Shielding the Beam Pipe

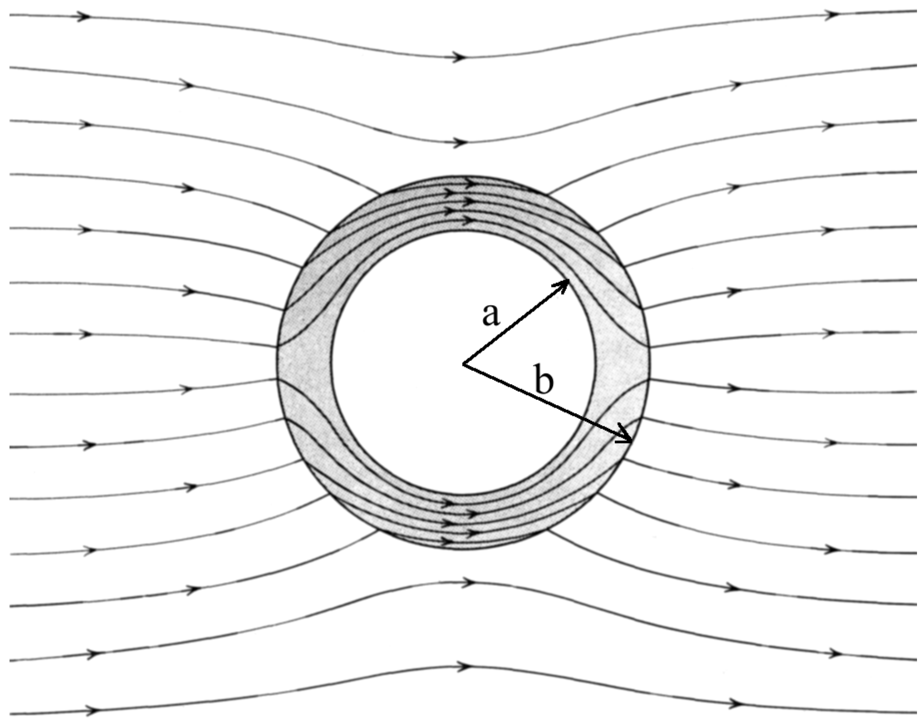
Rick Baartman, TRIUMF

October 24, 2011

Basic E&M

Familiar
pic at right (borrowed from Jackson).

In polar
coordinates (r, θ), with $\theta = 0$ being the direction of the external field B_0, the field in the shielded region $r < a$ is uniform and a constant:



$$B_i = \frac{4\mu}{(\mu+1)^2 - (a/b)^2(\mu-1)^2} B_0$$

(where μ is the relative permeability) while the maximum field in the shield material is

$$B_\mu = \mu B_i$$

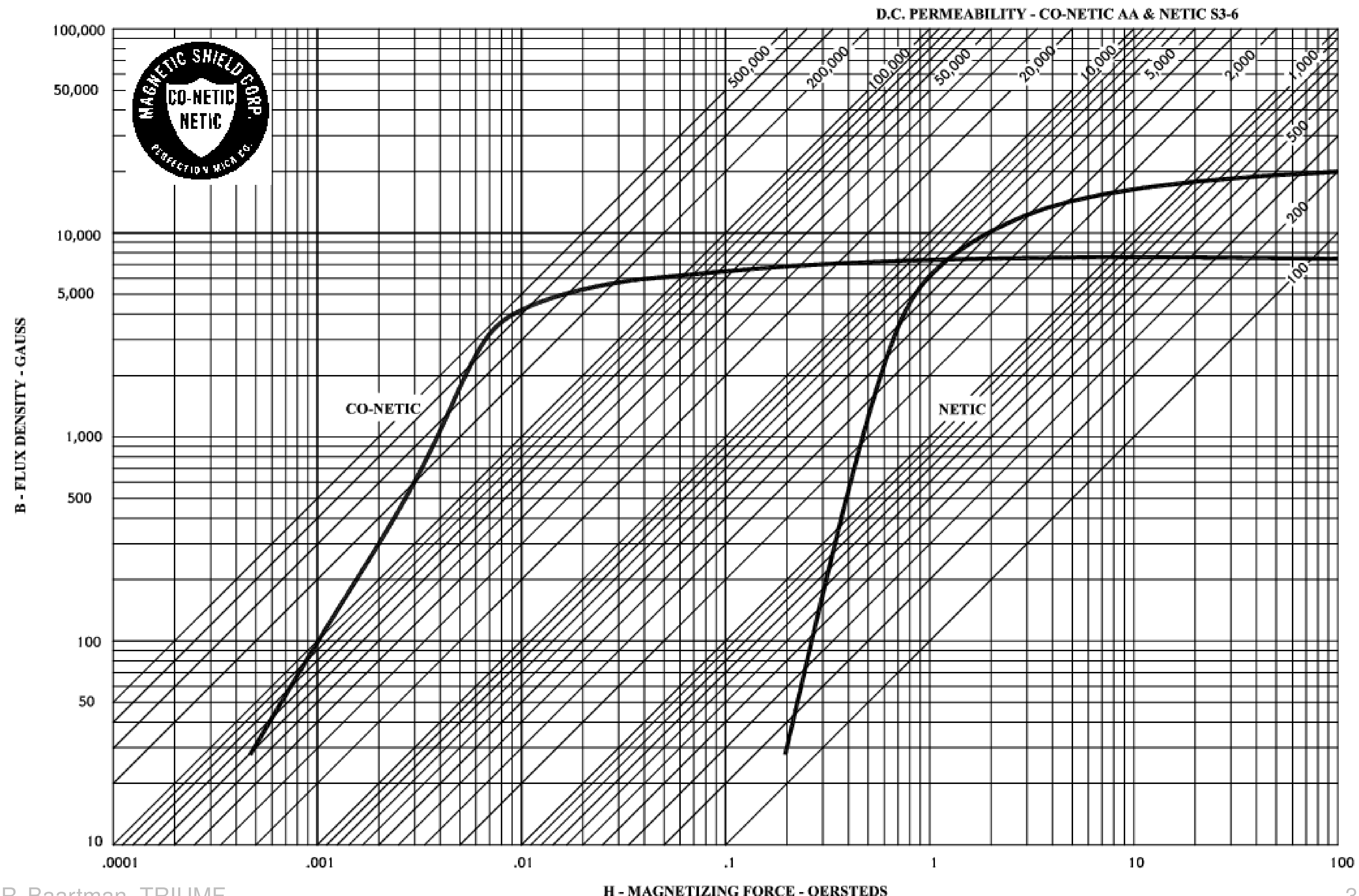
Let t be the thickness $b - a$. Then in the limits $t \ll b$, $\mu \gg 1$, we have much simpler formulas:

