PSI Center for Accelerator Science and Engineering

Beam-based Alignment

Current Status

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Principle of Beam-based Alignment

The principle algorithm is „dispersion-free steering".

Though it should rathe rbe named: „dispersion-compensating steering", since it does not eliminate kicks but applies kicks at certain locations to minimize the accumulated dispersion along the undulator beamline.

The basic algorithm is devleopped by SLAC (P.Emma) and adapted to SwissFEL by E. Ferrario. I combined Eugenio's code into a single application to avoid errors due to frequent application "hoping".

And it is a"Pandora's Box" …

(the more one explore the algorithm the nastier it gets….)

Principle of Beam-based Alignment

The measured orbit at position x_M is the contribution of the initial incoming orbit (defined at an arbitrary reconstruction point x_0), the accumulated effect of orbit kicks within the undulator section, and the BPM calibration offset. The underlying physics of the beam transport is expressed by the transport matrix R.

$$x_M = R_{11}(z_M, z_0)x_0 + R_{12}(z_M, z_0)x'_0 + \sum_j R_{12}(z_M, z_j)x'_j - \Delta x_{bM}$$

Injection (position and angle) into undulator lattice

Quadrupole kicks

BPM offsets

The quadrupole kick arises by an offset Δx of the quadrupoles (correctors are set to zero):

$$x'_j = (k_1 \cdot L_q)_j \cdot \Delta x_{qj}$$

For *N* pairs of BPMs + Quadrupoles one has *N* measurement but 2·*N*+2 free parameters

Principle of Beam-based Alignment

Since the BPMs are mounted on the quadrupole movers an offset of the mover is also also affecting the BPM calibration. The orbit, expressed in mover offset and BPM calibration is then:

$$x_M = R_{11}(z_M, z_0)x_0 + R_{12}(z_M, z_0)x'_0 + \sum_j R_{12}(z_M, z_j)(k_1 L)_j \Delta x_{qj} - \Delta x_{qM}$$

To obtain a overdefined system, we measure for different configuration:

- Keeping the energy and changing k_1 → explicit calibration of Δx_{bM} → *what Masamitsu is doing*
- Keeping k_1 and changing the energy → Dispersion-free steering → *what I am doing*

M energies x N orbit readings as a function:

- N mover positions
- N bpm calibration
- 2M Initial conditions

→ Needs at least 3 energies to have an overdefined system

Practical Implementation - Contraints

To avoid large values due to some error in the orbit measurements (or transport matrix model), the solution for the BPM and Quadrupole offsets should have some constraints.

A simple implementation is:

$$\sum_j \Delta x_j = 0$$

$$\sum_j j \cdot \Delta x_j = 0$$

Pro:

- Can be represented as a linear matrix operation and added to the linear system for the measure orbit.
- Linear solver can be used (e.g. SVD)

Cons:

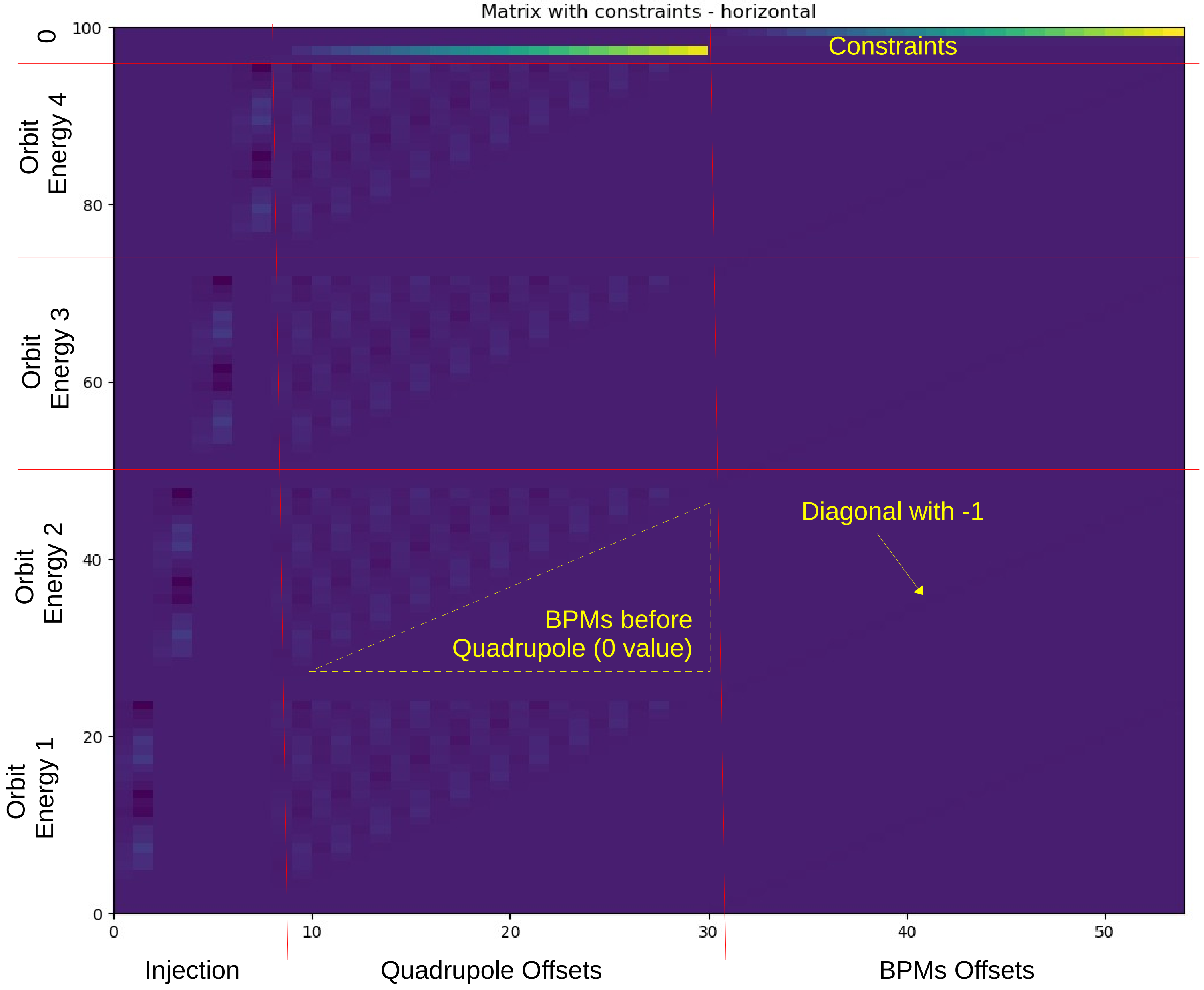
- Better to minimize the L_2 norm ($||\Delta x||_2$)
- Large changes cannot be found (e.g. the starting condition from the last BBA)
- The trivial solution (Dx = 0) might not be limit but a class of polynomial function of second order or higher.

