Accumulator Ring Beam Optics

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Abstract

A new Proton Accumulator Ring is being proposed as a future upgrade to the Fermilab Complex for new physics experiments. This ring will extract the beam from the Linear accelerator at 0.8 GeV and then inject into the PIP-II Booster ring, enabling a 0.8 - 1.0 GeV upgrade. While studying the beam optics of the current Booster ring, a preliminary lattice design of the Proton Accumulator Ring was transcribed from an older version of Methodical Accelerator Design to a more recent version (MAD-X). A successful translation of the ring optics is verified by a comparison of the twiss outputs between both versions of the program.

Background

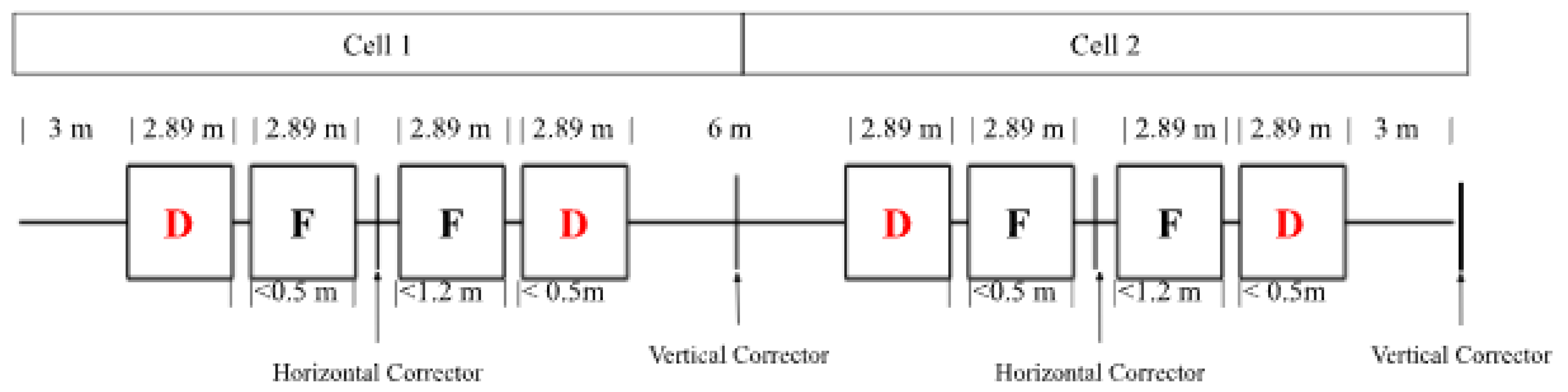

Figure 1. Idealized Booster Lattice Cell.

