FCC-EE TUNING SIMULATIONS WITH PYAT

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FCC-ee tuning WG meeting

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Previous correction results (V22 @ Z FODO arc lattice at 45 Gev, 4D)

Sextupoles OFF → Errors applied → SVD Orbit correction → Sextupoles On 100% in one step → Fit tune & chromaticity → 2 iter of beta beating correction (LOCO) + fit tune & chrom 1 iter coupling correction (LOCO)+ 1 iter beta cor (LOCO) fit tune & chrom.

- Applying Hor & Ver displacement errors to **ARC** components

10 seeds (mean values)	rms orbit x (μm)	rms orbit y (μm)	$\Delta\beta x/\beta x\%$	$\Delta\beta y/\beta y\%$	Δ ηx (mm)	Δ ηy (mm)	ε_h (nm)	ε_v (pm)
10	709.51	905.97	0.62	1.28	1304.66	11689.3	-	-
Cor	2.19	2.26	0.14	0.23	0.51	0.17	0.71	**0.15**
20	1230.71	1710.57	1.197	2.11	2203.8	20984.3	-	**-**
Cor	4.51	4.53	0.72	0.54	0.93	0.36	0.71	**1.37**

Including sextupole ramping

1. Sextupoles off.
2. Errors applied.
3. Increasing sextupoles strength in steps of **10%**:

   -Orbit correction (One iteration with **1500** singular values).

   -Tune correction (all arc QF & QD, function provided by S. Liuzzo).

   -When correction failed, keep the previous statue.
4. Chromaticity correction (**all arc SF & SD**).
5. Beta beating and coupling correction (**LOCO** iterations with tune & chroma correction in between).
6. Final tune and chromaticity correction.
7. Emittance calculations at 45.6Gev.

Correction results with sextupole ramping (at 45.6 Gev, 4D)

- Applying Hor & Ver displacement errors to **ARC** components **20 & 30 μm**

10 seeds (mean values)		rms orbit x (μm)	rms orbit y (μm)	$\Delta\beta x/\beta x$%	$\Delta\beta y/\beta y$%	Δ ηx (mm)	Δ ηy (mm)	ε_h (nm)	ε_v (pm)
20 μm on arc quads & sextupoles	**After Sextupoles ramping**	1.80	1.67	1.24	1.65	8.85	9.86	0.70	**0.37**
	Final cor. result	1.84	1.75	0.34	0.56	0.86	0.33	0.71	**0.56**

10 seeds (mean values)		rms orbit x (μm)	rms orbit y (μm)	$\Delta\beta x/\beta x$%	$\Delta\beta y/\beta y$%	Δ ηx (mm)	Δ ηy (mm)	ε_h (nm)	ε_v (pm)
30 μm on arc quads & sextupoles	**After Sextupoles ramping**	2.65	2.57	1.69	3.56	13.96	12.48	0.71	**0.71**
	Final cor. result	2.80	2.88	0.54	0.64	1.73	0.54	0.71	**3.66**

Beta beating and coupling correction (LOCO iterations with tune & chroma correction in between).

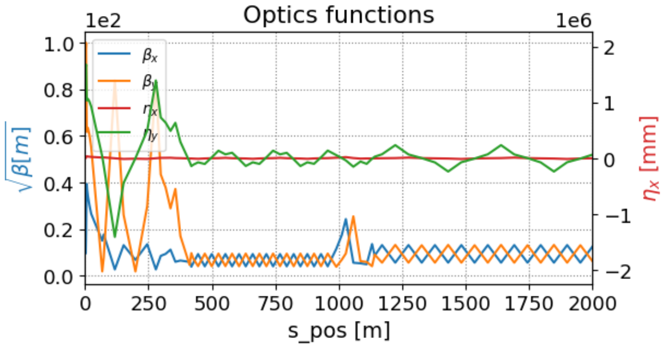
Correction results with sextupole ramping (at 45.6 Gev, 4D)

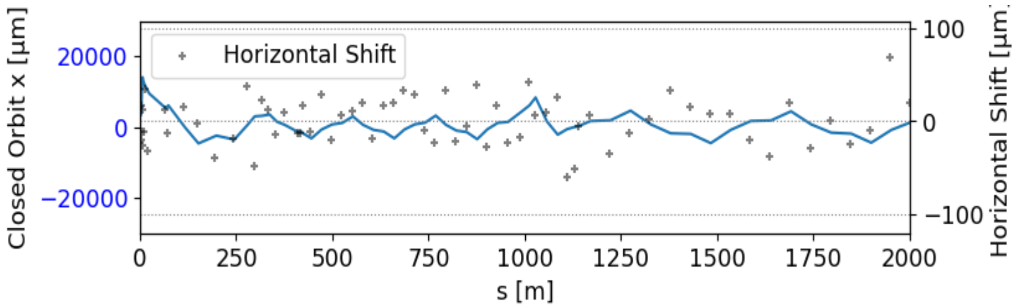
- Applying Hor & Ver displacement errors to **ARC** components **80 μm**

10 seeds (mean values)		rms orbit x (μm)	rms orbit y (μm)	Δβx/βx%	Δβy/βy%	Δ ηx (mm)	Δ ηy (mm)	ε_h (nm)	ε_v (pm)
80 μm on arc quads & sextupoles	**With err**	4055.12	6622.46	7.63e-7	0.0002	7871.54	67371.9	-	-
	After Sextupoles ramping	6.81	6.77	4.94	8.14	38.01	35.94	0.71	6.19
	Beta beating cor.	8.06	10.61	1.61	2.48	33.04	35.28	0.71	205.46
	Coupling cor.	8.57	12.38	2.79	6.93	1.31	2.45	0.71	360.16
	Final cor. result	8.59	12.72	1.53	2.50	6.53	2.39	0.71	407.25

