Update on Rectilinear Cooling Lattice

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2024.7.4

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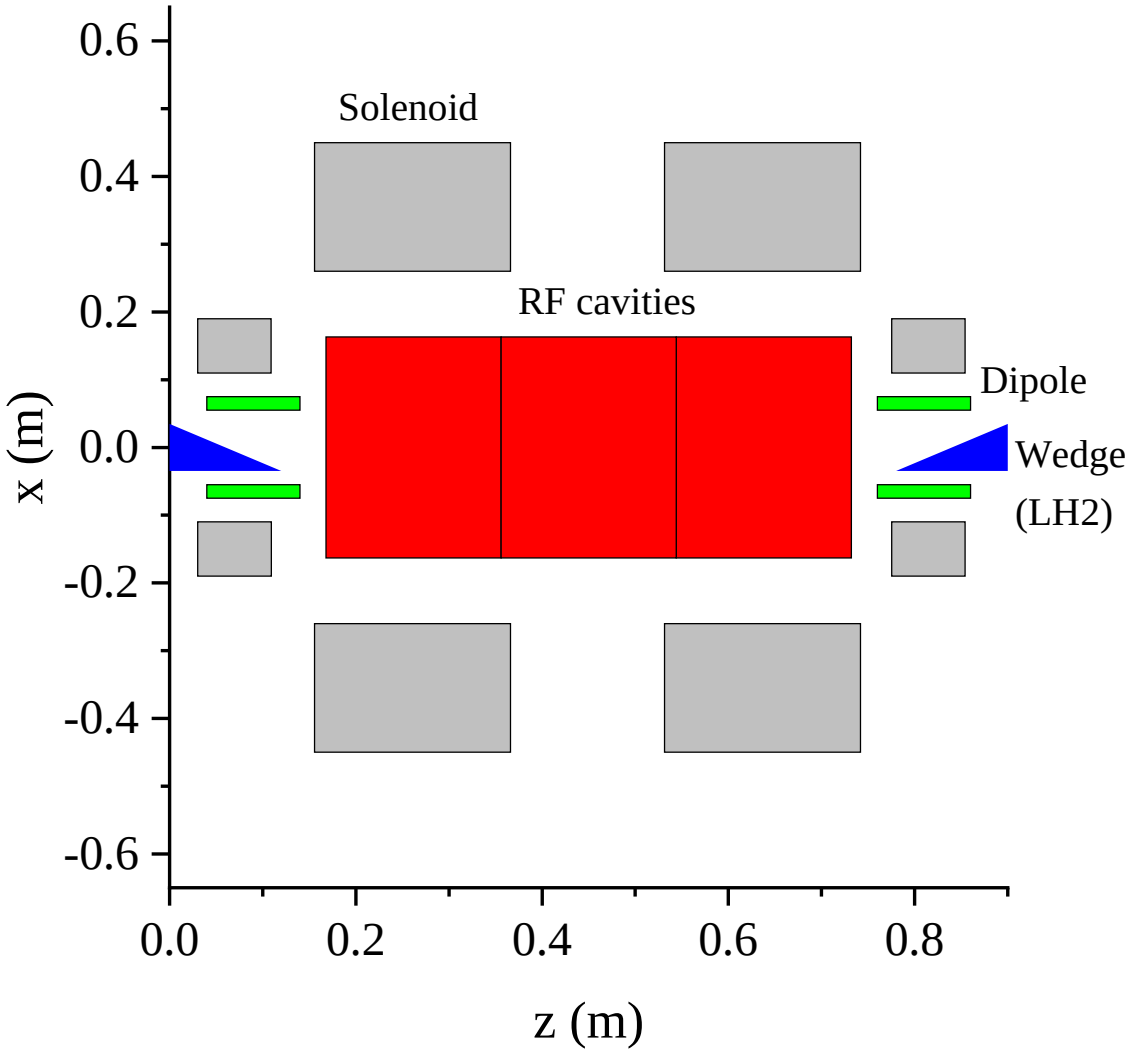
Error analysis (π-mode stage5)



param cell_length=900
param solpos1=0.09472161930764822
param coil_length1=78.88455942289049
param coil_radius1=110
param coil_width1=80
param current1=218.29618904749944
param solpos2=0.2898909079135813
param coil_length2=210.41528714423515
param coil_radius2=260
param coil_width2=190
param current2=149.40015444416457

