half-integer resonances are approached.

4 Dynamic Aperture

We next looked at the dynamic aperture, using `elegantRingAnalysis`. First, we looked at the off-momentum dynamic aperture for the ideal machine. These are shown in Figure 4. These results look quite good. Note that no small-aperture ID chambers are included. Only standard 8-mm chambers are used.

Following this, we looked at the on-momentum dynamic aperture with errors. Since we assume that the orbit and optics will be eventually corrected, the magnitude and type of errors were restricted to the following:

- Quadrupole and sextupole tilt errors of 0.5 mrad rms.
- Quadrupole and sextupole strength errors of 0.01% and 0.05%, respectively.

The quadrupole errors are small in order to provide small beta function variation such as we might get after lattice correction. Peak variation in the beta functions over the lattices was about 1 to 2.5%, which is comparable to what we get from lattice correction. Figure 5 shows the dynamic aperture results as a 2-dimensional histogram of the dynamic aperture for the 50 seeds. This looks like a workable dynamic aperture. Of course, if the effective errors are larger than assumed here, it will be worse.

5 Conclusion

We have presented an alternating high- and low-β_x lattice for the APS providing low emittance to all users. The dynamic aperture of the lattice looks workable. The sextupoles are quite strong, requiring attachment of noses to most of the sextupoles.

Several issues were not explored here, but should be looked into:

- We may need special optics in the injection area, which will impact lattice performance.
- How does this lattice impact beam losses due to Touschek scattering, particularly at the high β_x straight sections?
- Once we have the alternating β_x lattice, customizing might be easier; i.e., not-so-high and not-so-low β_x.
- Is a lattice with lower chromaticities possible using existing sextupole strength limits? If so, we might be able to test the lattice without upgrading the sextupoles, provided the desired bunch current is not too high.

6 Acknowledgements

Hairong Shang provided help with the parallel optimizer.

References

[1] M. Borland, private communication, 2004.

[2] V. Sajaev,private communication, 2004.

[3] H. Shang, private communication, 2004.

[4] M. Borland, “elegant: A Flexible SDDS-Compliant Code for Accelerator Simulation,” Advanced Photon Source LS Note LS-287, September 2000.

[5] S. Kim, private communication.

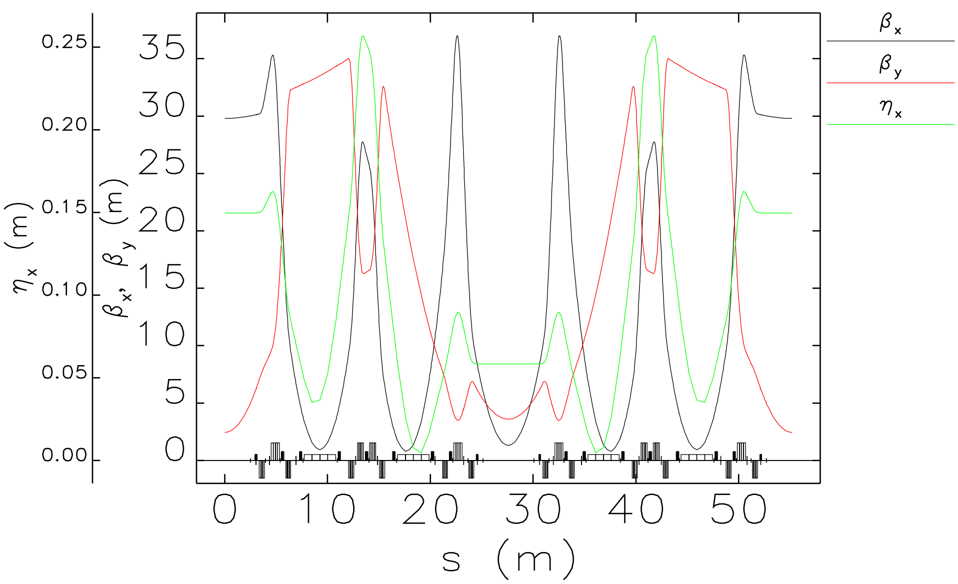

Figure 1: Lattice functions for the alternating-β_x lattice.

