Modeling of CW/CCW calibration in a FS-type lattice

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Overview

- Optimization of sextupole strengths for reducing decoherence;
  - problem with simultaneous suppression of x- and d-offset decoherence.
- Modeling of the CW/CCW calibration procedure;
  - spin freeze problem.

Optimization of sextupole strengths

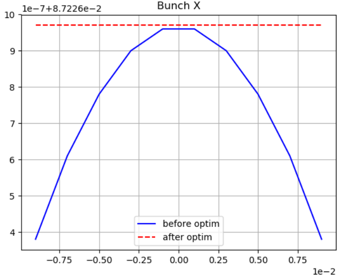
for the reduction of decoherence

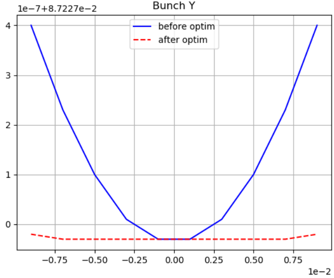
- Three sextupole families (GSX, GSY, GSD), each expected to suppress decoherence, resp., in X-,Y-,D-planes;
- spin tune Taylor expansion (COSY Infinity) assumes the form (some terms omitted):

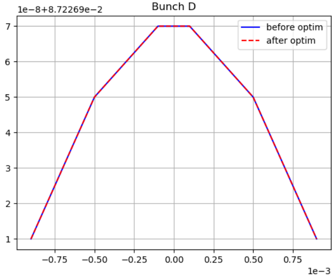
$$\mu(x, y, d) = \mu_0 + a_{xx} \cdot x^2 + a_{yy} \cdot y^2 + a_{dd} \cdot d^2 + a_{xd} \cdot x \cdot d + a_{yd} \cdot y \cdot d;$$

- parabolic dependence of spin tune on the x, y, d variables (confirmed by spin tracking) $\Rightarrow$ objective function $f = a_{xx}^2 + a_{yy}^2 + a_{yd}^2$;
- the reason a_{dd}, a_{xd} are not involved in f: a_{xx}, a_{dd} couldn't be minimized simultaneously (analysis below).

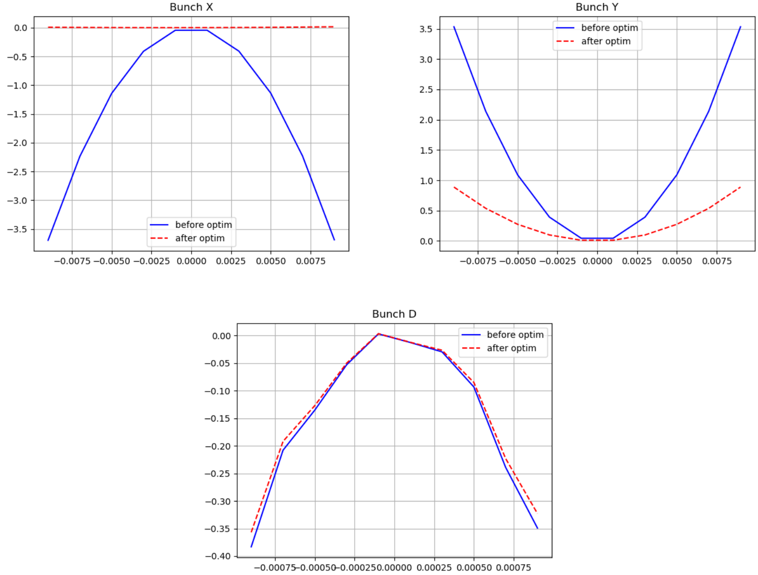
Computed as $\mu_i = \mu(x_0^i, y_0^i, d_0^i)$