param rf_length=188
param rf_fre=0.704
param rf_grad=26.254094132273284
param rf_ph=23.832963383834894

param wedge_window_length=0.09
param rf_window_length=0.03

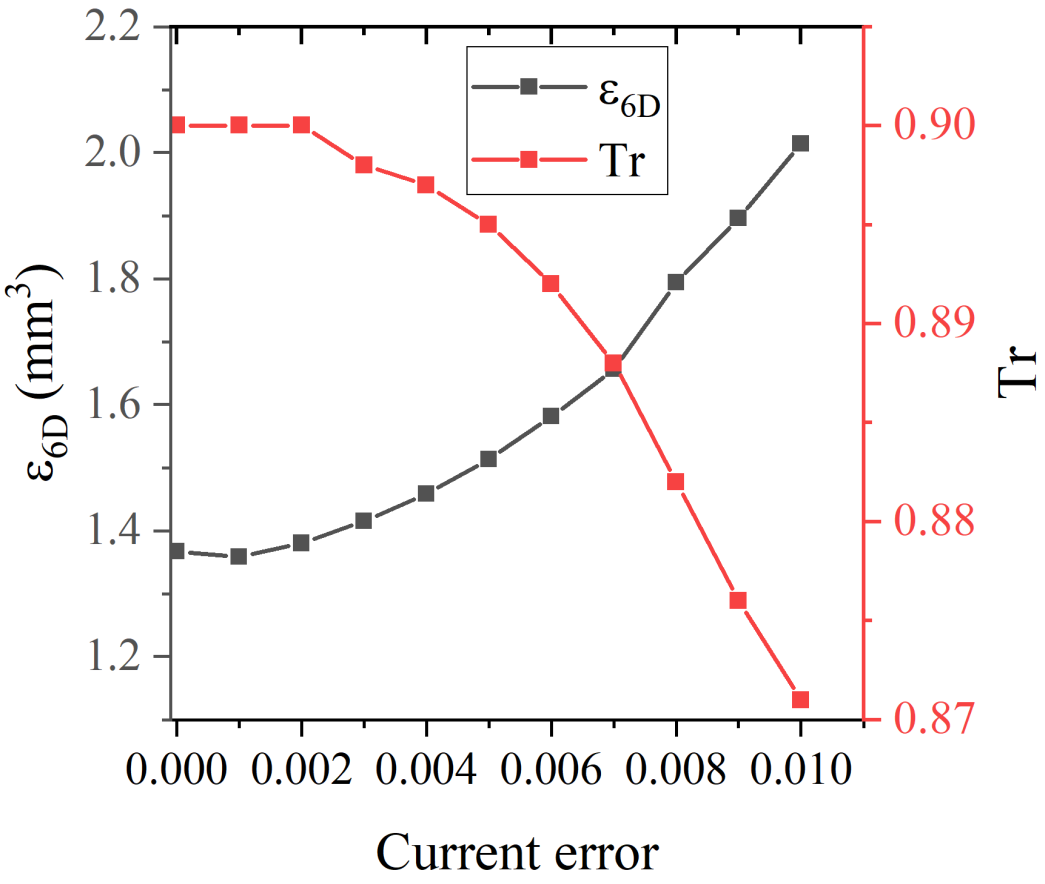
Error analysis (π-mode stage5)

➢ Simulation setup:

- Generate random numbers (errors) from truncated Gaussian distribution (3sigma, mean=0, sigma).
- Add these random numbers (errors) to the coils and RF cavities.
- Run the tracking simulation for 100 times. Average the emittance and transmission.

Current error of solenoid coils

$Error_{sigma}$	ε_T (mm)	ε_L (mm)	ε_{6D} (mm^3)	Transmission
0	0.7082	2.569	1.367	0.9
0.1%	0.7068	2.573	1.358	0.9
0.2%	0.7115	2.579	1.38	0.9
0.3%	0.722	2.583	1.415	0.898
0.4%	0.7295	2.59	1.458	0.897
0.5%	0.7419	2.602	1.513	0.895
0.6%	0.758	2.604	1.581	0.892
0.7%	0.7737	2.623	1.656	0.888
0.8%	0.8005	2.646	1.794	0.882
0.9%	0.8206	2.661	1.896	0.876
1%	0.8429	2.671	2.014	0.871

