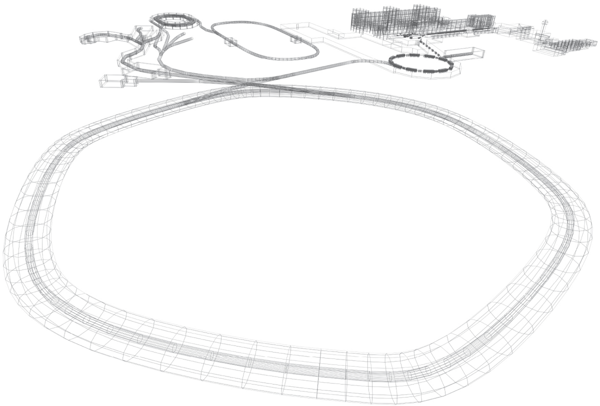
Methods of Closed Orbit Correction for Particle Accelerators

TECHNISCHE UNIVERSITÄT DARMSTADT

Plan for Master Thesis



Thesis: Methods of Closed Orbit Correction for Particle Accelerators

- What is a Closed Orbit?
- And why do you need to correct it?
- Which methods will be used for the correction?

Motivation

- Quadrupole misalignment and field errors in main dipoles
(manual correction/ correction specified for a certain accelerator)
- Flexible target orbits (e.g. around obstacles or on a sensor)
- External perturbing field

⇒ Correction methods, which steer the beam on the desired target orbit

⇒ Most commonly used method is Singular Value Decomposition (SVD)

⇒ More iterations are needed because of nonlinearities

Thesis Contents

1. Robustness of conventional correction methods in case of degeneracy & asymmetry:
    - electron cooler dipole correctors perturbing the global orbit
    - σ optics shifting γ_t by splitting up even and uneven sector quadrupole families

2. Use Bayesian inference model to:
    - correct closed orbit at the BPMs
    - correct closed orbit along entire machine (in between BPMs)

1. Compare methods of closed orbit correction

Examine robustness of different methods:

- Singular value decomposition (SVD)
- Harmonic correction
- Correction using a Bayesian inference model

Conventional correction methods

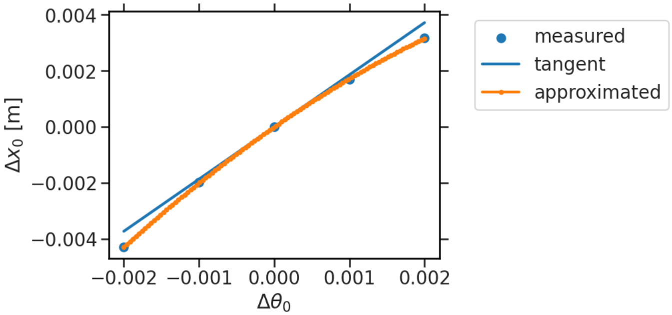
The examined conventional correction methods (SVD and harmonic correction) are based on orbit response matrix (ORM):

$$\Delta\theta_{\text{steerer}} = \Omega^{-1}\Delta x_{\text{BPM}}$$

1. Orbit response matrix Ω is needed (measured in an accelerator or extracted from a model)
2. Pseudo inverse of orbit response matrix is calculated
3. Steerer angle θ is calculated
4. Nonlinear machine needs more iterations

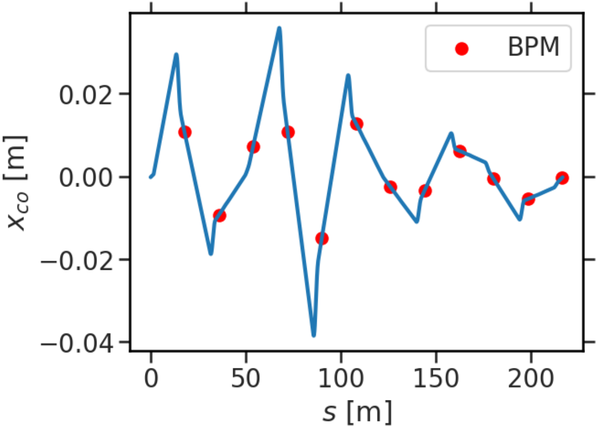
Measurement of orbit response matrix

$$\Delta x_{\mathrm{BPM}} = \Omega \Delta \theta_{\mathrm{steerer}}$$



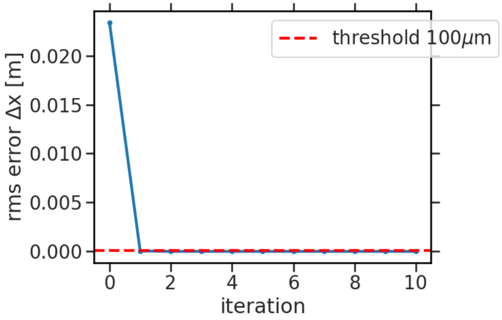
- A nonlinear machine (SIS18) with chromaticity correction is shown
- Simulated with Mad-X
- Approximated via polyfit
- Linear component is expressed via the ORM

Closed orbit of a nonlinear machine

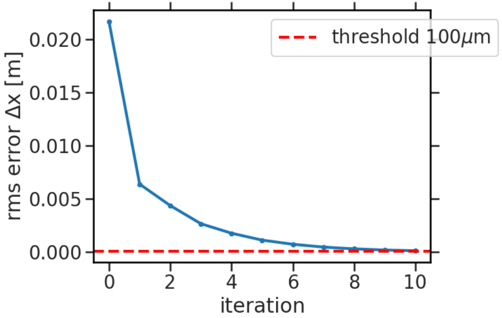


- Includes errors due to quadrupole misalignment and field errors of main dipoles
- Includes chromaticity correction with sextupoles

