Considerations in the design of the new TBTS

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July 23, 2014

Introduction

Motivation

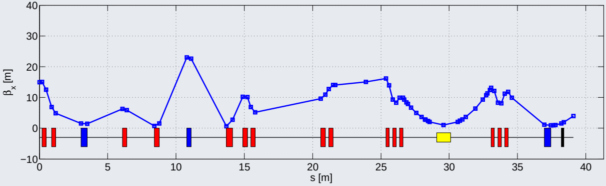
- The two beam module will be installed in September this year.
- Request from CTF3 for input regarding a proposed design of the new TBTS.
- Due to the low energy ($\sim$150MeV) aperture restrictions could lead to large beam losses resulting in poorer experimental results.
- Found a solution that seems to perform better then the previous proposal.
- The beam line should be equipped with correctors and BPMs.

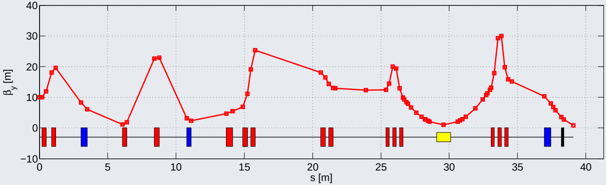
Content

Current lattice

- Beta functions in drift regions are parabolas.
- The envelope has to be large at the triplets due to drift length of ~ 5 m.

Old optics



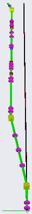


Requirements of the lattice

Properties of lattice

- The lattice consists of:
  - A horizontal dogleg.
  - Straight section with TBTS. + 1 old PETS.
  - Momentum determination at the end.
- The needed functionalities are:

1. Zero dispersion in straight (TBTS) section.
2. Ensure small envelope throughought lattice. Particularly in PETS sections.
3. Narrow horizontal beam on MTV screen for accurate momentum determination.
4. Flexibility and modular design are not strictly necessary, but imposed on the design.



Content

1. Description of requirements
2. Working hypothesis
3. Imperfections
4. Orbit correction
5. Conclusions

Working hypotheses

PETS

- The most decelerated particles experience the voltage $V = \frac{(R'/Q)\omega F(\lambda)\eta_\Omega}{4v_g} L^2 I$ (linac convention).
- $\rightarrow$ Scale deceleration according to $V = 1.4\text{MV}\left(\frac{L}{0.23m}\right)^2 \frac{I}{101A}$.
- For primed PETS, we assume energy conservation - means that the primed PETS decelerate an additional half the decelerating voltage of the first PETS (since the first PETS signal is split into both the final PETS.).
- Assume that the PETS wake behaves as in an RF cavity (on phase).

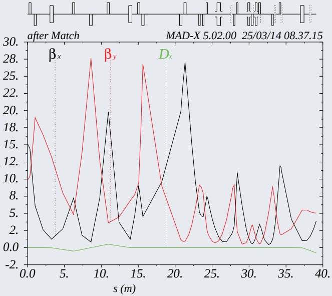
Steering

- Linear transverse optics.
- Emittance 150 μm. CAUTION - this is smaller than measured.
- Initial twiss parameters $\beta_x = 15$ m, $\beta_y = 10$ m, $\alpha_x = 0$, $\alpha_y = 0$.
- The TBM quadrupole movers can be used as correctors.

- BPM resolution is neglected.

Optics functions

Beta functions

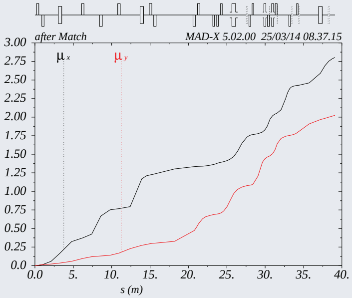


Ideally..

- The correctors and BPMs should be placed in regions with large β functions - the leverage of the correction scales with it.

Optics functions

Phase advance



Ideally..

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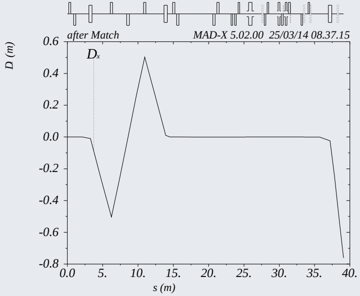
- The phase advance between correctors should be approximately 0.25 (in the units on the plot).