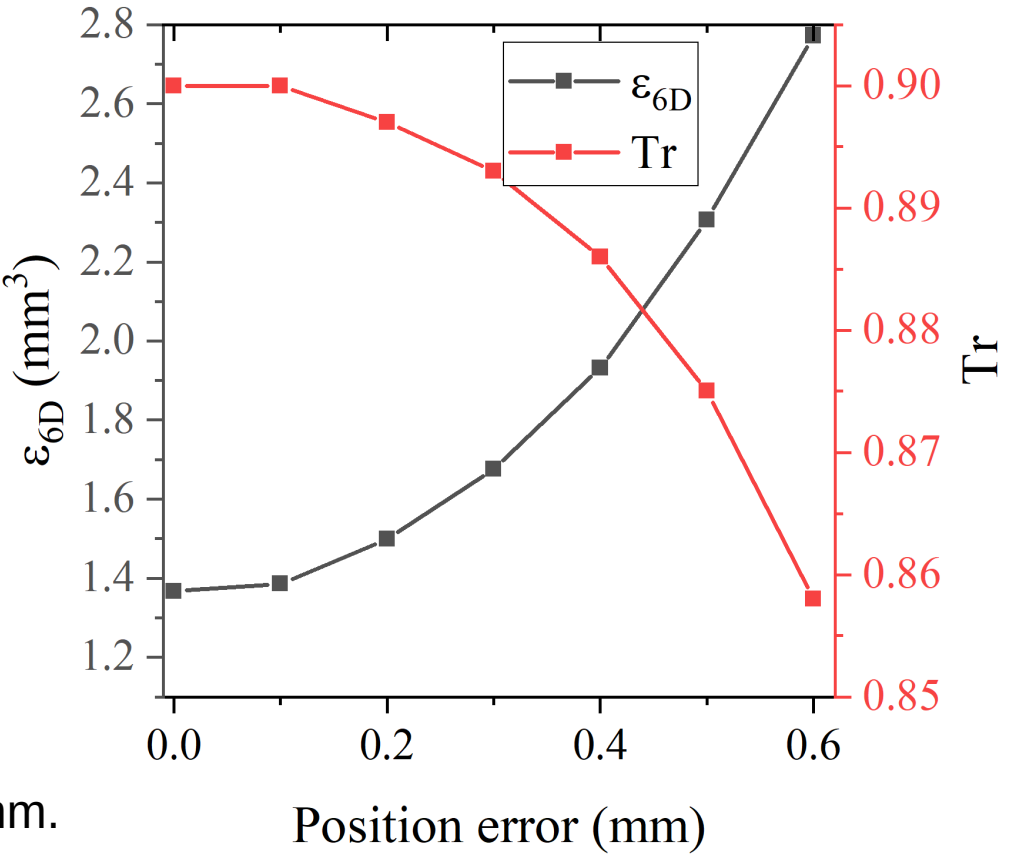


Performance starts to degrade when current error is above 0.3%.

Position error of solenoid coils

Move solenoid coils transversely (x and y) and longitudinally (z)

$Error_{sigma}$ (mm)	ε_T (mm)	ε_L (mm)	ε_{6D} (mm^3)	Transmission
0	0.7082	2.569	1.367	0.9
0.1	0.7151	2.574	1.386	0.9
0.2	0.7488	2.578	1.499	0.897
0.3	0.7978	2.581	1.676	0.893
0.4	0.8624	2.585	1.932	0.886
0.5	0.9491	2.591	2.306	0.875
0.6	1.041	2.619	2.772	0.858