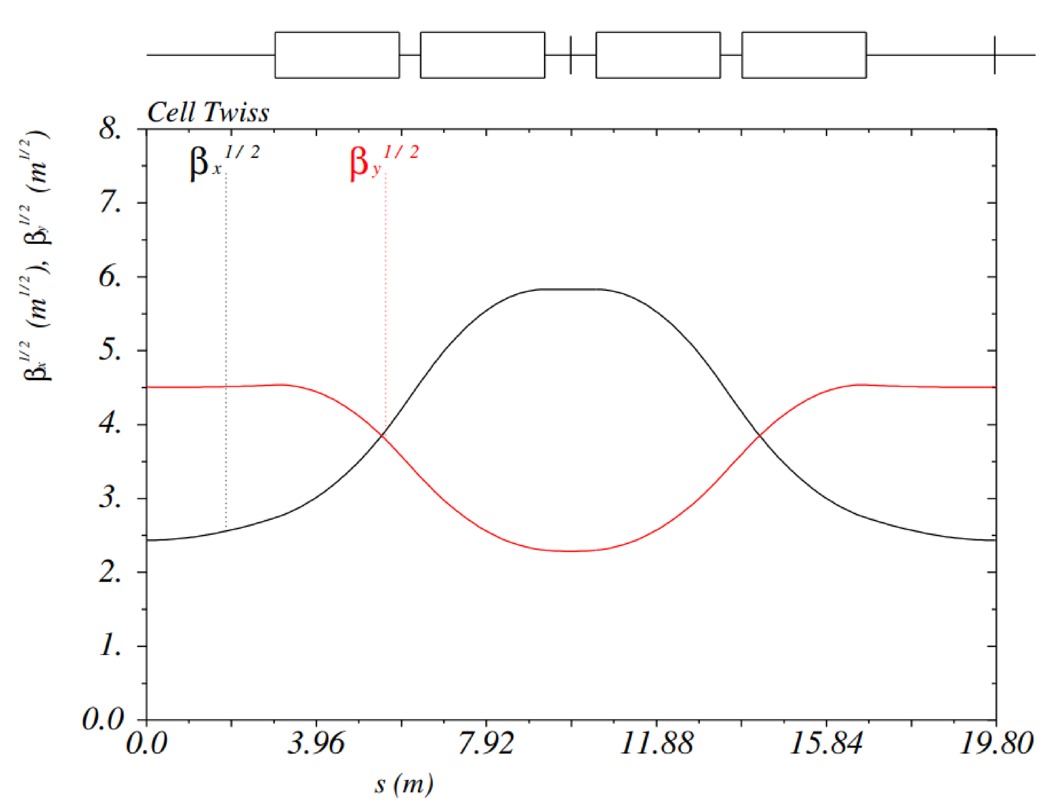

Figure 2. Booster Cell Twiss Plot.

- **The Courant-Snyder** parameters β_x and β_y are determined by the optics of the ring.
- ***Focusing*** magnets focus horizontally, while ***Defocusing*** magnets focus vertically.

Courant-Snyder Parameter β

- The amplitude of a particle's oscillation is described by the beta function, β(s).

$$x(s) = A\sqrt{\beta_x(s)}cos(\psi_x(s) + \phi) \quad (1)$$

- $\beta_x{}^{1/2}$ and $\beta_y{}^{1/2}$ are proportional to the beam size in the transverse planes [1].

