Development of A High Field Magnet for Neutrino Factory Storage Rings

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LDRD Project # 01-79

PURPOSE:

The purpose of this LDRD is to develop and demonstrate (to the extent possible by the level of funding) a dipole magnet design that allows a compact Neutrino Factory Storage Ring. Since the storage ring must be tilted a compact design would minimize the environment impact as the entire ring can remain above the ground water table at BNL with the top of the ring residing under a modest size artificial hill. In addition the magnet is being designed to minimize the energy deposition on the superconducting coils due to showers initiated by muon decay products.

APPROACH:

We are developing a new racetrack coil magnet design, with an open midplane gap, that keeps decay particles in a neutrino factory muon storage ring from directly hitting superconducting coils. This eliminates the need for an expensive "tungsten liner". These flat racetrack coils have a large bend radius in the ends that allows the use of "react and wind" magnet technology using Nb_3Sn superconductor.

TECHNICAL PROGRESS AND RESULTS:

After exploring several options, we have chosen and optimized the basic magnetic and mechanical design. The cross-section of this design is shown in Fig. 1. The superconducting collared coils inside a cryostat clear the magnet midplane region where most of the decay energy goes. A warm iron yoke structure around the coils then allows heat generated by decay particles to be removed efficiently at a higher temperature.

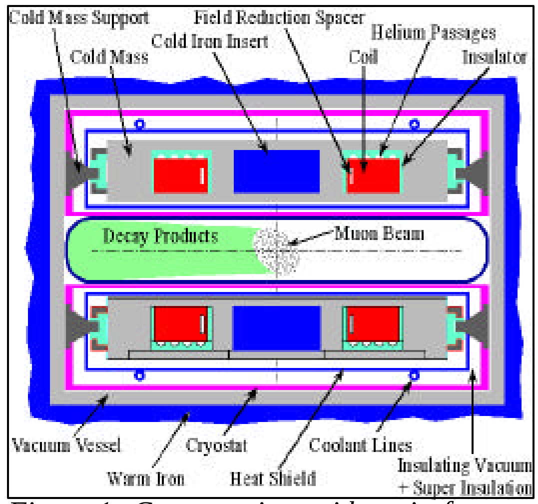

Figure 1: Cross section, with main features labeled, of neutrino factory muon storage ring magnet that avoids decay particles directly hitting superconducting coils.

The dipole operating field is 6.93 T and the design quench field is over 8 T for an operating field margin of over 15%. The maximum field on the conductor at quench is significantly higher than the central field and excludes using NbTi at 4.2 K. The coils therefore are made from brittle Nb_3Sn superconductor. A large bend radius in the ends and a simple pancake coil (racetrack) geometry allows the use of "react and wind" magnet technology.

The superconducting coils are contained in cold masses surrounded by a heat shield and cryostat. Large vertical forces, that could be either attractive or repulsive, depending on the configuration, are contained with the help of support keys mounted to the yoke. The overall magnet structure is designed to minimize the heat leak through the support keys while containing the large Lorentz forces. The finite element analysis codes were used to minimize the deflections and stresses on the superconducting coils and on the support structure.

To maintain field strength, we minimize the vertical distance between the coils and the beam cavity. The cryostat wall thickness is minimized on the side near the beam tube. The beam tube is warm and its thickness is as small as possible. Surrounding both cold masses and the beam cavity is an outer vacuum vessel that eliminates differential pressure on the cryostats and beam tubes and prevents them from collapsing under vacuum.

In FY 2002, we plan to complete the detailed engineering design of the magnet coils. In addition, we also plan to build and test the superconducting coils.

This project does not involve animal vertebrates and human subjects.

SPECIFIC ACCOMPLISHMENT:

We have developed a new magnet design that allows compact Neutrino Factory Storage Rings to be constructed at BNL site. It was observed, during the course of this LDRD, that a skew quadrupole lattice avoids the direct hit of a large number of decay particles on quadrupole magnets as well. A lattice with skew quadrupole has been developed and presented in the following paper:

B. Parker, Skew-Quadrupole Focusing Lattices and Their Applications, 2001 Particle Accelerator Conference, Chicago, 18-22 June, 2001.

In addition, a novel magnet system designed has been developed where all focusing is provided in the ends (see Fig. 2 and Fig. 3). This concept has been presented in the following paper:

B. Parker, M. Anerella, A. Ghosh, R. Gupta, M. Harrison, J. Schmalzle, J. Sondericker, and E. Willen, Magnets for a Muon Storage Ring, 2001 Particle Accelerator Conference, Chicago, 18-22 June, 2001.