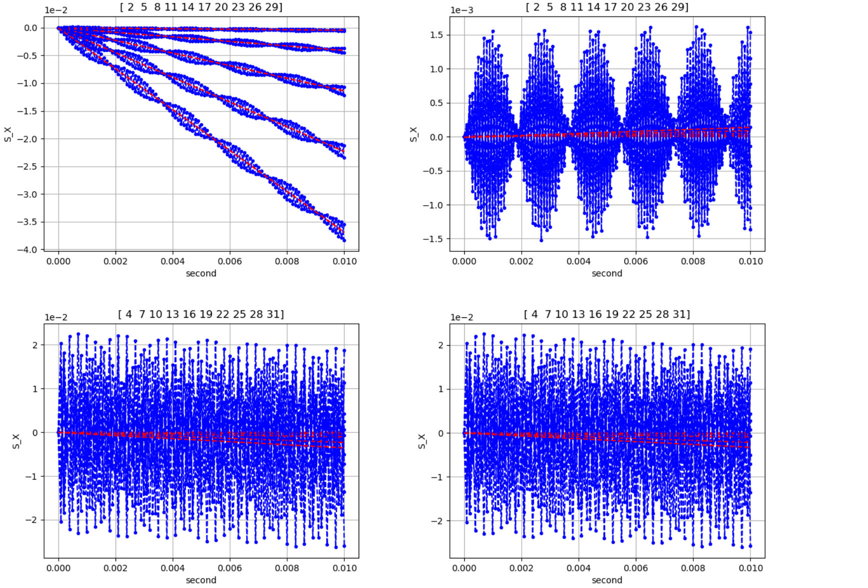




Linear fit of tracking data



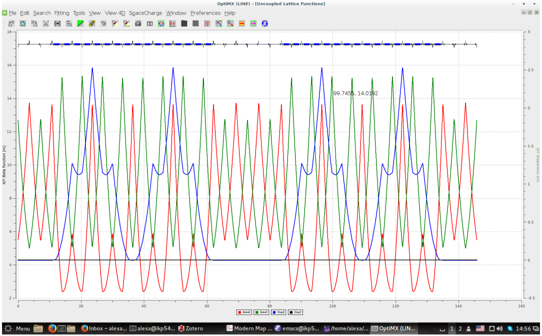
Example fits (X-,D-bunch)



Gradient sweep analysis

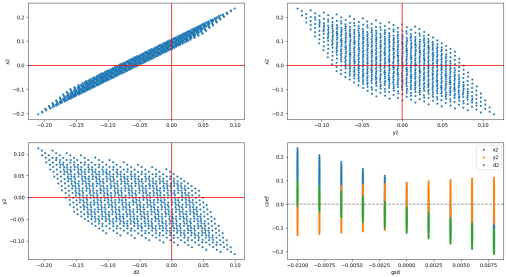
FS-type lattice beta functions

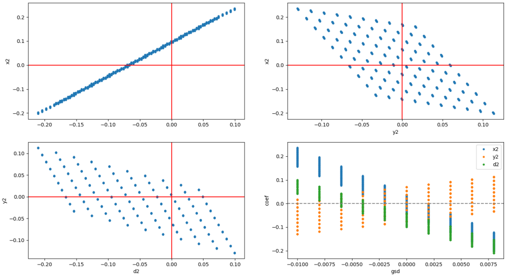
- Sextupoles are placed in the maximums of the corresponding beta functions;
- because DispX, BetaX maxima coincide, considered 3 cases: 1) GSD only in big DispX maxima, 2) GSD only in smaller maxima not coinciding with BetaX maxima, 3) GSD in both types DispX maxima.



Gradsweep cases 4&12

- Took a grid GSX, GSY, GSD: $\pm 10^{-2}$ T/cm^2 (10 points each axis);
- computed the spin tune, and extracted the a_{xx}, a_{yy}, a_{dd} coefs (plotted);
- observe that a_{xx}, and a_{dd} cannot be simultaneously set to 0.





CW/CCW B-field calibration procedure

Rationale

- The core idea of the procedure is to use the x-z plane spin precession frequency as a measure of the B-field;
- an element tilt θ introduces a B_x field component, which induces a $\Omega_x^{\mathrm{MDM}} \propto B_x$;
- $\Omega_y^{\mathrm{MDM}} \propto B_y$, and B_y and B_x are strictly related via θ;
- θ doesn't change going from CW to CCW, hence by reproducing Ω_y^{MDM} we can be sure to reproduce B_y, and also B_x and Ω_x^{MDM}.