Optics functions

Dispersion



Ideally..

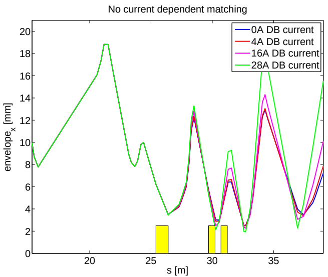
- The correctors and BPMs should be placed in regions with large β functions - the leverage of the correction scales with it.
- Dispersion is completely cancelled with the updated longitudinal positions

Intervention

- This setup requires:
  - Moving the first triplet (3 quads).
  - Moving the old PETS tank.
  - Moving one magnet from the final triplet.
  - Installing a new quadrupole.
  - Installing a the two beam module.
  - A soft requirement is re-alignment of some quadrupoles.

Optics with realistic PETS currents

New optics, without current dependent matching



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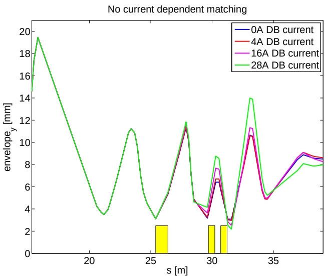
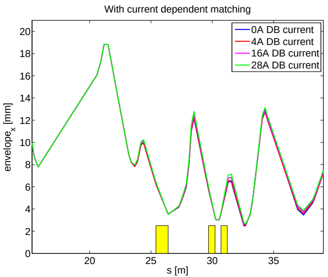


Optics with realistic PETS currents

New optics, with current dependent matching



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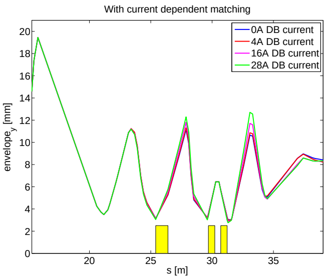
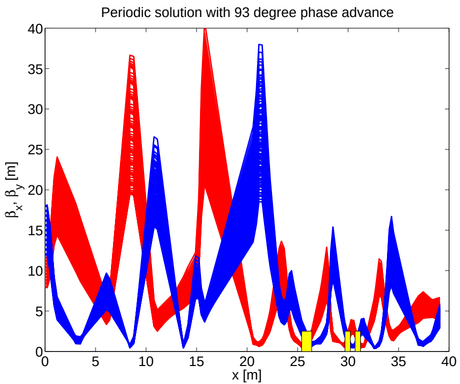


Content

Varying twiss parameters

- Simulate effects of unknown incoming twiss parameters.
- Nominal: β_x=15m and β_y=10m, $\alpha_x = \alpha_y = 0$.
- Vary $\beta_{x,y}$ by $\pm$20% and $\alpha_{x,y}$ in the interval [-3;3] in a rectangular grid.
- Observe effect on beta beating. Acceptable

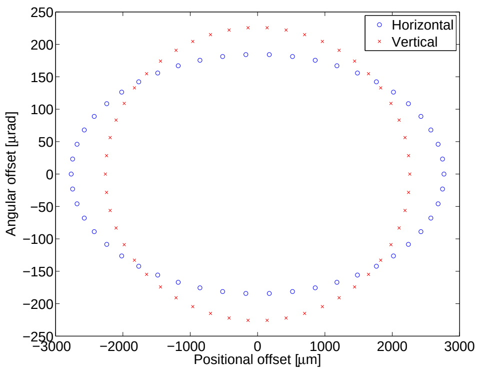


Content

Steering recipe

- Calculate the response matrix: The response of the lattice with respect to changes in the correctors.
- $b = R \cdot c$.
- To apply corrections for random misalignments $c = pinv(R) * b$.
- Notice that correctors give angular kicks.
- Notice that BPMs record spatial positions.
- $x_{final} = M \cdot x_{initial}$ ($x_{initial,final}$ are vectors of positions and angles)
- $b_j = \sum_i M^j_{1,i} x_{initial}(i)$

- Inject particles with an offset in angle and position. Put it on the phase space ellipse corresponding to the incoming twiss parameters.
- Used offset corresponds to 150μm$\cdot$rad (nominal emittance).
- Propagate beam and correct the orbit.
- Observe needed corrector strengths.
- Maximum needed strength: 170μrad$\cdot$GeV $\rightarrow Bl = pc\theta/qc = 5.67$Tm
- The strength scales as the root of the offset magnitude, A, so the strength is $5.67 \cdot 10^{-4} Tm \cdot \sqrt{A/150\mu\text{m rad}}$.



