Sensitivity of Fields within Magnetically Shielded Volumes to Changes in Permeability

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Abstract

Future experiments seeking to measure the neutron electric dipole moment (nEDM) require stable and homogeneous magnetic fields. The stability of the magnetic field within a magnetically shielded volume is influenced by a number of factors. In this paper, we study one of these factors, which is the dependence of the internally generated field on the permeability of the material. We also provide measurements of the temperature-dependence of the permeability of the material, and indicate the extrapolation yet required to adequately use these measurements to design future nEDM experiments.

Keywords: Magnetic Shielding, Neutron Electric Dipole Moment, Magnetic Field Stability

1. Introduction

The next generation of neutron electric dipole moment (EDM) experiments aim to measure the EDM d_n with proposed precision $\delta d_n \lesssim 10^{-27}$ e-cm [1, 2, 3, 4, 5, 6, 7, 8, 9]. In the previous best experiment [10], which discovered $d_n < 2.9 \times 10^{-26}$ e-cm, effects related to magnetic field homogeneity and instability were found to dominate the systematic error. A detailed understanding of passive and

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Preprint submitted to Nuclear Instruments and Methods in Physics Research A May 25, 2016

active magnetic shielding, magnetic field generation within shielded volumes, and precision magnetometry is expected to be crucial to achieve the systematic error goals for the next generation of experiments. Much of the R&D effort for these experiments is focused on careful design and testing of various magnetic shield geometries with precision magnetometers [11, 12, 13, 14, 15].

- General requirements on field, stability of field, stability of gradient.
- List all possible factors that can affect field stability - degaussing, vibrations, etc. possibly with additional references.
- State the problem addressed in this paper (changes in μ) and the result.

The nEDM experiment at TRIUMF aims to determine $\delta d_n \sim 10^{-27}$ e·cm. This level of precision requires a 1 μT magnetic field with the homogeneity of ¡ 1 nT/m and the stability of pT over the UCN free-precession time.

2. Sensitivity of Internally Generated Field to Permeability of the Shield $\boldsymbol{B_0(\mu)}$

2.1. Analytical Calculations in Spherical and Cylindrical Geometry

- State basic physics of problem, define reaction factor, note return flux through shield, etc.
- State formulae and results for reasonable parameters.
- Possibly one graph of $B_0(\mu)$ with both geometries.

2.2. Magnetostatic Simulation Results

- I think it would be easy to provide results in axisymmetric geometries from FEMM.
- If any result is available from OPERA, it could be included here.
- Results should be for a restricted set of possible nEDM coils.
- One graph?

2.3. *Self-Shielded Coils*

- Explain principle (reaction factor = 1, or no field at shield so no return flux)
- Simple analytic results - reaction factor is identically unity.
- FEMM/OPERA - demonstrate that sensitivity is reduced by factor of XX for simple geometry.
- One graph, or include on previous graph?

2.4. *Summary of $B_0(\mu)$*

Insert summary here.

3. Measurements of $\mu(T)$

3.1. *Previous Measurements and their Relationship to nEDM Experiments*

- Coucheron et al.?
- Krupp-VDM data sheet?
- Proper literature search on past measurements of $\mu(T)$.
- State caveats in order to use these: dependence on B, H, f.
- State typical B, H, f that nEDM needs. Motivates additional measurements.

3.2. *Axial Shielding Factor Measurements*

- Describe experimental setup and important considerations (e.g. relationship of data to effective μ)
- Explain B, H, f, and dominant systematic effects.
- One data graph? One figure of experimental setup?
- State overall result and systematic error.

3.3. Transformer Core Measurements

- Describe experimental setup and important consdierations (e.g. relationship of data to effective μ)
- Explain B, H, f, and dominant systematic effects.
- Understanding in terms of Jiles-Atherton. Complications that this does not translate well into "μ".
- One data graph? (Perhaps the Jiles-Atherton one?)
- State overall result and systematic error.

3.4. Summary of $\mu(T)$

Insert Summary Here.

4. Summary and Conclusions

- We determined $dB_0/d\mu$. For reasonable parameters its $\sim$ XXX. For self-shielded it's reduced by a factor of XXX for realistic windings.
- We measured $d\mu/dT$. We constrained it to be in the range 0.1 to 2.3 percent per Kelvin. Dominant errors are XXX for each method. Neither method is for correct B, H, f. Both methods are very difficult to achieve consistent sub-percent determinations, but tend to agree on sign and magnitude of problem.
- Results imply temperature stability to XXX Kelvin for stability goal of XXX pT. Show that this could be a dominant issue for stability for future experiments. Not addressed by many other measurements which tend to focus on stability at zero field or overall stability in full EDM experiment.
- Future work: build full EDM experiment. Capability of various internal coil geometries and best achievable temperature stability are both important to success.

5. To Do List

1. Collect graphs and figures.
   (a) Analytical comparison reaction factor vs. μ for sphere and/or cylinder with reasonable geometry/μ.
   (b) Same or additional comparison for more realistic geometry in simulation. May include self-shielded geometry.
   (c) Axial shielding factor figure of setup.
   (d) Axial shielding factor data.
   (e) Transformer core Jiles-Atherton comparison?
2. Write.

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