CW/CCW B-field calibration procedure

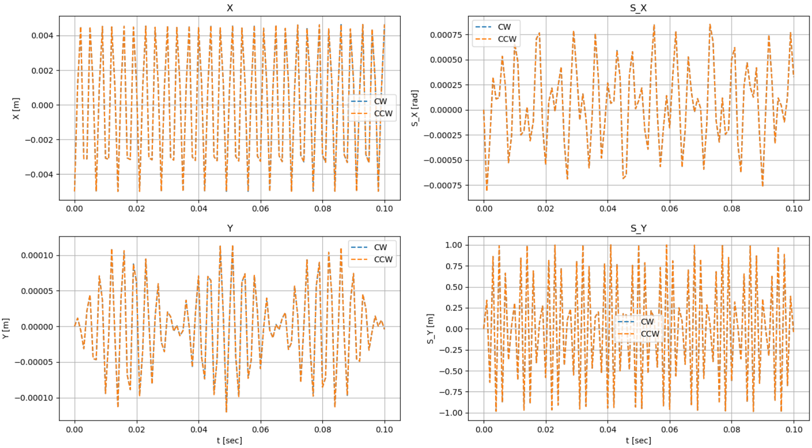
Modeling

1. distribute element tilt errors $\theta \sim N(\mu_j, \sigma_j), j \in J$;
2. for an ensemble of initial conditions $\{(x^i, a^i, y^i, b^i, t^i, d^i)\}_{i \in I}$ compute array of $\{(\Omega_x^i, \Omega_y^i)\}_{i \in I}$;
3. compute statistics:
   $S_1 \equiv |\Omega_x^{\mathrm{CW}}| - |\Omega_x^{\mathrm{CCW}}|,\ S_2 \equiv |\Omega_y^{\mathrm{CW}}| - |\Omega_y^{\mathrm{CCW}}|$;
4. repeat for $j \in J$.

Spin freeze

$\theta = \theta_0$

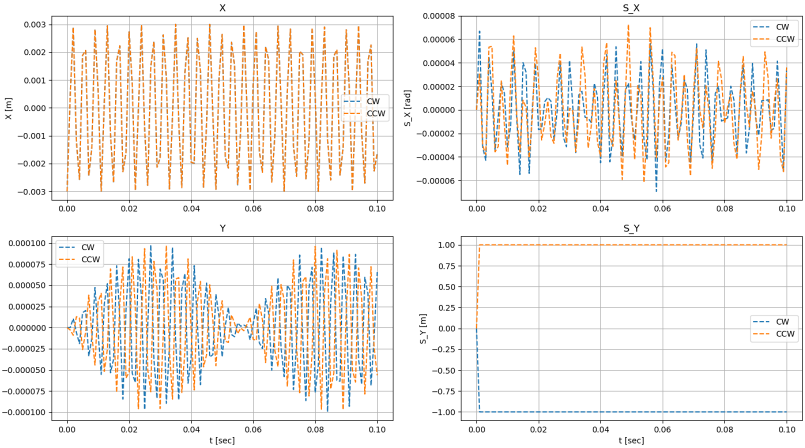
All WF are tilted by the same angle θ_0; S_y oscillates as expected.



Spin freeze

$\theta \sim N(0, \sigma)$

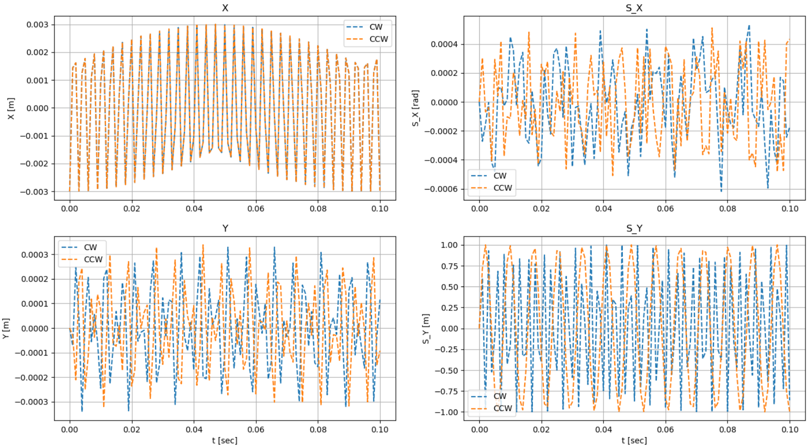
Reaching the apex, spin freezes at $(S_y, S_z) = (1, 0)$.



