SURF Progress Report 1: Effects of superconducting lead endcaps on boundary conditions of magnetic fields

Aritra Biswas, with Filippone Group
W.K. Kellogg Radiation Laboratory, California Institute of Technology

I. MOTIVATION

The discovery of charge-parity symmetry (CP) violation in the decay of neutral kaons has incited various attempts to extend the Standard Model.[1] Measurements of the electric dipole moments of various particles provide important restrictions on these attempts and could guide these reformulations.[2]

Previous efforts[2] to determine the electric dipole moment of the neutron (nEDM) have yielded a numerical limit of $|d_n| < 2.9 \times 10^{-26} e$ cm. The nEDM collaboration intends to improve this limit[3] by measuring the behavior of trapped ultra-cold neutrons (UCN) in a magnetic field. The experiment is currently being modeled at half-scale at Caltech.

Determining the nEDM involves observing neutron movement in a magnetic field that must be uniform; if not, a "geometric phase effect" creates the same shift in Larmor precession that would be measured if there were an EDM, thus creating the semblance of a false EDM.[5] The primarily experimental challenge is to create a contained magnetic field that can be controlled to point uniformly along a specific direction. To eliminate the influence of the Earth's field and other interference, and to contain the field, the setup is surrounded by a cylindrical superconducting lead shield. While this method shields the center of the experimental setup well, it can create undesired behavior in the magnetic field profile at the circular faces of the cylinder, which were previously not covered with superconducting material.

We plan to cover the faces of the cylinder with superconducting lead endcaps to create favorable boundary conditions for the magnetic field. While various styles of bridging the gap between the cylinder and the endcaps for the nEDM experiment have been explored,[4] further measurements are required to determine the effects of these endcaps on the boundary conditions of the magnetic field.

A fuller understanding of these effects is critical to controlling the magnetic field and addressing potential challenges in the final nEDM experiment before they arise.

II. EXPERIMENTAL SETUP

The half-scale model magnet model at Caltech, shown in Figure 1, consists of various cylindrical shells placed inside each other. The innermost structure is a G-10 plastic rod holding a 3-axis magnetic probe; these are encircled by a warm bore cylinder and a liquid nitrogen thermal shield.

out-eps-converted-to.pdf

FIG. 1. Stylized diagram of the experimental setup.

Surrounding this foil is an acrylic structure with various coils of wire arranged in a $\cos\theta$ coil geometry to approximate a sheet current and produce the desired magnetic field profile.[5] These coils are collectively referred to as the B_0 coil.

Each individual current in the B_0 coil, including shimming coils necessary for correcting non-uniformities in the field,[5] is controlled through a NI LabView Virtual Instrument (VI).

The B_0 coil is covered by a cylindrical Metglas 2705M magnetic alloy which serves to redirect the horizontal magnetic field from the B_0 coil vertically along the surface of the Metglas. Surrounding this layer is the the superconducting lead cylinder, to which the endcaps in question will be attached. The external cryostat shield surrounds this structure.

The bottom endcap is a G-10 annulus with a wall along the outer edge; this forms a "cup" shape with an access hole at the bottom. A lead sheet is fitted along the underside of the annulus and around the outside face of the wall, creating an enclosure over the top of the wall. The top endcap, while designed, has not yet been installed.

Along the lead shield are several helium cooling lines. While there are no cooling lines directly on the bottom endcap, the endcap sits on an aluminum plate which has cooling lines underneath it. This aluminum plate serves endcap.png

FIG. 2. The lead shield and the attached bottom endcap.

as a base for the entire setup and bears the weight of the B_0 coil, the Metglas shield, the lead shield, and the bottom endcap (totaling approximately 500 lbs), and will also cool the bottom endcap by contact.

Temperature probes are installed at various points, including on the B_0 coil, on multiple areas of the lead shield, and on multiple areas of the bottom lead endcap. Lakeshore DT670 silicon diode temperature sensors are used on the endcap.

