Trajectory Correction and Tuning

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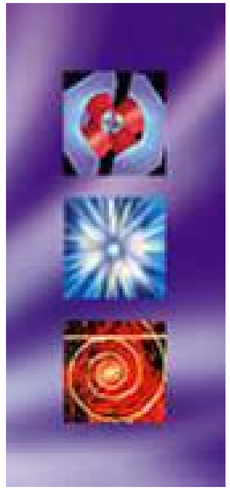


Introduction

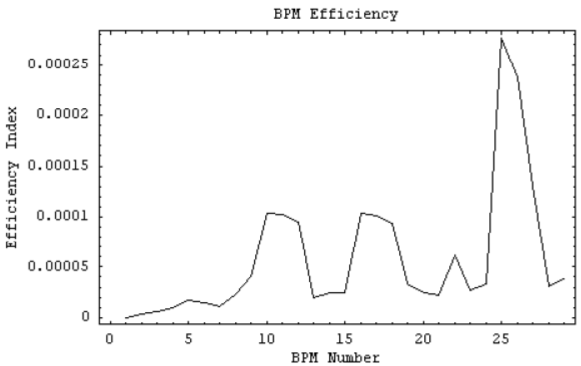
- As part of the BDS design it is important to understand, and have strategies for, compensation of the vertical emittance dilution due to errors.
- The correction of the vertical emittance is primarily composed of two complementary parts:
  - Correction of the beam trajectory
    - Emittance dilution is primarily caused by both feed-down effects and higher-order non-linear effects in magnets, which scale with the beam position away from the nominal magnetic axis.
  - Correction of higher-order aberrations
    - Correction of those aberrations which are not, or cannot, be corrected by the trajectory correction algorithms.
- This talk will look at both of these algorithms, especially related to the ILC BDS test accelerator – ATF2

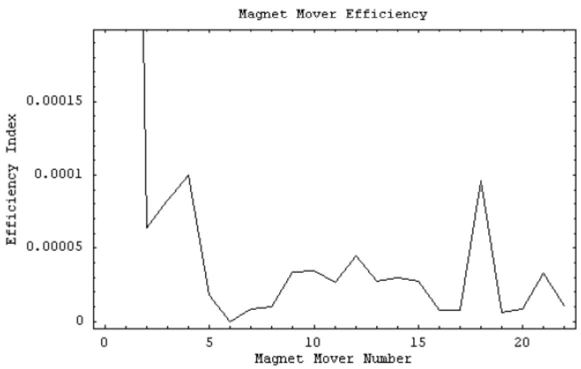
Trajectory Correction

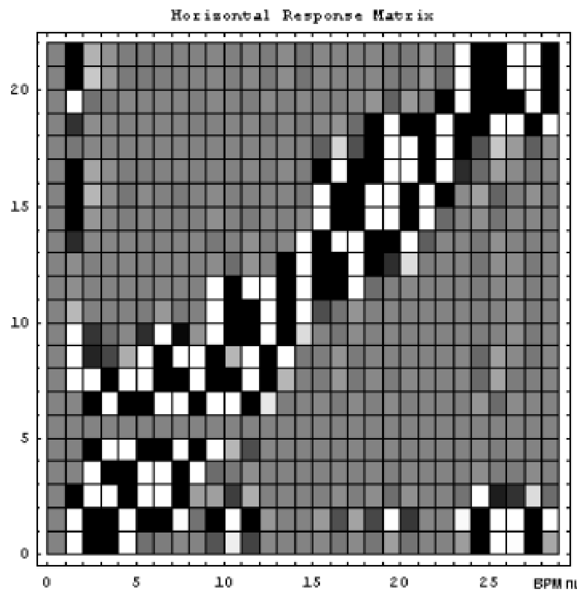
- Previous studies of the trajectory correction have used both 1-to-1 steering algorithms and dispersion free steering algorithms.
- Trajectory correction uses dipole kicks to steer the beam through a set of monitors
  - The dipole kicks can come from either dipole correctors, or from displaced quadrupoles
- The use of a “global” SVD trajectory-response matrix inversion algorithm has been investigated
  - Singular value decomposition allows the algorithm to more finely balance the competing demands of minimising the trajectory, and minimising the corrector strengths.