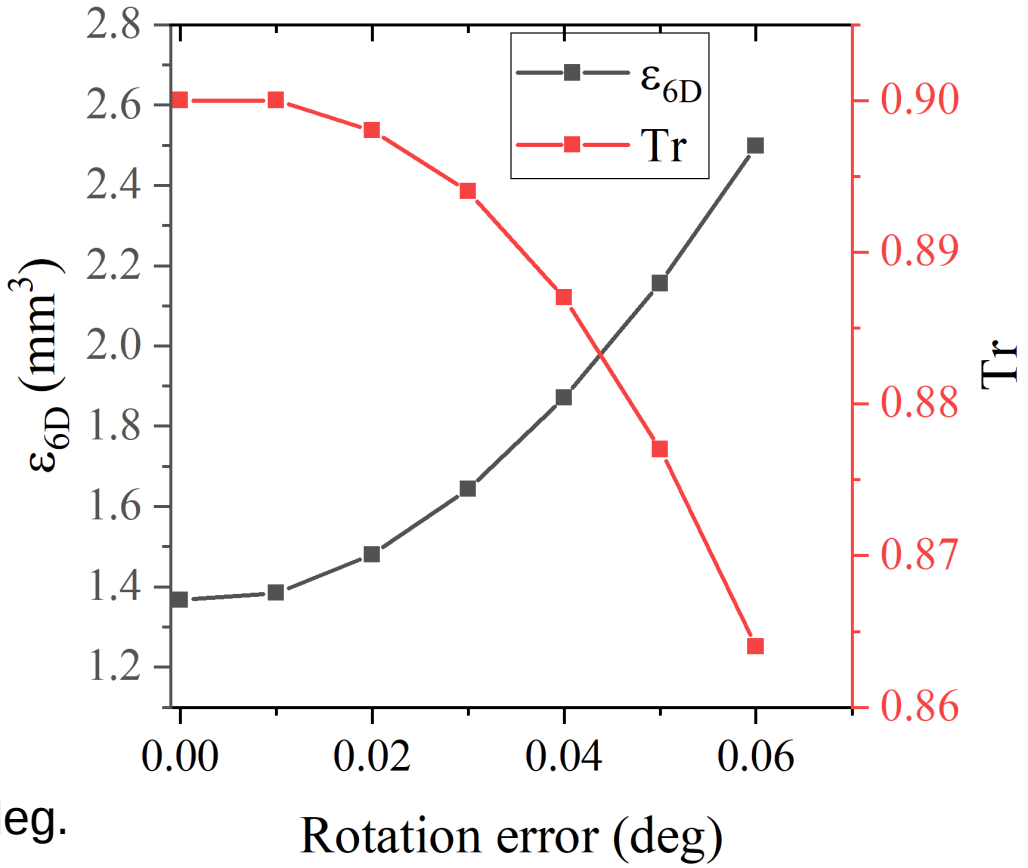
Performance starts to degrade when position error is above 0.1 mm.

Although position error perturbs By and Bx, only transverse emittance has obvious change.

Rotation error of solenoid coils

Rotate solenoid coils transversely (x and y) and longitudinally (z)

$Error_{sigma}$ (deg)	ε_T (mm)	ε_L (mm)	ε_{6D} (mm^3)	Transmission
0	0.7082	2.569	1.367	0.9
0.01	0.7145	2.576	1.384	0.9
0.02	0.7432	2.577	1.48	0.898
0.03	0.7892	2.574	1.643	0.894
0.04	0.848	2.574	1.871	0.887
0.05	0.9145	2.58	2.155	0.877
0.06	0.9947	2.587	2.498	0.864