Booster Ring Twiss

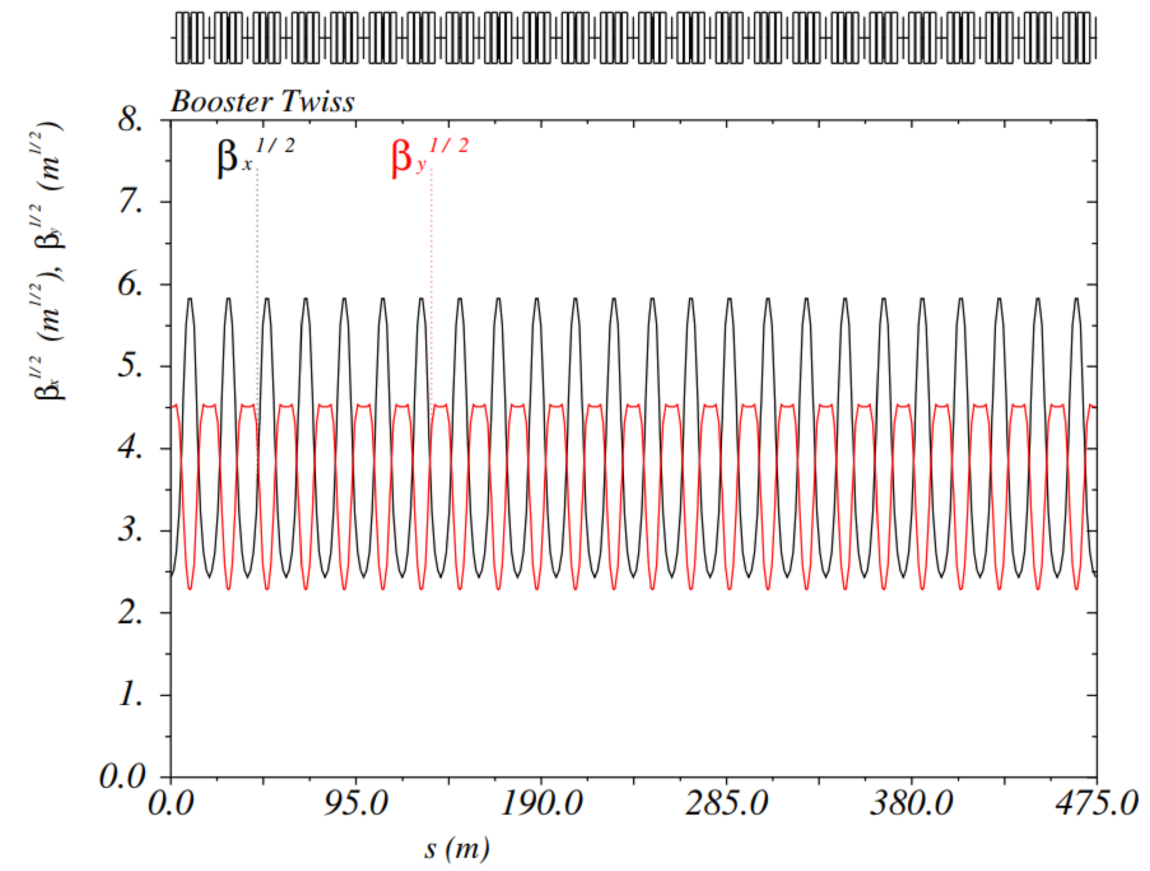

Figure 3. Booster Ring Twiss Plot.

- **The Booster Ring** consists of a unique cell (Fig. 2) repeated 24 times (Fig. 3).

Particle Tracking

Analysis of the beam aperture and trajectory is done through MAD-X tracking. A program written in MATLAB takes output values from MAD-X tracking file and plots them in phase-space. The stability of the beam can then be verified throughout the lattice of the ring.

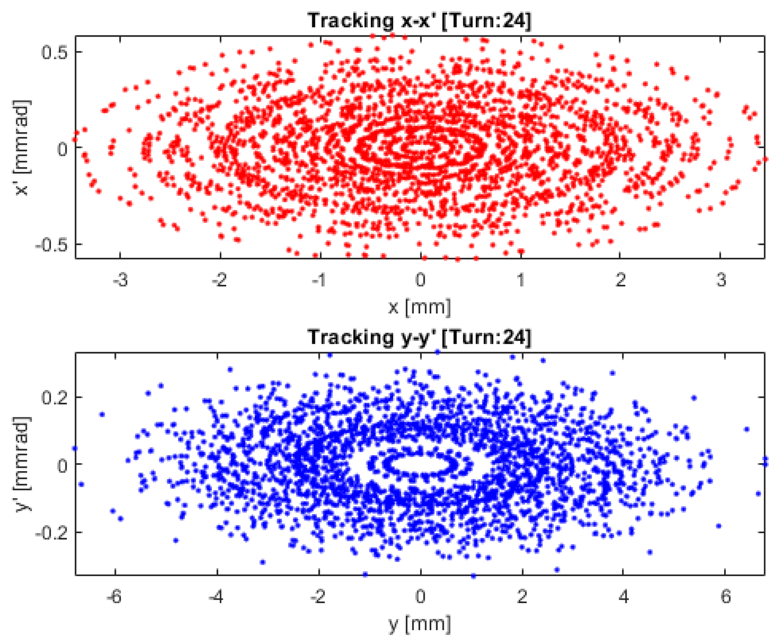

Figure 4. Booster Tracking Phase-Space.

- Here, 100 particles were tracked through the Booster Ring and plotted for **24** turns (Fig. 4).

In phase-space, particles move in an elliptical orbit through a number of turns. This verifies where particles are being lost and also determines the aperture required to build a ring without leading to collisions.

Tune

Tune describes the number of betatron oscillations per beam revolution. It is also equivalent to the phase advance, $\psi(s)$, around one orbit.

$$\nu = \frac{1}{2\pi}\oint\frac{1}{\beta(s)}, ds \quad (2)$$

Resonances

Tune values must be chosen carefully because certain values, such as integer values (ν = 1, 2, 3, ...) and half integer values can cause betatron resonance, leading to beam loss [1].