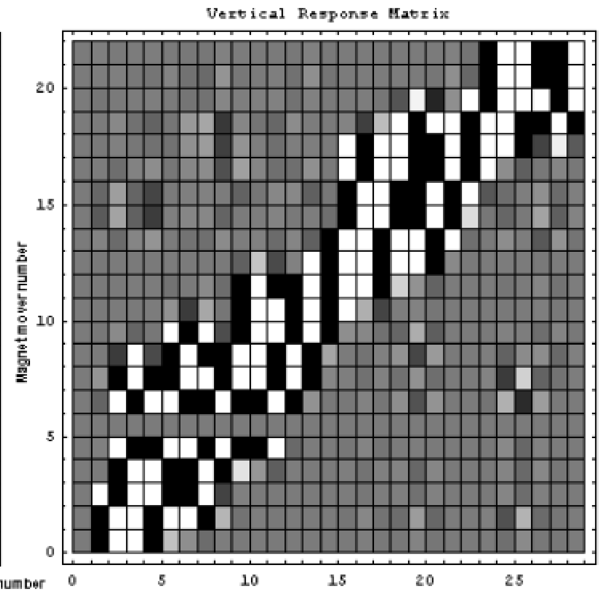
SVD Analysis

- Using SVD inversion, analysis has been performed of the efficiency of both the BPMs and the correctors.
- Analysis of the optimal number of eigenvalues in both planes, has also been investigated.