Correction with SVD



- Linear machine
- Includes quadrupole misalignment errors

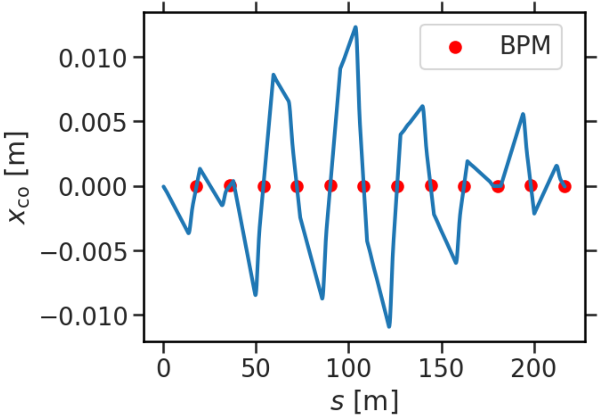


- Nonlinear machine due to chromaticity correction
- Includes quadrupole misalignment errors

Plans

- Try SVD with use cases: electron cooler setting and sigma optics setting
- Compare to harmonic correction
- Include measurement errors and steerer current errors

Corrected closed orbit of a nonlinear machine



- After 9 Iterations closed orbit at BPMS corrected
- In between BPMs still shifted

2. Bayesian inference

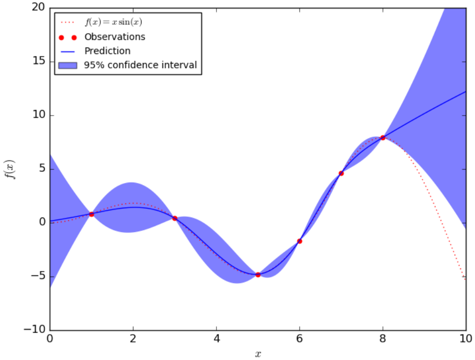
What is Bayesian inference?

Bayesian inference or Bayesian learning is an approach to statistical inference that allows beliefs (prior) about a hypothesis or model to be updated (posterior) by integrating new data (evidence).

Bayesian inference is used to build a surrogate model

- with Gaussian Process
- based on physical model

Bayesian inference model with Gaussian process

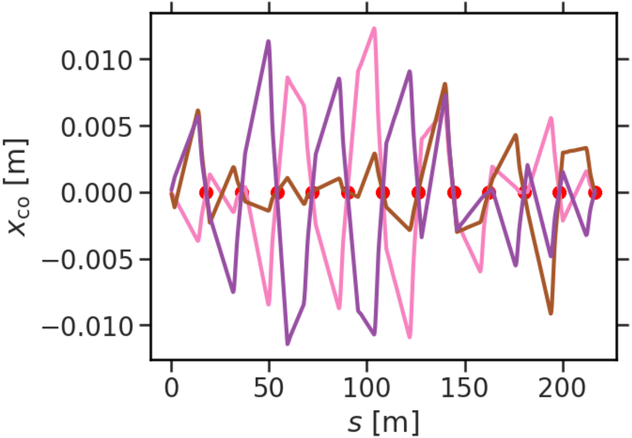


source: https://scikit-learn.org/0.17/auto_examples/gaussian_process/plot_gp_regression.html

Gaussian process:

- Represents a function whose function values, can only be modeled with certain uncertainties and probabilities
- Is constructed from suitable functions of the expected values, variances and covariances
- Is a probability distribution of functions

Bayesian inference model based on physical model



- Constructed from a set of closed orbits based on various field error distributions
- Uses the knowledge about the physics of closed orbits

Possible Applications

- Idea 1: Use BI model to correct closed orbit at BPMs
- Idea 2: Use BI model to correct closed orbit along entire machine (in between BPMs)
  - systematic measurement error
  - systematic steerer error
- Idea 3: Use BI model to include angle x' for correction
- Idea 4: Compare correction based on BI model to conventional methods in case of BPM failure

$\rightarrow$ robustness with the different use cases?

Summary & Outlook

1. Robustness of conventional methods
   - Preparatory work: implemented correction using SVD (with measurement module)
   - Robustness of methods in case of degeneracy and asymmetry
   - Comparison of the correction methods
2. Bayesian inference model
   - Correction at BPMs
   - Correction in between BPMs
   - Learn systematic errors
   - Comparison to conventional methods in case of BPM failure

Outlook: Try correction methods for use cases in real machine during beam time.

Anhang

Use cases/ Scenarios

1. controlling to no/small deviation of target orbit realistic machine
2. sigma optics / changing transition energy setting
3. electron cooler setting
4. Included errors $\rightarrow$ realistic machine
   - measurement errors BPM
   - error of control elements

Blöcke

Untertitel

Standardblock mit Titel

Blockinhalt

Ohne Titel

Exampleblock

Blockinhalt

Alertblock

Blockinhalt

The certain Input

Objective

An universal algorithm, which gets a certain input and finds the optimal correction parameters, which steer the beam on the desired target orbit.

Input:

- Target orbit (depending on use case)
- (ideal) model of the accelerator
- ”state” of the accelerator via the python interface