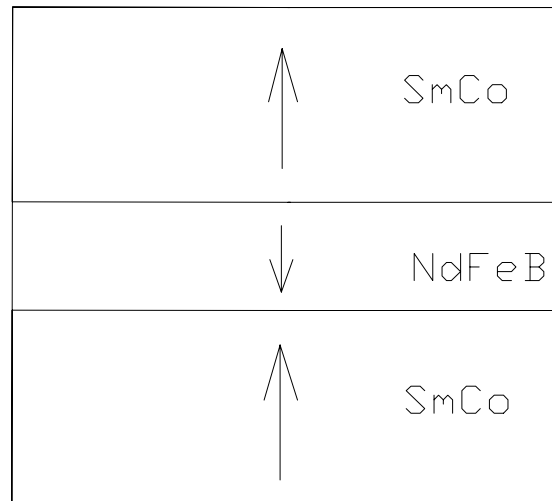


The method of temperature compensation for permanent magnet final focus quadrupole.



Temperature compensated permanent magnet combined element.

Temperature compensation with addition of NdFeB material of opposite direction of magnetization to SmCo material.

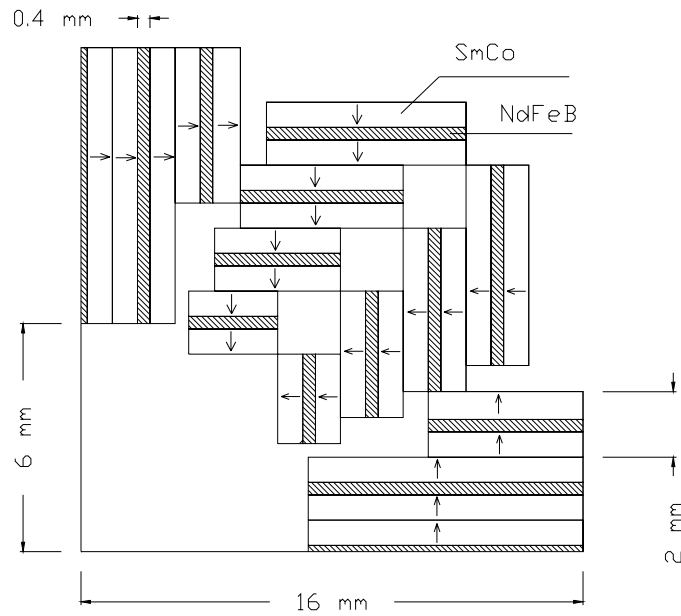
Required condition:

$$\text{temperature coef.}_{\text{SmCo}} \times \text{PM volume}_{\text{SmCo}} \times \text{Br}_{\text{SmCo}} = \text{temperature coef.}_{\text{NdFeB}} \times \text{PM volume}_{\text{NdFeB}} \times \text{Br}_{\text{NdFeB}}$$

Temperature coefficient of Br:

for SmCo material is 0.0003/degree

for NdFeB material is 0.0011/degree



Quadrupole lens consisted from combined Permanent magnet elements.
(only $\frac{1}{4}$ cross-section is shown)

General parameters:

Inner diameter	5 mm
Outer diameter	16 mm
Gradient	100 T/m

Parameters of combined elements:

Thickness of SmCo material	1.6 mm
Thickness of NdFeB material	0.4 mm
Remanence field of SmCo material	1.1 T
Remanence field of NdFeB material	1.2 T

Field changing at radius of 5 mm for temperature changing of 10 degree is 0.2 G.

Field changing at same temperature changing for quadrupole without temperature compensation is 15 G $(G \times R \times \text{temp. coef.} \times \Delta T)$

Harmonic content for quadrupole.

Radius=5 mm

$$By = A_n \cos(n \cdot f) + B_n \sin(n \cdot f)$$

n	An	Bn
0	0.000000	0.000000
1	-4.58319	0.000000
2	0.000000	0.000000
3	-0.0164859	0.000000
4	0.000000	0.000000
5	0.0548909	0.000000
6	0.000000	0.000000
7	-0.0202780	0.000000
8	0.000000	0.000000
9	0.0884673	0.000000
10	0.000000	0.000000
11	0.0116353	0.000000
12	0.000000	0.000000
13	0.0238908	0.000000
14	0.000000	0.000000
15	0.0285650	0.000000
16	0.000000	0.000000
17	0.143999	0.000000

Changing harmonic content for temperature changing of 10 degree.

Radius=5 mm

$$By = A_n \cos(n \cdot f) + B_n \sin(n \cdot f)$$

n	An	Bn
0	0.000000	0.000000
1	0.000248359	0.000000
2	0.000000	0.000000
3	1.08754e-005	0.000000
4	0.000000	0.000000
5	0.000110083	0.000000
6	0.000000	0.000000
7	-3.14438e-005	0.000000
8	0.000000	0.000000
9	-5.48694e-005	0.000000
10	0.000000	0.000000
11	-2.56871e-005	0.000000
12	0.000000	0.000000
13	8.17931e-005	0.000000
14	0.000000	0.000000
15	1.22594e-005	0.000000
16	0.000000	0.000000
17	7.99828e-005	0.000000