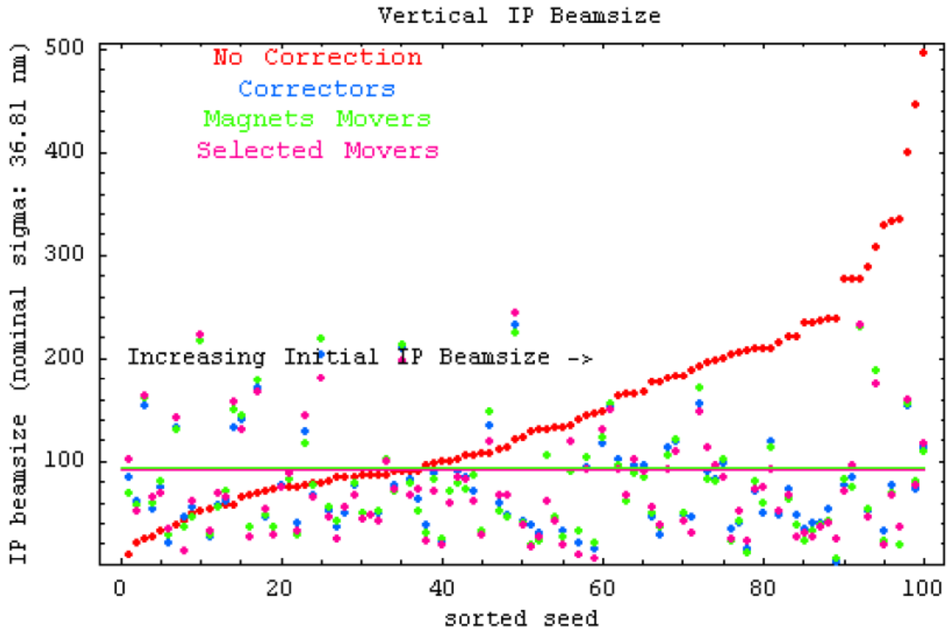


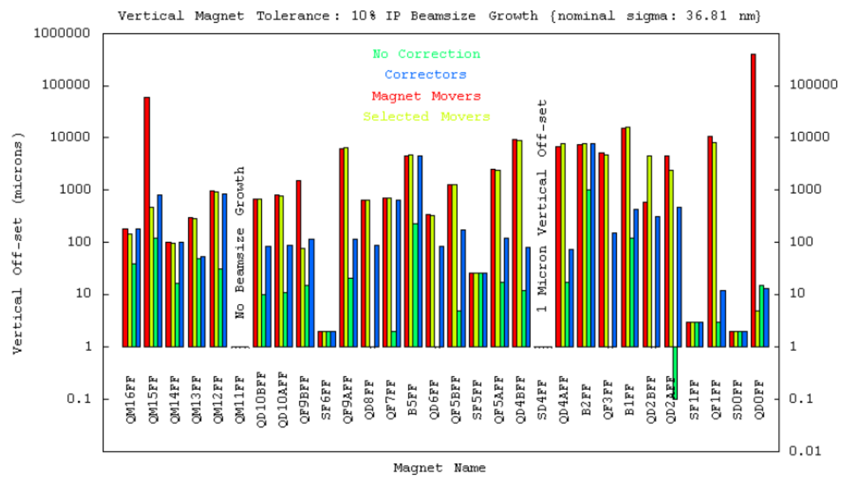




Tolerances

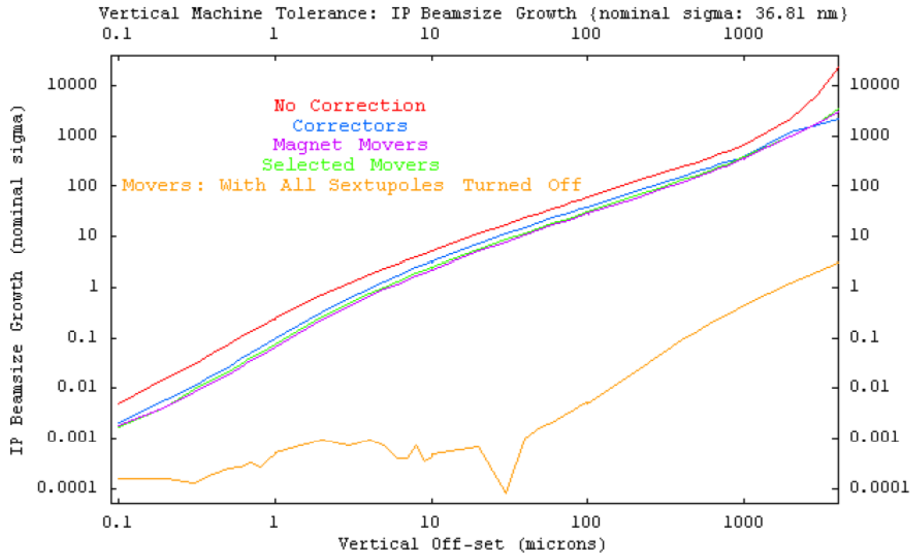
- Tolerances to errors using the SVD based formalism have been calculated, for the cases of Magnet Movers, correctors, and a reduced number of correctors.
- The results show that in general there is an irreducible component to the vertical emittance, that requires further tuning.

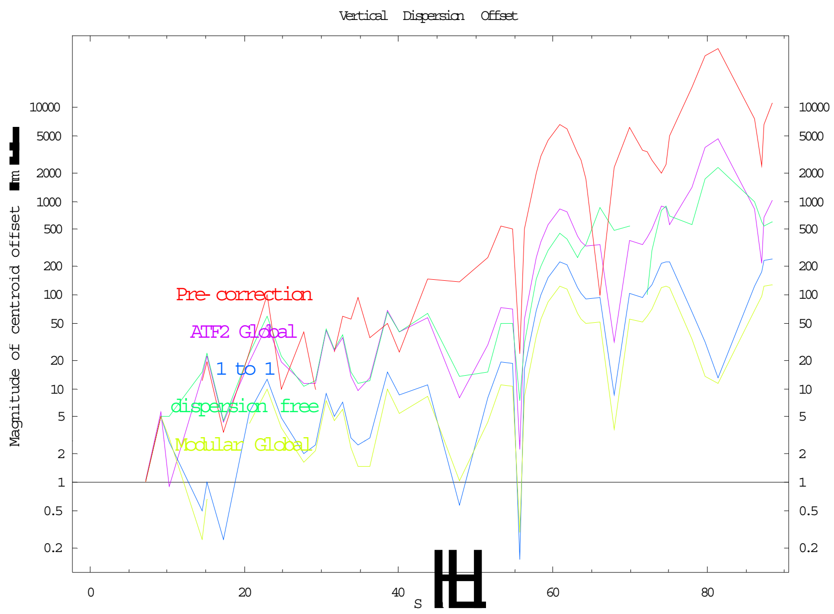




Analysing the linear lattice

- Analysing the purely linear lattice, it is clear that the remaining vertical emittance growth is due to higher order elements in the lattice.





- The vertical dispersion effects are also small
- Same magnitude as other algorithms
- It may be possible to tune this further by optimising the number of eigenvalues in the inversion

Further Work

- Although the analysis has been performed in simulation, it is important to test the algorithms in real machines!
- Tony is a task-leader for the trajectory correction software task on ATF-2
  - Involves defining and testing the algorithms for the new accelerator
  - Defining controls software and interaction with both new and old control systems at KEK
  - Experimentally test and tune the new algorithms
- This work will enable a better understanding of the requirements and changes required for the trajectory correction systems of the new design BDSs.

Beam Tuning

- To restore the vertical emittance we must use higher order elements to tune the beam at the IP.
- This is done using the final 5 sextupoles of the lattice.
- The 4 degrees of freedom of these magnets provide a wide variety of correction terms
  - The 4 degrees of freedom are: Horiz. And Vert. Displacement, roll around the s-axis, and magnetic field strength.
- The 5 sextupoles and the 4 degrees of freedom are then combined to produce tuning knobs that (in theory) are orthogonal, and which effect some element of the beam transfer, and so the vertical emittance at the IP.

