Magnetic field distribution for 400 MHz all-REBCO magnet after ferromagnetic shimming with sequential search design method

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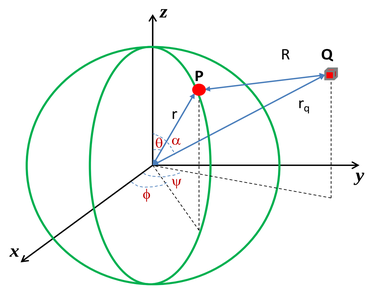
Background

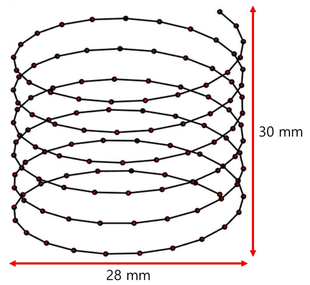
- It is difficult to shim the all-REBCO magnet because of the screening current induced field.
- Ferromagnetic shimming is one of very effective methods for all-REBCO magnet.
- The design with sequential search is a intuitive method and results can be obtained quickly.

Objectives

- Application of a ferromagnetic shimming to all-REBCO magnet .
- Ferromagnetic shimming design with sequential search method.
- Estimation of the magnetic field distribution for a 20 mm diameter spherical volume (DSV).

Theory





Helical mapping path

- Number of locations : 128
- Diameter : 28 mm
- Height : 30 mm
- Revolution : 6
- dρ : 17.0014 °

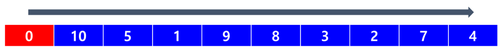
An iron piece @ point Q generates a magnetic vector potential at point P

$$\mathbf{B}_z = \mu_0 \frac{\chi \cdot dV \cdot H_z}{4\pi} \frac{1}{r_q^2} \sum_{n=0}^{\infty} \sum_{m=0}^{n} \varepsilon_m \frac{1}{{r_q}^n} \frac{(n-m+1)!}{(n+m)!} P_{n+1}^m(\cos\alpha)\ r^{n-1}(n+m) P_{n-1}^m(\cos\theta) \cos m(\varphi-\psi)\,\mathbf{z}$$

Sequential search design method

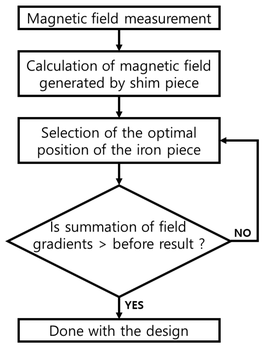
Theory

- Sequential search method checks each element that makes target value minimum.

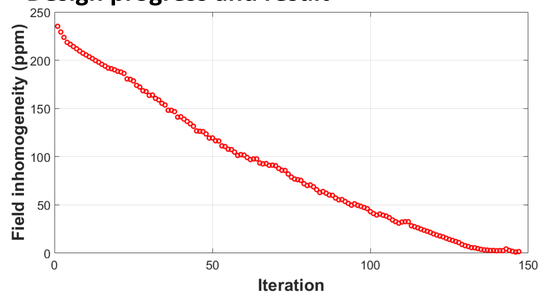


- Excluding one of the n variables, n-1 variables are fixed to improve the approximation point.
- Continue searching by selecting one of the n-1 variables fixed in the previous iteration.
- Select all coordinate directions sequentially and search them in n directions.

Flowchart



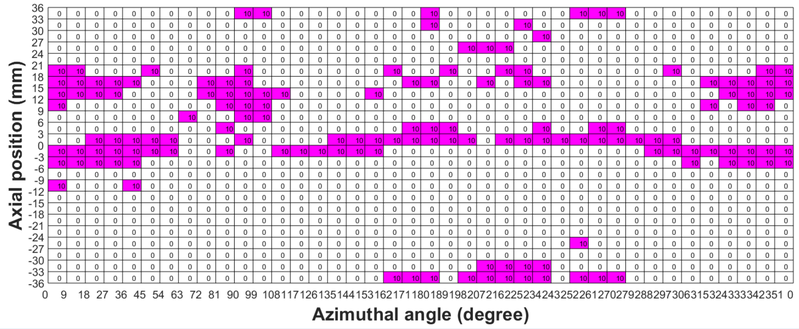
Design progress and result



- The field homogeneity(@ 20 mm DSV) can be improved with a total 146 processes from 241.06 ppm to 1.15 ppm.

