Permanent Magnet Quadrupole Lens with Variable Strength

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• PMQ, iPMD (saturated iron PMQ)
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Halbach's dipole REC magnet.

1.37 T @\(r_1\), \(r_2=1\) cm, 4 cm

\[ B = B_r \ln \left( \frac{r_1}{r_2} \right) \cos \left( \frac{\pi}{M} \right) \sin \left( \frac{\pi}{M} \right) / \pi \]
• SuperPMD

Modified Halbach's magnet.

1.64 T @r_1, r_2=1cm, 4cm (was 1.37T)
• 4.45T Dipole

Achieved 4.45T @-29°C  (3.9T @room temperature)

M. Kumada et al.,  CERN Courier, vol. 41, no.7, Sep. 2001, p. 9
PMQ & iPMQ – Gradient (Field plot)

\[ B = 2B_r \frac{(1-r_1/r_2)}{M} \cos^2(\pi/M) \sin(2\pi/M) / (2\pi/M) \]

\[ B_x \text{ (iPMQ1 w/Permendur)} \]
\[ B_x \text{ (iPMQ w/Fe)} \ [T] \]
\[ B_x \text{ (PMQ16)} \ [T] \]

- ID: ø20
- OD: ø240

Fe

with Fe 2.4 [T/cm]
with Permendur 2.5 [T/cm]
PM only 2.2 [T/cm]
• IP

Superconducting Q  Room temp. Q
need some merging for leaving beam
Let the beam go through

Beam pipe for leaving beam?
5~10cm/unit —> 20~40 units/2m
... some units may be fixed

Strongest: F F F F F F F F F F F F F

Middle 1: F F F D F D F D F D F D F D F

Middle 2: F D F D F D F D F D F D F D F

Weakest: F D F D F D F D F D F D F D F

Stepwise variable
Higher resolution by binary increment of the length: 1, 2, 4, ... cm

Centroid move
- X-Y stage supplied by NanoControl Co.Ltd.

Piezo Actuator
stroke: $15\mu m / 2cm$

Supersonic Motor or Pneumatic system
• Some issues

- Strength: $10^{-5}$ ?
- Displacement: 0.2 nm ?
- Rotation (skew): $3\mu$ rad ?

Above three needs temperature compensation

- Step size?
- Multipole component? (dodecapole)

- Radiation damage?
- Temperature coefficient?
- Helical Quadrupole (round beam)?
- Temperature Coefficient Compensation

Basic idea from E. Antokin

NdFeB: $-0.11\%/{ }^\circ C$
SmCo: $-0.03\sim0.04\%/{ }^\circ C$

$\{ \}$ x4 difference

![Diagram showing heat source along the axis with SmCo, NdFeB, SmCo layers and their ratio 2:1:2]
• Quad center monitor

Accuracy of $10^{-4}$ may locate the magnetic center with $5 \text{ mm} \times 10^{-4} = 0.5 \mu\text{m}$ or better including multipoles.

Radiation damage?
Drifts?