Beam Line Tuner for the FAST linac

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Outline

- Motivation
- Studies
- Results & Future Work
- Additional Learnings
- Conclusion
Motivation

- Importance to keep beam on design trajectory
- Track beam through linac
- Create beam bumps
- Correct and create simulated beam trajectories

Steer beam to have it on desired trajectory

These elements participate in steering process:

- Corrector
- Quadrupole (should only focus but steers if beam is off center)
- Beam Position Monitor (BPM)

Picture credit: USPAS
Studies I: Orbit Correction Algorithm

- Orbit Correction Algorithm: Singular Value Decomposition

\[
x = Rq \\
q = R^{-1}x
\]

- \(x\): Beam Position (BPM) change (m)
- \(q\): Corrector kick angle (mrad)
- \(R\): Response matrix

Find pseudoinverse of Response matrix

Know which corrector angles we need to achieve certain position offsets

\#BPM \neq \#Correctors

With angles: Calculate new current for correctors

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Studies I: Orbit Correction Algorithm

- What to do with that?
  - Beam bump
  - Correct beam to a specific setting of BPM readings
  ➔ Elegant simulations
  ➔ Feed in desired positions, try to adjust beam trajectory as good as possible to that
Goodness of fit increases with amount of SV (if #BPM>#correctors)

Using BPM resolution $\sigma = 50\mu m$ for $\chi^2$
Studies II: Analysis of Singular Values (SV):
Example: Beam Bump (location: Before Cryomodule (CM), using 90 m of beamline including 13 correctors and 21 BPM, quads set to zero)

- 90 m of linac (until H480)
- Quads are off
- If #BPM>#correctors:
  Result gets better while increasing amount of SV with no upper limit

![Beam position graph](image-url)
Studies III: Simulate beam trajectory with steering in Injector (before CM)

- Using realistic, simulated lattice containing focussing for injector to CM beamline
- Use BPM measurements from 03/13/2019
- Correct beam to these values
- Output corrector strengths
- Correction not always within error bars
Results & Future Work

• Results
  – Corrector Strengths
    • Injector beam bump
    • Realistic beam trajectory

• Future Work
  – Improve Elegant lattice files
    • Correspondence with actual linac (model for CM not clear)
  – Turn corrector strengths into magnet current settings
  – Controls interface
Additional Learning

- Learn to work with Linux cluster and elegant
- Understand behavior of components in a beam line
- Understand what are the limits and possibilities of steering in a beam line
- Understanding of quad steering
- Understanding of beam based alignment
Conclusion

• Learning about beam simulation and tracking
• Outcome: Usable routines

Thank you for your attention!
(...and for your help and for organising!)
Backup - Steering in y plane

Steering in y plane and x plane works simultaneously
Still more detailed analysis needed but it seems that the steering preserves the beam size.
Backup - Steering after CM

- Model for the Cryomodule not clear, problems with steering through the CM
- No correctors directly after the CM, difficult to adjust to first BPMs directly after CM
- Correction further downstream works
s=0 means here 0 meters after the CM
Backup
More Details to Singular Value Decomposition (SVD)

Not square matrix: \[ A = U W V^T \]

- **U**: Columns have eigenvectors of \( A A^T \)
- **W**: Has Singular Values on diagonal, are square root of the eigenvalues of both \( A A^T \) and \( A^T A \)
- **V**: Rows have eigenvectors of \( A^T A \)

Pseudoinverse: \[ A^+ = V^T W^+ U \]
Comparison using different BPM noise levels

Difference of the simulation when using BPM resolution of 25 um, 50 um and 100um
Backup - Zoom of bump

Zoom of bump to show error bars
This bump was constructed using 90 m of the linac (until H480). This part of the beamline has 13 horizontal correctors, hence we get 13 SV.
Backup - Zoom of Chi Squared

Zoom for the Chi Squared Values for the use of 10 to 13 singular values