Tuning Knob Creation

- Due to the inherent non-linearities in the tuning-knob response matrix, creation of orthogonal tuning knobs can be made more robust:
  - Invert the response matrix to create a tuning knob
  - Use an optimiser (Nelder-mead Simplex or other...) to improve the orthogonality with errors

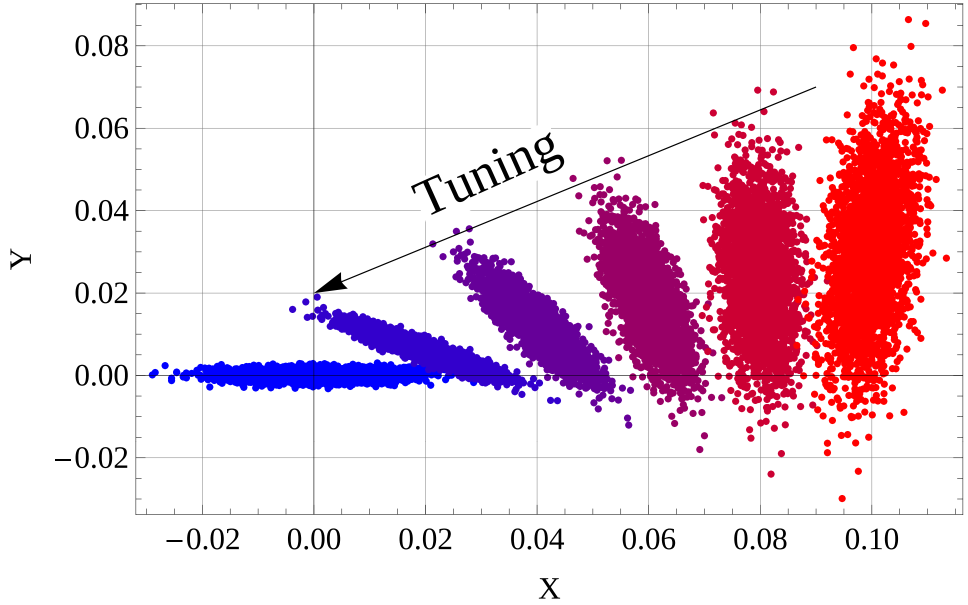
- Once we have our tuning knobs, they are applied to the lattice using a simple optimiser for each knob
  - This ensures that the algorithm is not limited by sensor issues where applicable

Traditional methods

- Traditionally the effects of the sextupole magnets is analysed in terms of the change in linear twiss parameters at the IP
  - BETX, ALFX, BETY, ALFY, DX and DY
  - The coupling terms
  - The second order matrix terms R_{ij}
- This method has been implemented on SLC, and has been proven to work.
- In general different degrees of freedom are related to different parameters.
- Care must be taken that, when there are large errors present, the tuning knobs are no longer linear and “bleeding” between degrees of freedom occurs.

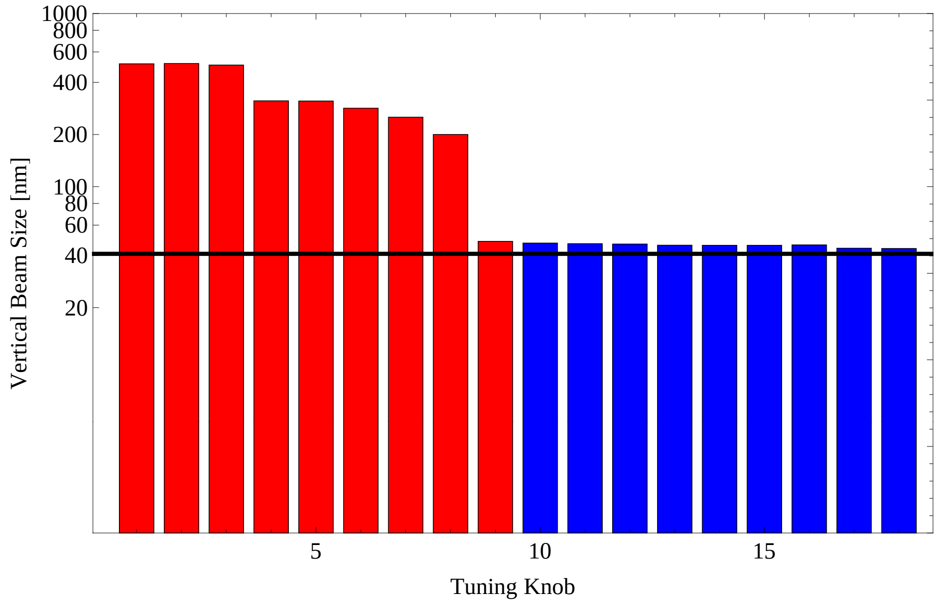
Beam Rotation Matrix

- The beam rotation matrix removes the veneer of accelerator physics from the correction of the vertical emittance.
- The correction of the emittance is reduced to rotation in all dimension of the error beam to the nominal beam.
- The method uses all 4 degrees of freedom, and (in simulation) records the response in terms of the 6x6 rotation matrix away from the nominal beam.
- As before the matrix is inverted using SVD, and as-orthogonal-as-possible tuning knobs are created.