III. PROCEDURE AND MEASUREMENTS

Over several hours, the cryostat will be evacuated for thermal insulation and the cooling lines will bring the lead shield to below superconducting temperature (4 K).

To assess the effectiveness of the bottom endcap design, we will measure its temperature over time. Although contact cooling in a vaccuum is difficult, because of the 500 pounds of normal force between the cooled aluminum plate and the lead endcap, we expect the thermal contact to be sufficient to bring the lead endcap to the desired superconducting temperature. If the contact is unsuitable, we will explore alternatives such as improving the contact surface with thermal grease or considering alternative endcap designs where the endcap is cooled directly.

We will conduct measurements of the magnetic field gradient at multiple points near the bottom endcap and compare these gradients with measurements obtained from the center of the apparatus and with previous measurements taken before the endcap was installed. These gradient comparisons will allow us to determine the general effectiveness of the endcap in generating favorable boundary conditions (uniformity of the field); in addition, they will provide an additional method to ensure that the bottom endcap is indeed superconducting.

The collection of magnetic probe data is carried out in another LabView VI. Data is collected for the magnetic fields along three axes to create B_x, B_y, and B_z arrays, each of which are plotted along the three spatial axes to create nine waveform graphs. We plan to analyze this data and create a model of the magnetic field behavior near the endcap compared to its behavior in other parts of the setup.

After examining the results, we will consider the effectiveness of the current endcap design, which could prompt modifications. Measurements will be repeated for the top endcap once it is installed to create a comprehensive profile of the changes caused by these endcaps in the boundary conditions of the field.

IV. PERSONAL WORK STATUS

Since November 2013, my work in this experiment has involved:

- editing and developing the LabView VI used for field monitoring and shimming to synchronize magnetic field measurement sampling rates,
- developing tools, including a new VI, to compare magnetic field mapping data from various runs, and
- assisting with the installation of the bottom endcap and re-assembly of the setup, including reconfiguring temperature sensors.

A potential checklist for the summer will include:

- finishing the development of the aforementioned tools necessary to compare magnetic fields mappings,
- assessing the effectiveness of the thermal contact between the bottom endcap and the support plate,
- comparing the magnetic field profiles at the boundary near the installed endcap vs. at the center of the B_0 coil,
- comparing the magnetic field profile of the post-endcap setup vs. the previous setup,
- assisting with the construction of a top endcap, its installation, and re-assembly of the setup,
- repeating magnetic field comparisons for the top endcap, and
- developing numerical data analysis tools as necessary.

These steps lead to a better understanding of the effect of superconducting endcaps on the magnetic field in our model. The results will be key to the planning of the nEDM experiment and could prove useful to other particle physics experiments using similar superconducting endcaps.

---

[1] Cronin, J. "Nobel Lecture: CP Symmetry Violation The Search for Its Origin," Nobel Media AB (2013).

[2] Baker, C. A., D. D. Doyle, P. Geltenbort, K. Green, M. G. D. Van der Grinten, P. G. Harris, P. Iaydjiev et al. "Improved experimental limit on the electric dipole moment of the neutron." *Physical Review Letters* 97, no. 13 (2006): 131801.

[3] "Search for the nEDM at Caltech." Kellogg Radiation Laboratory ⟨krl.caltech.edu⟩ (2014).

[4] Malkowski, S., R. Y. Adhikari, J. Boissevain, C. Daurer, B. W. Filippone, B. Hona, B. Plaster, D. Woods, and H. Yan. "Overlap Technique for End-Cap Seals on Cylindrical Magnetic Shields." *IEEE Transactions on Magnetics* 49, no. 1 (2013): 651-653.

[5] Perez Galvan, A., B. Plaster, J. Boissevain, R. Carr, B. W. Filippone, M. P. Mendenhall, R. Schmid, R. Alarcon, and S. Balascuta. "High uniformity magnetic coil for search of neutron electric dipole moment." *Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment* 660, no. 1 (2011): 147-153.