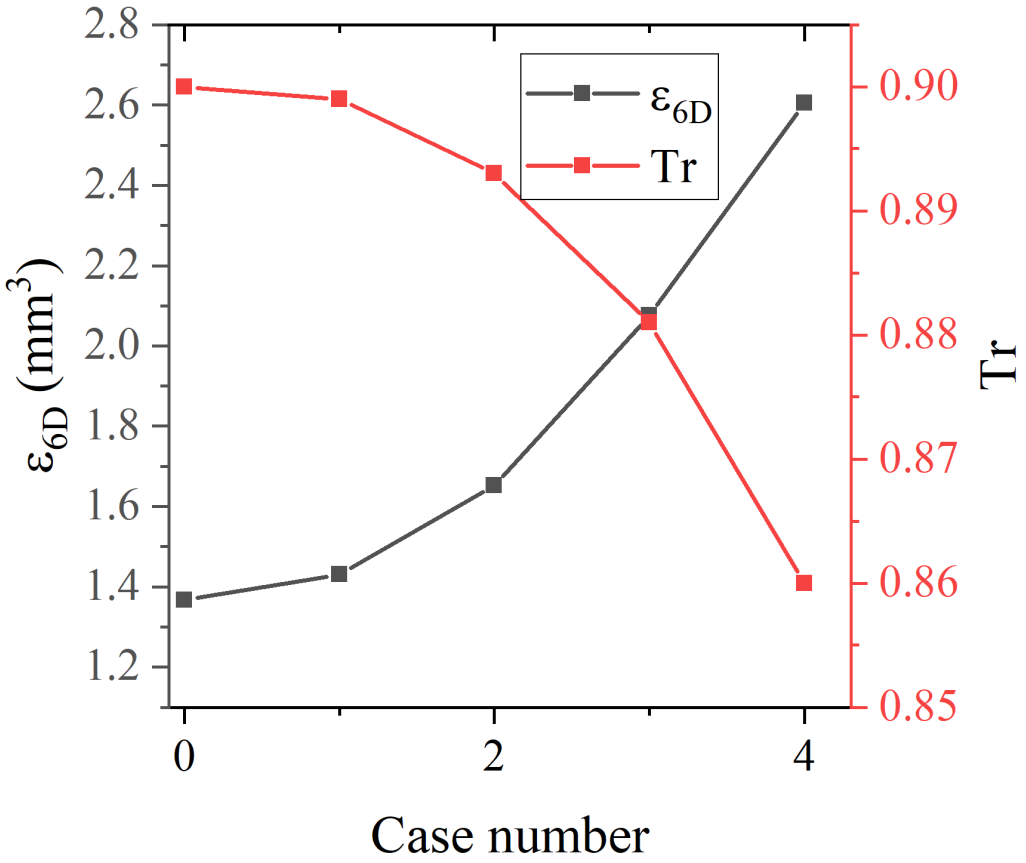
Performance starts to degrade when rotation error is above 0.01 deg.

Although rotation error perturbs By and Bx, only transverse emittance has obvious change.

Current+position+rotation error of solenoid coils

Error$_{sigma}$ (mm deg)	ε_T (mm)	ε_L (mm)	ε_{6D} (mm^3)	Transmission
0 0 0	0.7082	2.569	1.367	0.9
0.1% 0.1 0.01	0.7278	2.577	1.43	0.899
0.2% 0.2 0.02	0.79	2.584	1.652	0.893
0.3% 0.3 0.03	0.8912	2.597	2.075	0.881
0.4% 0.4 0.04	1.004	2.619	2.605	0.86

Performance starts to degrade when combination error is above (0.1% 0.1mm 0.01 deg).



Gradient and phase error of RF cavities

➢ Gradient error

$Error_{sigma}$	ε_T (mm)	ε_L (mm)	ε_{6D} (mm^3)	Transmission
0	0.7082	2.569	1.367	0.9
1%	0.7067	2.570	1.356	0.9
10%	0.7136	2.585	1.397	0.896

10% RF gradient and phase error still don't affect performance.

➢ Phase error

$Error_{sigma}$	ε_T (mm)	ε_L (mm)	ε_{6D} (mm^3)	Transmission
0	0.7082	2.569	1.367	0.9
1%	0.7072	2.569	1.357	0.9
10%	0.7099	2.583	1.379	0.9

RF failure

As pi-mode RF cells are coupled, if one RF cell doesn't work, the other two in the same RF structure will stop working as well.

Number of RF structure in failure	ε_T (mm)	ε_L (mm)	ε_{6D} (mm^3)	Transmission
0	0.7082	2.569	1.367	0.9
1	0.7203	2.620	1.455	0.89
2	0.7289	2.660	1.528	0.876
3	0.7302	2.701	1.548	0.863
4	0.7455	2.762	1.668	0.843

Failure of one RF structure (3 cavities) doesn't influence performance too much.

