Magnetic Shielding of PMTs II

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Some Magnetic Basics

• Physics education stresses magnetic fields by themselves.

• Iron perturbs B fields in a way that is highly nonlinear, and usually left out of books on E&M.

• The Maxwell stress tensor explains a lot,

\[
T = \frac{\varepsilon_0}{2} \begin{bmatrix} E^2 & 0 & 0 \\ 0 & -E^2 & 0 \\ 0 & 0 & -E^2 \end{bmatrix}, \quad \text{or,} \quad T = \frac{1}{2\mu_0} \begin{bmatrix} B^2 & 0 & 0 \\ 0 & -B^2 & 0 \\ 0 & 0 & -B^2 \end{bmatrix}.
\]

Stated another way, “The field transmits a tension \(\varepsilon_0E^2/2\) (or, \(B^2/2\mu_0\)) parallel to the direction of the field and a transverse pressure of magnitude \(\varepsilon_0E^2/2\) (or, \(B^2/2\mu_0\)) transverse to the direction of the field.”
Iron makes things complicated.

- The maximum B field within iron is around 2T.
- It provides a low reluctance path for magnetic field lines.
- Ferromagnetic materials have a range of properties.
A quickie way of estimating stresses.

• While software can be useful, it helps to know what is going on.

• Nonlinear problems are hard to solve, this gives a worst case.

\[
\frac{B^2}{2\mu_0} \text{(Area)}, \quad \text{with} \\
\frac{B^2}{2\mu_0} = \text{Pressure}_{\text{Atm}} = 4B_{\text{T}}^2, \quad \text{(and } B=2)\]
Shielding basics.

• Our geometry has high fields, and PMT's don't like them. => Need attenuations ~ 100

• Software can be useful, particularly. TOSCA and ANSYS.

• Analytical solutions can be relevant, Inf. cylinder

\[ \text{Attenuation} = 1 + \frac{\mu t}{4r} \left(2 - \frac{t}{r}\right), \]

• Simple, scale models can also very useful.

• The ultimate nonlinear problem – if you do it right.
Tubes shield transverse fields better than longitudinal.

- End effects are complicated.
- Transverse fields similar to dipole fringe fields, Enge, RSI, 35 ('64) 278.
The alloy, and the annealing, matters.

- 1010 Steel, mumetal and grain oriented steel should be useful
Suggestions

• I did numerical and experimental studies of shielded beam pipes exposed to high transverse fields for a microtron design, and a magnetic septum that used an iron tube almost within the gap of a dipole magnet to shield low energy (15 MeV) electron beams.

• Useful tips:
  - Small experimental models can be very useful.
  - The problem is complex. There are many variables: tube size and type, orientation, how many layers to use, alloy, heat treatment.
  - An elegant design, with efficient use of iron in a complex geometry, is tricky
  - The degree of the saturation of the iron is usually the crucial parameter.
  - The degree of saturation can be measured by putting thin, ferromagnetic shims in the shield tubes. These will stick to the interior of tube if it is close to being saturated, and not stick if it is unsaturated.
  - Models give a feel for the problem that you don’t get with software.