Practical Implementation – Solver choice

Graphical representation of the response matrix

Solutions:

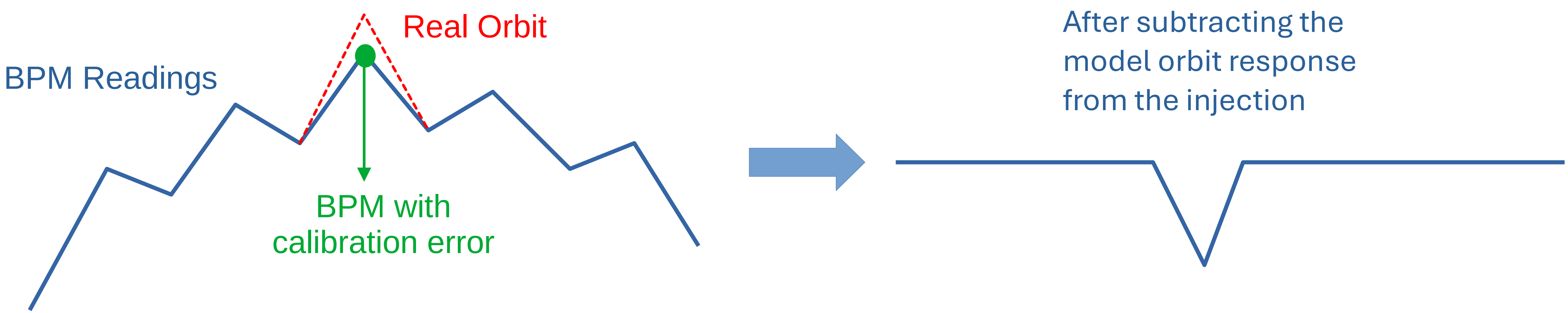
- Strong dependence on solver. They also have the tendency to not converge
- Contraints in angle bias the response matrix too strong.
- Response matrix close to being degenerative, e.g. in a FODO lattice with scaled quadrupoles, the rows of a give BPM reading is identical for all energies !



Practical Implementation – BPM Calibration

Algorithm relies on a good BPM calibration for the given orbit, in particular if the orbit has been tilted for the FEL pointing and the electron beam goes far from the electrical center of the BPM.

An error in the BPM calibration results in a systematic error:



Algorithm sees this as an orbit bump and will shift three quadrupoles off-axis to compensate for the bump.