Betatron Tunes		
Horizontal	43.801	
Vertical	20.729	
Natural Chromaticities		
Horizontal	-127.734	
Vertical	-53.241	
Lattice functions		
Maximum β_x	35.026	m
Maximum β_y	35.020	m
Maximum η_x	0.257	m
Average β_x	14.362	m
Average β_y	17.017	m
Average η_x	0.113	m
Radiation-integral-related quantities at 7 GeV		
Natural emittance	2.210	nm
Energy spread	0.095	%
Horizontal damping time	9.653	ms
Vertical damping time	9.658	ms
Longitudinal damping time	4.830	ms
Energy loss per turn	5.338	MeV
High-β_x Straight Sections		
Effective emittance	2.530	nm
β_x	29.805	m
η_x	0.150	m
β_y	2.446	m
Low-β_x Straight Sections		
Effective emittance	3.191	nm
β_x	1.298	m
η_x	0.058	m
β_y	3.599	m
Miscellaneous parameters		
Momentum compaction	1.88×10^{-4}	
Damping partition J_x	1.000	
Damping partition J_y	1.000	
Damping partition J_δ	2.000	

Table 1: Parameters of the alternating-beta lattice.

Quadrupole Strengths		
A:Q1	-0.159	$1/m^2$
A:Q2	0.589	$1/m^2$
A:Q3	-0.715	$1/m^2$
A:Q4	-0.777	$1/m^2$
A:Q5	0.876	$1/m^2$
B:Q5	0.726	$1/m^2$
B:Q4	-0.895	$1/m^2$
B:Q3	-0.281	$1/m^2$
B:Q2	0.874	$1/m^2$
B:Q1	-0.900	$1/m^2$

Table 2: Quadrupole magnet strengths

Sextupole Strengths		
A:S1	9.307	$1/m^3$
A:S2	-23.117	$1/m^3$
A:S3	-23.092	$1/m^3$
A:S4	17.821	$1/m^3$
B:S3	-22.771	$1/m^3$
B:S2	-23.299	$1/m^3$
B:S1	23.846	$1/m^3$

Table 3: Sextupole magnet strengths

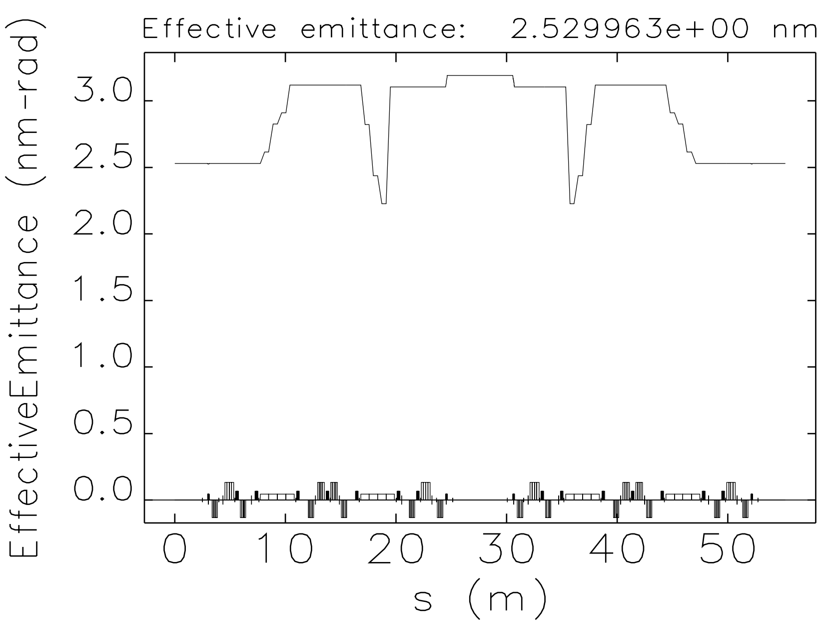

Figure 2: Effective emittance for the alternating-β_x lattice.

