Design and Implementation of Ferromagnetic Shims for a 3-T 100 mm All-REBCO No-Insulation Magnet

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Background

❖ REBCO magnet has large screening-current-induced field.

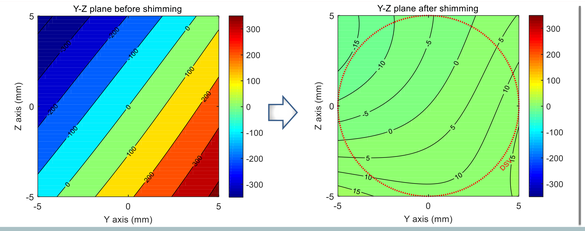
❖ Shimming technology is one of key technologies for all-REBCO NI magnet for NMR.

Objectives

❖ Design and implementation of ferromagnetic shims for a conduction-cooled 3-T 100 mm winding diameter no-insulation (NI) all-REBCO magnet

❖ More homogeneous magnetic field distribution only by ferromagnetic shimming without any active shims.

Conclusion

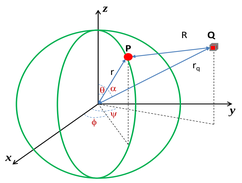


❖ Magnet field uniformity was drastically improved; from 634 ppm to 53.9 ppm.

❖ The results imply the first shimming test of all-REBCO no-insulation magnet, which will be a basis for our upcoming high-resolution all-REBCO NMR magnet currently being developed.

Shimming method

Theory



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

$$\Phi = -\frac{\chi \cdot dV \cdot H_z}{4\pi} \cdot \frac{1}{r_q^2} \cdot \sum_{n=0}^{\infty}\sum_{m=0}^{n} \varepsilon_m \frac{(n-m+1)!}{(n+m)!} P_{n+1}^m(\cos\alpha)\left(\frac{r}{r_q}\right)^n P_n^m(\cos\theta)\cos[m(\phi-\psi)]$$

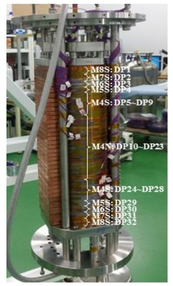
$$\mathbf{B}_z = \mu_0 \cdot \frac{\chi \cdot dV \cdot H_z}{4\pi} \cdot \frac{1}{r_q^2} \cdot \sum_{n=0}^{\infty}\sum_{m=0}^{n} \varepsilon_m \frac{1}{r_q^n} \frac{(n-m+1)!}{(n+m)!} P_{n+1}^m(\cos\alpha)\, r^{n-1}(n+m) P_{n-1}^m(\cos\theta)\cos m(\phi-\psi)\mathbf{z}$$

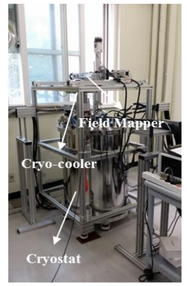
Experimental setup

3-T all-REBCO magnet

❖ Specifications
- No-Insulation
- Multi-width (4.1~8.1mm)
- Conduction cool (< 20 K)

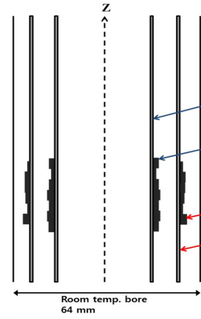
- B_0: 3 T (130 MHz)
- I.D.: 100 mm
- O.D.: 115.36 mm
- Inductance : 465 mH
- I_{op}: 201 A
- RT bore: 64 mm

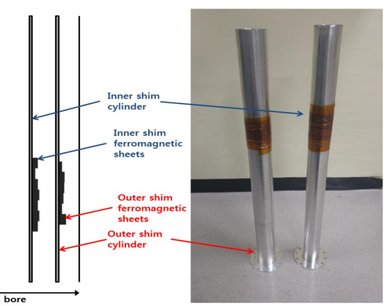




Shim set structure

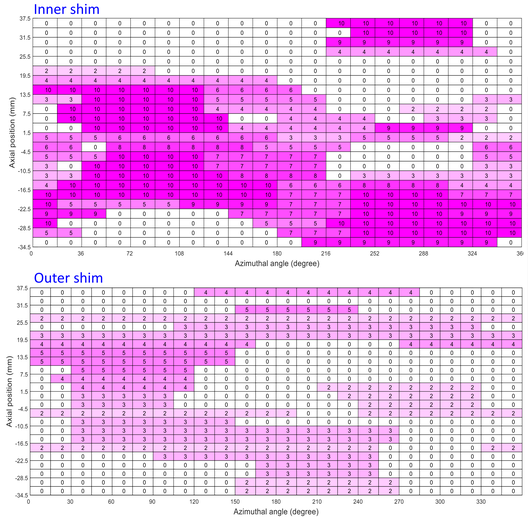
❖ **Double-layer shim**
- Inner shim:
  - Ø 54 mm
  - Each shim size: 8.48 mm (w) x 3 mm (h)
  - 480 possible positions
  - Max. thickness: 10 mi. (0.25 mm)
- Outer shim:
  - Ø 60 mm
  - Each shim size: 7.85 mm (w) x 3 mm (h)
  - 576 possible positions
  - Max. thickness: 5 mil. (0.125 mm)