$$B_i = \frac{2}{\mu}\,\frac{b}{t}\,B_0 \;\text{ and }\quad B_\mu = 2\,\frac{b}{t}\,B_0$$

Roughly, the ambient field at worst is $B_0 \sim 3$ G. As originally envisaged, we want $B_i < 0.1$ G. We choose the standard material (commonly referred to as "Mu-metal"), which has $\mu \sim 10^5$, see "CO-NETIC" in figure below. (Co-netic AA is the trade name used by Perfection Mica Co. for Supermalloy.) The permeability is ill-defined as, owing to the irreversibility, B and H are not proportional.

This is available in foil with adhesive backing. (Catalog here.) Let us choose $t = 0.10$ mm, since it is easy to handle and contributes little to the beam pipe size. We know $b = 26$ mm, so

$$B_i = 16\,\text{mG, and } B_\mu = 1.6\,\text{kG.}$$


D.C. PERMEABILITY - CO-NETIC AA & NETIC S3-6
MAGNETIC SHIELD CORP.
CO-NETIC
NETIC
PERFECTION MICA CO.
100,000
50,000
10,000
5,000
1,000
500
100
50
10
B - FLUX DENSITY - GAUSS
.0001
.001
.01
.1
1
10
100
H - MAGNETIZING FORCE - OERSTEDS
500,000
200,000
100,000
50,000
20,000
10,000
5,000
2,000
1,000
500
200
100
CO-NETIC
NETIC

Notice that the 1.6 kG field in the material is independent of μ. Happily, this is well below saturation.

Looking at the permeability curves, we see that μ is more nearly 3×10^5, and so $B_i \sim 5$ mG. Further, the coercive force appears to imply fields less than a mG, so I conclude that coercivity will not contribute appreciably. (The manufacturer provides a calculator, and this finds for 2-inch dia. shield in 3 G field: $B_i = 4.3$ mG, in agreement.)

Near the Quadrupoles

What will be the effect near quadrupoles?

It would be preferred to keep the shielding material well away from the quadrupole field, since as little as $10\,$G will saturate the shield.

Scaling from the 12Q12 field survey results, the fringe field would be $1/10$ the peak field at a distance $47\,$mm from the quad centre, and dropping a factor of 2 every $10\,$mm. Most quads are at integrated strength of $\sim 0.2\,$T, with the peak field being $\sim 0.1\,$T. To drop a factor 100 to $10\,$G, requires a distance of $77\,$mm, meaning that the shield interruption is $154\,$mm in length. As the quad spacing is $2\,$m, the ambient field ($3\,$G) is on average

$$\overline{B} = \frac{154\,\mathrm{mm} \times 3\,\mathrm{G} + (2000 - 154)\,\mathrm{mm} \times 0.0043\,\mathrm{G}}{2\,\mathrm{m}} = 0.23\,\mathrm{G},$$

which is larger than the desired $0.1\,\mathrm{G}$.

Compensation

A possible solution is to compensate the field in the non-shielded regions. Simple Helmholtz coil loops can be used. As the quads are $R_w = 224/\sqrt{2}$ mm axis to edge distance, the Helmholtz radius R that fits over the quad to give the necessary layout (coil loop separation $= R$) is given by:

$$R = \frac{2}{3} R_w = 106\,\mathrm{mm},$$

but we inflate this by 15 mm to allow for wire thickness, etc.

The well-known field formula

$$B = \frac{\mu_0 I}{R} \left(\frac{4}{5} \right)^{3/2}$$

gives

$$I = 40\,\mathrm{A}.$$

Compensation/Steering

This could be achieved with a pair of single loops, or divided in 10-100 turns to optimize power supply cost.

We could run many in series in regions where the ambient field is constant, or set individual currents, and this may obviate the need for some of the Radiabeam correctors.

They will certainly be cheaper and more convenient than those correctors, plus this would free up some space along the beam.