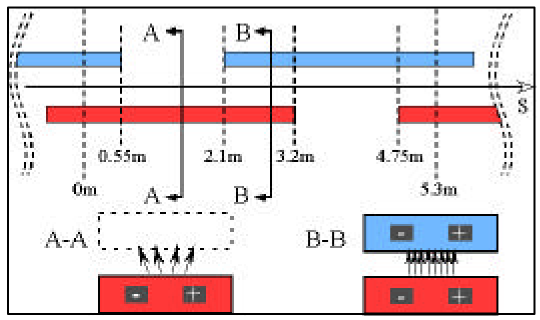

Figure 2: Design-A coil and cryostat layout schematic. Regions with no coil overlap, A-A, have half strength dipole field + skew quadrupole field. Full dipole field and no skew quadrupole occurs in overlap region, B-B.

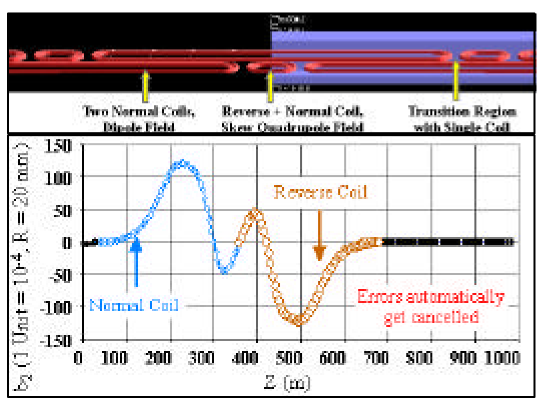

Figure 3: Design-B coil layout and an example of end harmonic cancellation. Since normal and reverse coils have same ends, their coil end field harmonics cancel.

In Fig. 2 (Design A), the coil packages are longitudinally staggered to provide focusing (F) or defocusing (D) skew quadrupole combined function magnets where there is only a single coil on the top or the bottom. A pure dipole field occurs in overlap regions. The dipole guide field in non-overlap regions is about half that in overlap regions. Thus, the structure has continuous bending and alternate gradient skew focusing. Space normally lost at coil ends and magnet interconnects is efficiently used.

In design B, we propose a novel approach of using small coils with reverse polarity. In addition to making a skew quadrupole, these reverse coils provide an automatic cancellation of normal and skew harmonics in the end region as shown in figure 3. The magnet cross section has been designed to produce a dipole field with a field error of only about one part in 10,000. This, however, still leaves an axial component of the field in the lattice.

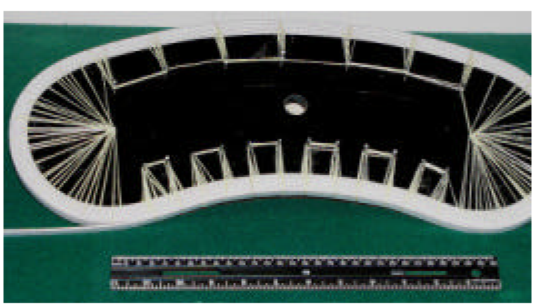

Figure 4: Winding technique for coils with reverse bends.

The coils for compact Neutrino Factory Storage Ring would have a considerable saggitta. Conventional coil construction techniques are not suitable for making coils with brittle material having a reverse curvature. A novel coil winding technique is being developed where the conductor is held in place with Kevlar strings. A successful test run of this concept is shown in figure 4. These curved coils will be vacuum impregnated. To this end we are adopting a "Vacuum Bag" technology for the first time in accelerator magnets.

The following are other significant publications that are based on the work performed under this LDRD:

S. Ozaki, R. Palmer, M. Zisman, and J. Gallardo ed., Feasibility Study-II of a Muon-Based Neutrino Source, BNL-52623 (2001).

N. Mokhov, C. J. Johnstone, B. Parker, Beam-Induced Energy Deposition in Muon Storage Rings, 2001 Particle Accelerator Conference, Chicago, 18-22 June, 2001.

In addition several talks are given by principle investigators at various meetings. These include Muon Collider Collaboration Meetings, Editorial Meetings on Neutrino Factory Feasibility Study, Symposium on Neutrino Factory Study II and presentations at Snowmass 2001.

LDRD FUNDING:

FY 2000	$98,000.00
FY 2001	$100,000.00