Spin freeze

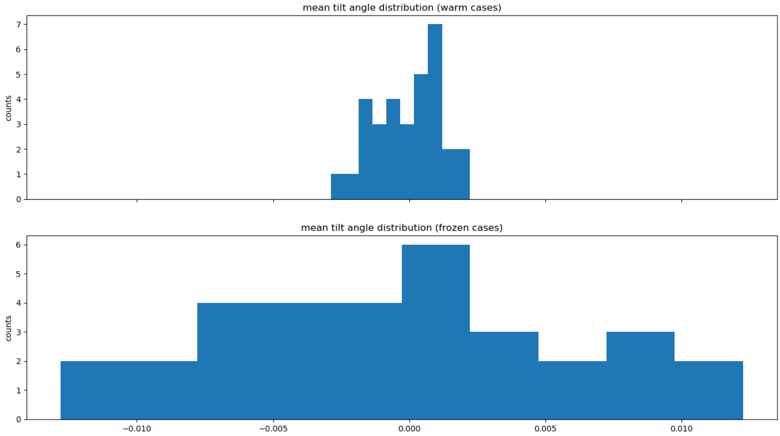
$\theta \sim N(0, \sigma)$

Another realization of the same distribution; this time there's no spin freeze.



Look at the lattice as a whole

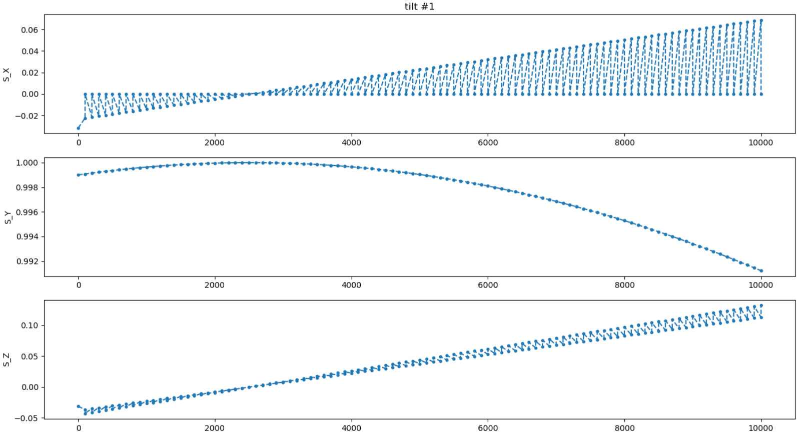
Hypothesis: something's wrong with the mean B_x value.
Simulation: Three values of $\sigma \in [1, 2, 3] \cdot 10^{-4}$ rad; 30 trials/value.



Look at particular WFs

Tilted WF #1 by 10^{-4} rad

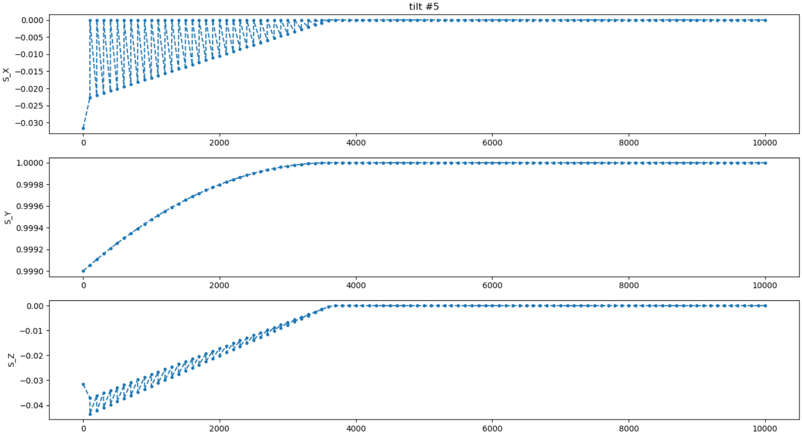
Spin doesn't have a problem crossing the apex.



Look at particular WFs

Tilted WF #5 by 10^{-4} rad

Spin freeze at the top.



Probable cause

There's evidence that spin freeze is not caused by my crooked hands; Eremey also encountered that problem:

- Spin freeze is not a computational artifact; it's a resonance implicit in the mathematical model;
- it occurs whenever the spin vector gets into a certain, fairly wide azimuth range close to $S_y = 1$.

And it looks like that range is dangerous in some places along the beamline, and not the others, seeing as tilting of WF ##1, 32, some others, doesn't cause freezing, whereas ##5, 8 does.