Design result of the ferromagnetic shimming

Ferromagnetic shim set composed of iron pieces



Specification of the design result

- Ferromagnetic shim set
  - Diameter : 66 mm
  - Height : 72 mm
  - Number of shim pieces : 146 (maximum 960)
- Shim elements
  - Width : 4.87 mm (azimuthal)
  - Height 3 mm (axial)
  - Thickness : 10 mil (= 0.254 mm) only
  - Estimated result @ 20 mm DSV : 1.15 ppm

400 MHz all-REBCO magnet

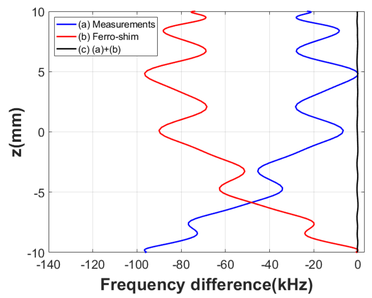
400 MHz all-REBCO magnet

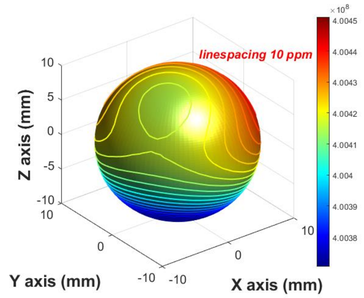
- Operating current : 185 A
- Operating temperature : < 20 K (conduction cooling system)
- Inner diameter :100 mm
- Outer diameter : 146.8 mm
- Height : 510 mm
- Number of DPs : 48
- Inductance : 10.3 H

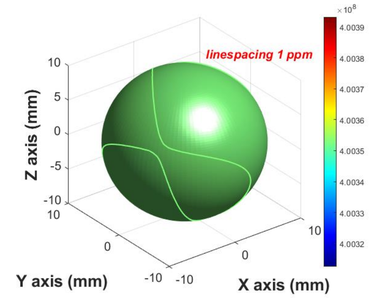
Conclusion

Estimation of field distribution @ 20 mm DSV

Gradient	order	Unit	Virgin	Ferro-shim	After shimming
Z0	0	MHz	400.41	-0.06	400.35
Z1	1	Hz/cm	34331.52	-34349.00	-17.49
X			-12291.33	12306.88	15.55
Y			-4745.30	4639.53	-105.77
Z2	2	Hz/cm^2	-26750.07	26717.43	-32.64
ZX			-2357.74	2409.71	51.98
ZY			-2887.79	2871.61	-16.18
C2			1201.82	-1291.44	-89.63
S2			-1633.43	1673.05	39.62
Z3	3	Hz/cm^3	2335.07	-2370.88	-35.81
Z2X			-2884.93	2861.77	-23.16
Z2Y			-4153.34	4037.70	-115.63
ZC2			288.56	38.92	327.47
ZS2			973.63	-997.67	-24.04
C3			-155.24	101.62	-53.62
S3			-201.92	173.22	-28.70
Field homogeneity		ppm	241.06	N/A	1.15







- The magnetic field was measured with 3-D field mapping experiment and ferromagnetic shimming simulation was performed.
- The ferromagnetic shimming design using sequential search method was developed, and the result capable of improving the field homogeneity 241.06 ppm to 1.15 ppm(@ 20mm DSV, 0.34 ppm @ 10 mm DSV) was obtained.
- It is necessary to conduct additional research and experiments to confirm the suitability and feasibility of the design method.