Results

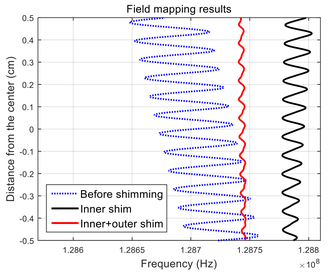
Design result of shim-sets

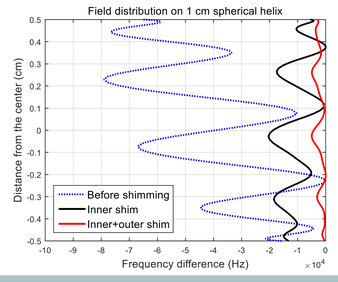


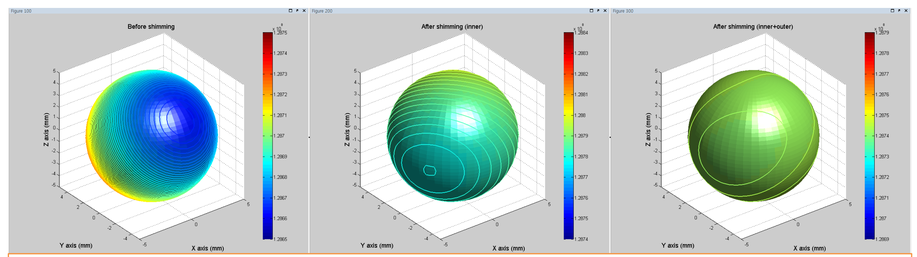
Field mapping & shimming

	Before shim	Inner shim	I&O shim
Z0 (MHz)	128.70	128.79	128.74
Z1 (Hz/cm)	-48523.95	7850.8	-2520.06
X (Hz/cm)	798.85	-13170.7	-2690.52
Y (Hz/cm)	-63964.78	-11596.4	-2719.96
Z2 (Hz/cm^2)	-2716.68	4941.2	1554.95
ZX (Hz/cm^2)	-11553.2	-7658.3	2490.85
ZY (Hz/cm^2)	-3788.19	-9616.2	-3441.17
C2 (Hz/cm^2)	-2343.05	-3737	-2032.85
S2 (Hz/cm^2)	1691.7	1351.6	-1375.65
Z3 (Hz/cm^3)	-2833.3	458.7	1161.73
Z2X (Hz/cm^3)	-490	4388.3	5479.61
Z2Y (Hz/cm^3)	5044.23	623.1	6387.84
ZC2 (Hz/cm^3)	-226.27	194.9	1632.67
ZS2 (Hz/cm^3)	1058.06	584.6	-2085.69
C3 (Hz/cm^3)	2213.29	1781	505.24
S3 (Hz/cm^3)	2254.22	-643.4	-843.52
ppm	**634**	167.71	**53.92**

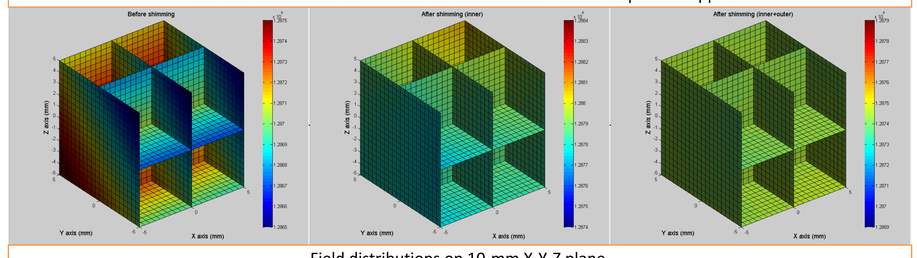
Field gradients before and after shimming.







Field distributions on 10-mm DSV surface: Contour lines are spaced 10 ppm.



Field distributions on 10-mm X-Y-Z plane.

Presented at the MT-25, 2017 Aug. 29; Session: D1 - Magnets for NMR; Program I.D. number:Tue-Af-Po2