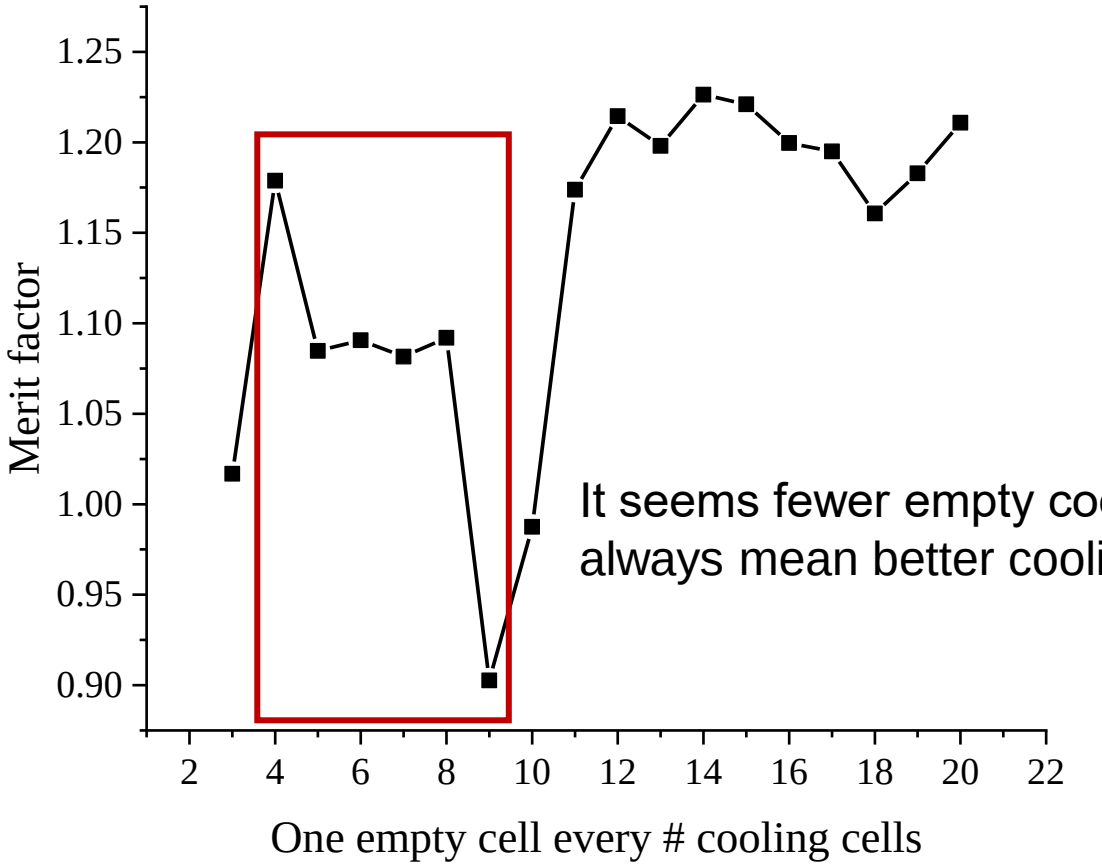
Empty cooling cells

No RF cavities and absorbers in empty cooling cells.
The empty cooling cells are for alignment and other beam instrumentation.

$$M(s) = \frac{T(s)^2}{\frac{\varepsilon_T(s)}{\varepsilon_T(0)}\sqrt{\frac{\varepsilon_L(s)}{\varepsilon_L(0)}}}$$

Error	Number of empty cells	ε⊥ (mm)	ε// (mm)	ε6D (mm^3)	Transmission	Merit factor
0	0	0.7082	2.569	1.367	0.9	1.32139
3	16	0.7749	3.425	2.079	0.875	1.01685
4	12	0.7354	2.921	1.668	0.889	1.17879
5	9	0.7875	2.954	1.925	0.881	1.08479
6	8	0.7811	2.984	1.95	0.883	1.09064
7	6	0.7496	3.14	1.887	0.862	1.08153
8	6	0.7536	3.005	1.83	0.856	1.09203
9	5	0.8306	3.646	2.722	0.859	0.90265
10	4	0.787	3.409	2.318	0.861	0.98751
11	4	0.7403	2.784	1.579	0.87	1.17382
12	4	0.7328	2.753	1.614	0.886	1.21443
13	3	0.7453	2.772	1.632	0.892	1.19802
14	3	0.7253	2.781	1.562	0.89	1.2263
15	3	0.7387	2.698	1.595	0.889	1.22106
16	3	0.7475	2.736	1.665	0.89	1.19963
17	2	0.7456	2.759	1.631	0.888	1.19497
18	2	0.7559	2.839	1.749	0.887	1.16065
19	2	0.7416	2.859	1.707	0.89	1.18288
20	2	0.7327	2.808	1.627	0.892	1.21078

Empty cooling cells



It seems fewer empty cooling cells don't always mean better cooling performance.

Conclusions

For the demo-like B-stage 5:

- The errors on the solenoid coils won't affect the cooling as long as they are not too huge.

- The errors on the gradient and phase of RF don't matter to cooling.