Beam Rotation Matrix - Results

- Using the beam rotation matrix method it is possible to recover the vertical emittance to within 10%, reliably, and with realistic errors.
- The choice of tuning knobs is critical
  - There are only 20 handles, but at most 36 constraints
  - To achieve any sort of orthogonality, some matrix elements must be ignored
- In general, the tuning knobs chosen are those directly related to the horizontal and vertical planes, the coupling between them, and to the energy terms.

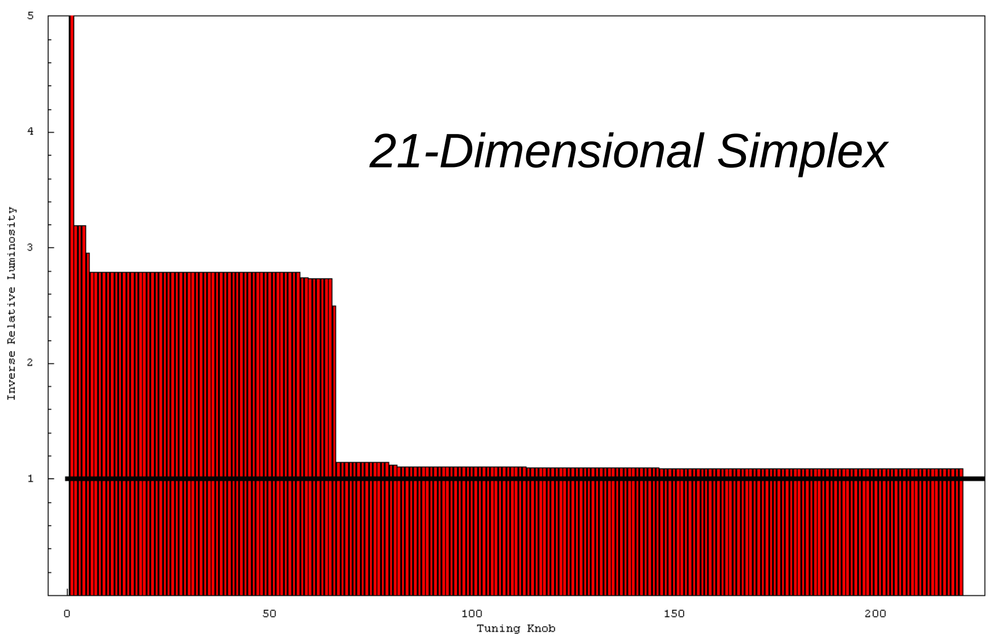


'Dumb' Optimisation

- To remove any sort of accelerator physics input into beam tuning, we can use 'dumb' algorithms to attempt to recover the vertical emittance.
  - The use of a Nelder-Mead simplex algorithm provides a reasonable balance between achieving the global minimum emittance, as well as a direct path to the solution.
  - We can use a genetic algorithm to explore the solution space to try and find the global maximum – which can be useful in cases where the machine is beyond the tuning range of traditional beam algorithms.
  - Other optimisation strategies are of course possible – and we should bear in mind the "No Free Lunch" theorem!
- It must be remembered that these algorithm are a backup solution!
  - Only to be used if all else fails...
- However it is instructive to:
  - Ensure that they work
  - Provide a benchmark for other algorithms (since they are designed to find the "global" maximum)
  - Investigate which algorithms are best...

‘Dumb’ Optimisation - Problems

- Studies show that the optimisation generally does converge to within 10% of the nominal emittance, and can do so with a larger set of errors than the beam-rotation method
- However, the tuning time for such algorithms can be prohibitively long – sometime, much longer than other methods



- Even if the algorithm does converge, it is much harder to understand the root cause of the emittance dilution, as there is no obvious link to any physics

Further Work

- We have created a robust set of simulations of possible “back-up” tuning algorithms
- Would like to test them on a real accelerator (probably/hopefully the ATF2)
- Need to further refine the models, and possibly integrate them into a full system simulation
- Investigate other tuning methods not discussed here
  - At the very least, look at other ‘dumb’ algorithms and investigate there strengths and weaknesses with this problem.