Correction results with sextupole ramping (at 1 GeV, 4D) at 45.6 Gev seeds dose not complete the ramping

- Applying Hor & Ver displacement errors to **ARC & IR** components **30 µm**





1 seed		rms orbit x (µm)	rms orbit y (µm)	Δβx/βx%	Δβy/βy%	Δ ηx (mm)	Δ ηy (mm)	ε_h (nm)	ε_v (pm)
30 µm on arc & IR quads & sextupoles	**With err**	4255.98	24823.40	1.2e-6	0.000475	9972.16	360364	-	-
	After Sextupoles ramping	3.97	5.20	4.34	168.24	11.49	32.588	-	-
	Final cor. result	3.99	5.28	7.74	60.27	8.35	4.31	0.76	12.04

Correction results with sextupole ramping (Hor & Ver displacement errors to ARC & IR)

Remarks

- Vertical beta beating increased significantly through the ramping.
- In many seeds the lattice optics becomes unstable after applying the optics correction results.

Optics correction performed (LOCO):

- Using all quadruples in the fit (arc & ir).
- All bpms were used and 20 steering magnets.

Attempts to improve optics correction (LOCO), however, results remained unchanged:

- Adjusting Singular Value Cut (600, 1000, 1500).
- Increasing number of used correctors from 20 to 40.
- ORMs and Jacobeans calculated while sextupoles are ON.

Different optics correction algorithms.

1. Sextupoles off.
2. Errors applied.
3. Increasing sextupoles strength on steps of **10%**:

   -Orbit correction (One iteration with **1500** singular values).

   -Tune correction (all arc QF & QD, function provided by S. Liuzzo).

   -When correction failed, keep the previous statue.
4. Chromaticity correction (**all arc SF & SD**).
5. **Instead of LOCO: rematching of the phase advance at the BPMs for beta beating and hor. dispersion cor and using the coupling resonant driving terms (RDT) for coupling correction.**
6. Final tune and chromaticity correction.
7. Emittance calculations at 45.6Gev.

Different optics correction algorithms.

Beta beating & Hor. Dispersion correction :

- Using rematching of the phase advance at the BPMs.
- All normal quadepoles (**1856).**
- Adjusting SVD cut off and weights ($w_{\phi x}, w_{\phi y}, w_{Dx} = 0.5$).

$$\Delta \vec{k_1} = -\mathbf{R}^{-1}(w_\phi \Delta\vec{\phi}, w_D \Delta\vec{D}, \Delta Q_x, \Delta Q_y)$$

Coupling correctoin:

- Using coupling resonant driving terms (RDTs)
- All normal quadepoles (**1856**) and skews (at sextupoles **632**)
- Functions to correct RDTs + dispersion + tune based on pyAT, analytical.
  [commissioningsimulations/correction/optics_coupling/resonance_driving_terms.py · main · BeamDynamics / CommissioningSimulations · GitLab (esrf.fr)]

$$\begin{pmatrix} \vec{f_{1001}} \\ \vec{f_{1010}} \end{pmatrix}_{meas} = -\mathbf{M}\,\vec{\mathbf{J}}$$

- **2 iter of beta beating correction (LOCO)**

10 seeds (mean values)		rms orbit x (μm)	rms orbit y (μm)	Δβx/βx%	Δβy/βy%	Δ ηx (mm)	Δ ηy (mm)	ε_h (nm)	ε_v (pm)
80 μm on **arc** quads & sextupoles	**After Sextupoles ramping**	6.81	6.77	4.94	8.14	38.01	35.94	0.71	6.19
	Beta beating cor.	8.06	10.61	1.61	2.48	33.04	35.28	0.71	205.46

- **Beta beating correction using phase advance**

10 seeds (mean values)		rms orbit x (μm)	rms orbit y (μm)	Δβx/βx%	Δβy/βy%	Δ ηx (mm)	Δ ηy (mm)	ε_h (nm)	ε_v (pm)
80 μm on **arc** quads & sextupoles	**After Sextupoles ramping**	6.83	6.57	3.80	8.96	34.52	42.17	0.71	6.12
	Beta beating cor.	8.08	8.02	4.33	2.29	10.18	41.32	0.70	43.75

Better vertical emittance compared to LOCO

Including RDTs coupling correction

Work is ongoing on choosing the proper variables (# of singular vectors, weights, ..)

10 seeds (mean values)		rms orbit x (μm)	rms orbit y (μm)	Δβx/βx%	Δβy/βy%	Δ ηx (mm)	Δ ηy (mm)	ε_h (nm)	ε_v (pm)
80 μm on **arc** quads & sextupoles	**Coupling cor.**	8.90	8.75	3.43	2.32	16.65	34.63	0.71	65.51
	Final cor. result	9.03	9.13	4.44	28.076	16.92	35.95	0.71	**103.14**

Resulted from the last tune and chromaticity fitting

To do next

- RDTs coupling correction.
- Sextupole ramping with beta beating, dispersion and coupling correction steps in between.
- Investigate the impact of errors ramping.
- Magnets to be used for correcting tune & chromaticity.

THANK YOU FOR YOUR ATTENTION