Lattice File Conversion

The Proton Accumulator Ring lattice (Fig. 5) was successfully converted from MAD-8 to MAD-X. Comparison of maximum twiss values and tunes (Table 1) demonstrate successful conversion.

Values	
β_x,max	18.72 m
β_y,max	18.80 m
ν_x	13.08
ν_y	13.95

Table 1. Proton Accumulator Ring Twiss and Tunes.

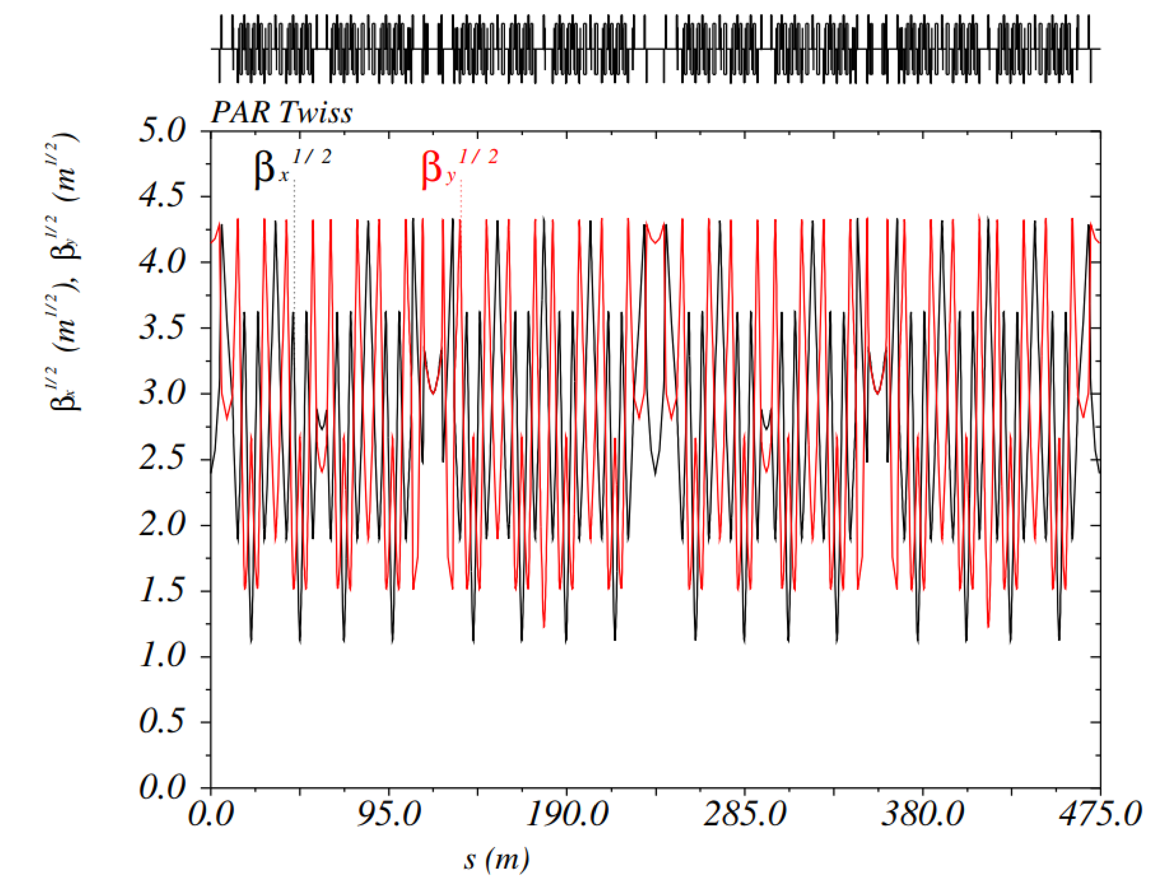

Figure 5. Proton Accumulator Ring Twiss Plot.

Acknowledgements and References

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[1] Dennis Barak et al. Concepts rookie book. *Accelerator Division - Fermilab Operations Department*, 2020.