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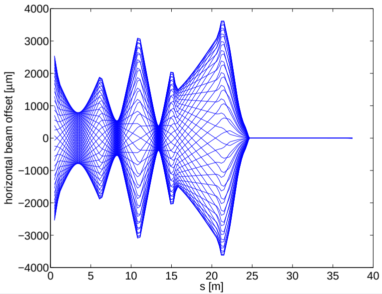
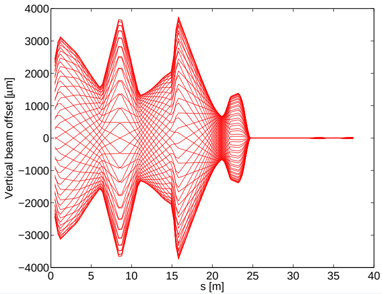


Figure: Horizontal orbits.



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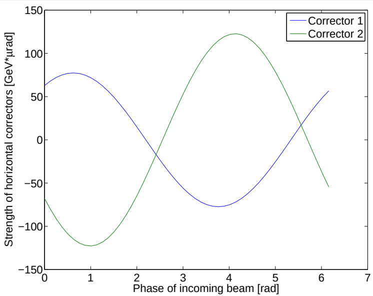


Figure: Horizontal corrector strengths.

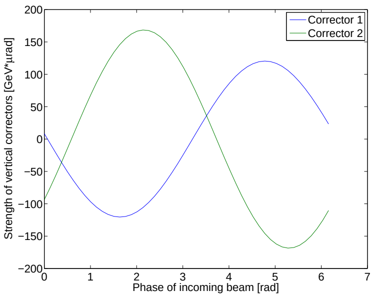
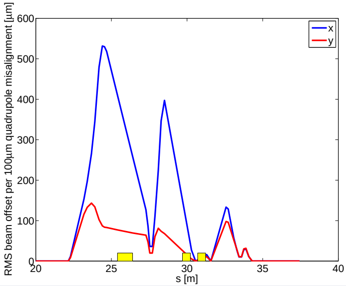


Figure: Vertical corrector strengths.

Quadrupole alignment errors.

- Assume that all quadrupoles after the first corrector have got the same amplitude of random Gaussian misalignment.
- Use 100μm RMS misalignment, 10000 machines.
- The scaling of offsets and corrector strengths is linear in the misalignment amplitude $\rightarrow$
- $Bl_{3\sigma,max} = 5.00 \cdot 10^{-4}\text{T m} \cdot [\text{RMS quadrupole misalignment}/100\mu\text{m}]$.
- $\Delta x_{3\sigma,max} = 1401\mu\text{m} \cdot [\text{RMS quadrupole misalignment}/100\mu\text{m}]$.
- $3\sigma_x(\text{PETS downstream}) = 1230\mu\text{m} \cdot [\text{RMS quadrupole misalignment}/100\mu\text{m}]$.



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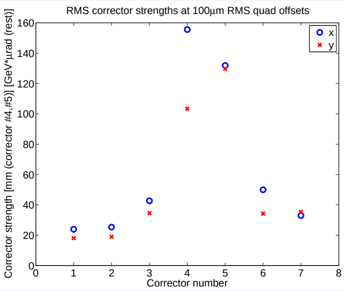

Content

Conclusions

- The new lattice is flexible and fulfills the requirements.
- The correctors are strong enough to steer the beam ☺.
- But it depends on the incoming beam quality.
- We can set limits on alignment imperfections with the response matrix approach. ☺
- Some quadrupoles will be re-aligned to improve beam transport. The RMS alignment is expected to be better than 100μm.
- All quadrupole currents are acceptable (in the linear approximation).