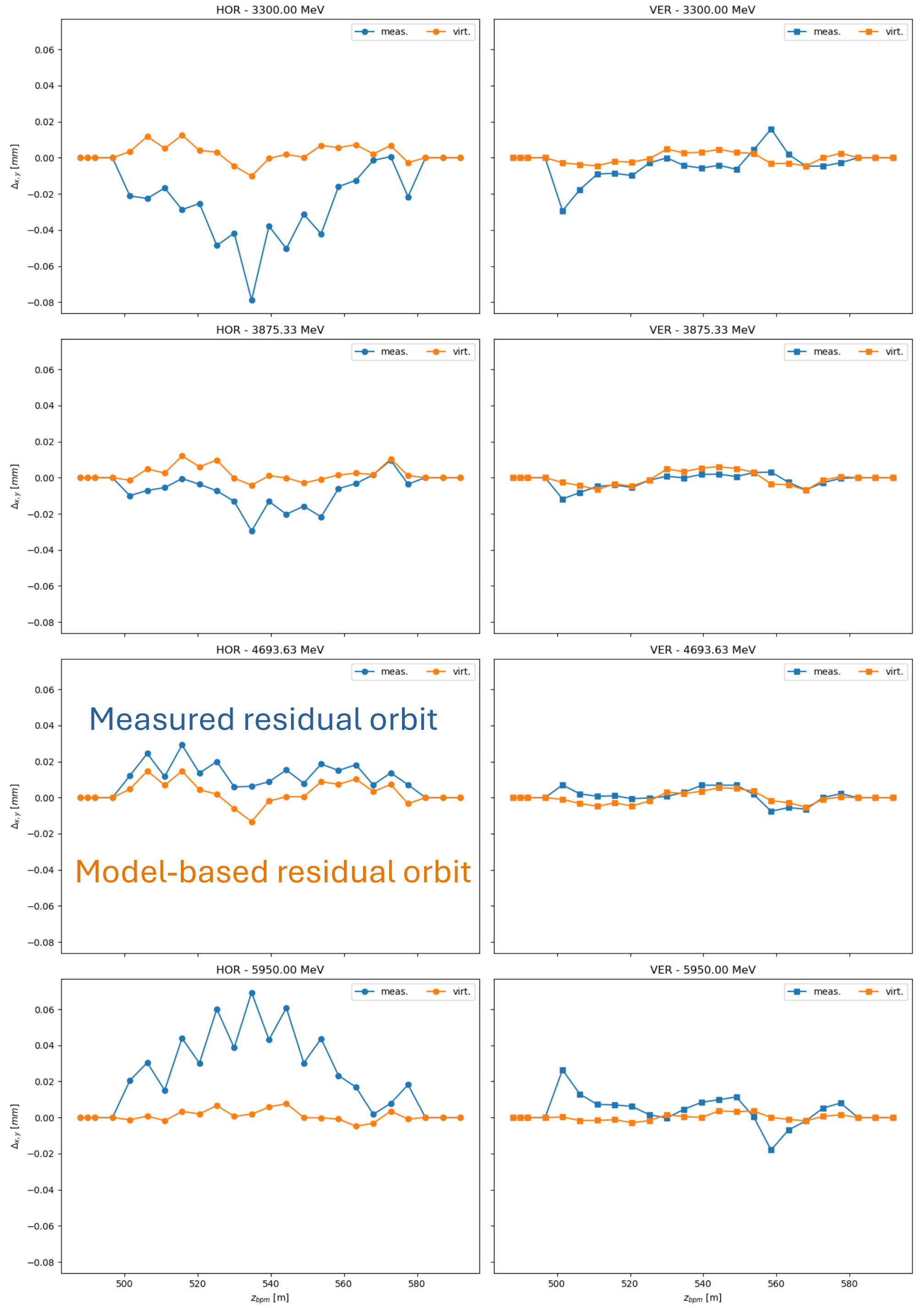
Practical Implementation – Residual Kicks

There are three types of kickes in the undulator:

- Constant kicks by quadrupoles (since their strength is scaled with energies)
- Kicks by residual kick correction of the undulators (entrance and exit kicker, earth magnetic field compensation coil), which scale with energy as 1/Energy
- Kicks by the natural focusing of misaligned undulator modules, which scale with energy as 1/Energy^2

The algorithm tries to find an average compensation of these kicks but there is a systematic kick to one side at higher energy and to the other side at lower energies.

This is in particular noticeable in the horizontal plane



Conclusion and Outlook I

The more I look into the implemented algorithm

the more I have my doubt that the algorithm is robust

(Pandoras Box)

There is a lot of room for improving the algorithm on its own but this will take some time and resources. Amin goal is to have a stable solution, independent on the solver choice

The deviation of the machine settings from the last „good BBA“ by Eugenio is large (e.g. up to 1 mm !) that the algorithm can cope with it. There, the deviation of the residual orbit were a few microns while the current BBA gives deviation of few hundrets of microns. It might be that the field integral of the undulators are not compensated when the beam has a significant horizontal offset (though the natural focusing should be still negligible).

Sanity checks of other algorithms (Masamitsu’s approach) are very welcome

Conclusion and Outlook II

Short Term Action Item:

- Avoid large changes in BPM and Quadrupole positions:
  - Assume current orbit is close to the ideal.
  - Convert corrector currents into quadrupole offsets and feedback target values.
  - Convert residual feedback target values into BPM offsets.
- Reduct the weight of the angle constraints in the response matrix.

Mid Term Action Item:

- Check BPM calibration or measure response matrix.
- Check optics model.
- Robustness studies with simulated orbits.

Long Term Action Item:

- Use non-linear optimized with a valid normalization of the result vector.
- Include residual fields in the model as an energy dependent kick besides the constant kick of the quadrupole.