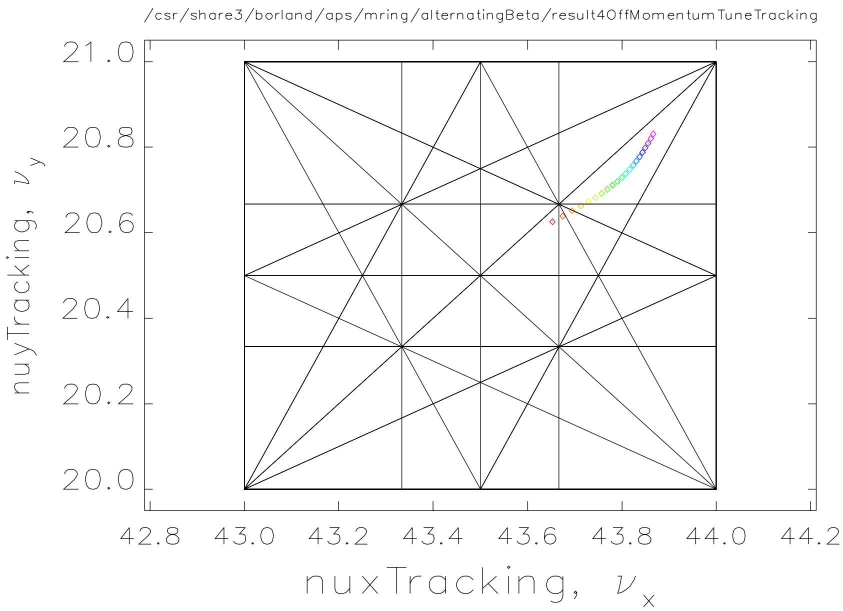

Figure 3: Tune footprint for momentum deviation of -2% to $+2\%$.

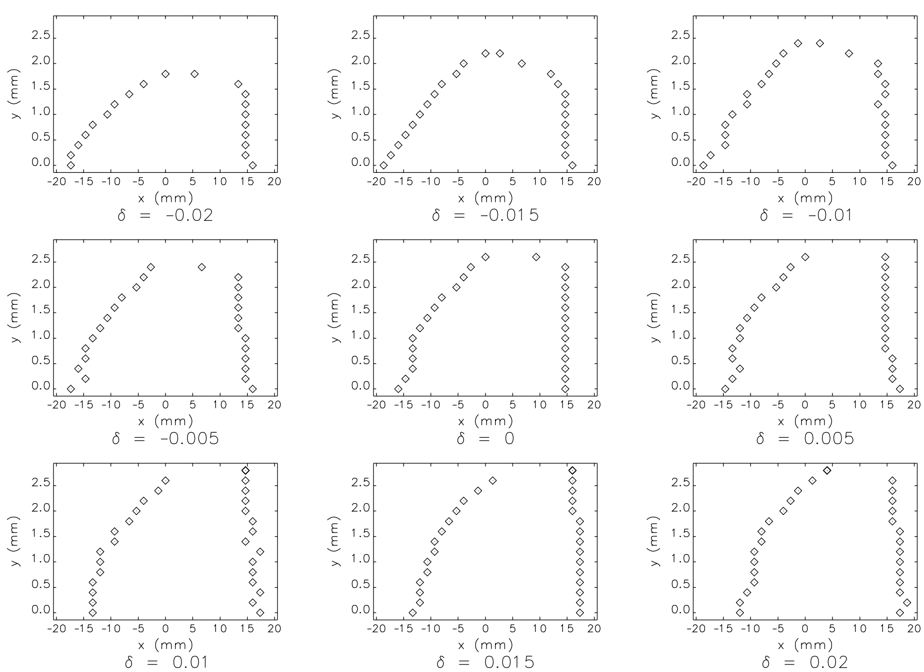

Figure 4: Dynamic aperture for the ideal machine for various momentum deviations.

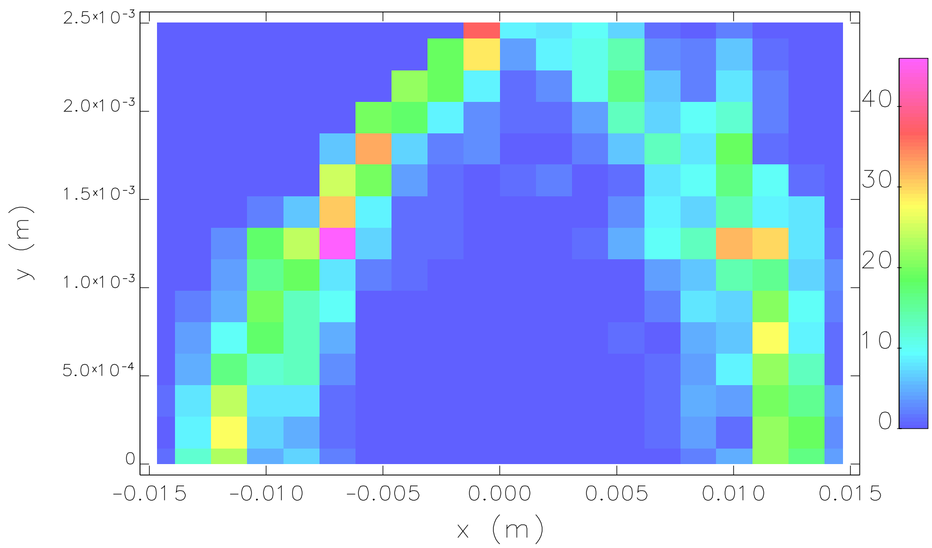

Figure 5: On-momentum dynamic aperture boundary distribution for the machine with errors.