Project name

Radiation damage studies of materials and electronic devices using hadrons

Classification

Accelerator

Institutions and personnel

University of California Davis: Maxwell Chertok, David E. Pellett (professors)
SLAC: James E. Spencer, Zachary R. Wolf (staff scientists)
Fermilab: James T. Volk (staff scientist)

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Project Overview

Many materials and electronic devices must be tested for their abilities to survive in the radiation environment expected at the proposed linear collider (LC). Radiation-sensitive components of the accelerator and detectors will be subjected to large fluences of hadrons as well as electrons and gammas during the lifetime of the accelerator. Examples are NdFeB permanent magnets which are being considered for the damping rings and final focus, electronic and electro-optical devices which will be utilized in the detector readout and accelerator control systems and CCDs which will be required for the vertex detector.

UC Davis has two major facilities which can be used to provide needed information on hadron radiation damage, the McClellan Nuclear Reactor Center (MNRC), located in Sacramento (approximately 50 mi. round trip from the Davis campus), and the radiation test beam at the UC Davis Crocker Nuclear Laboratory (CNL) cyclotron (on campus).

The MNRC reactor has a number of areas for irradiating samples with neutron fluxes up to 4.5×10^{13} n/cm^{2}s. A specialized area allows irradiation with 1 MeV-equivalent neutrons in a flux of 4.2×10^{10} n/cm^{2}s while suppressing thermal neutrons and gammas by large factors. Other areas allow irradiating very large objects at lower fluxes. In conjunction with physicists from the University of Oregon, we have used MNRC to irradiate CCDs.

The CNL radiation test beam consists of protons of up to 63.3 MeV kinetic energy spread over a rather uniform beam spot 7 cm in diameter. A typical central flux is 4.2×10^9 protons/cm^{2}s (0.56 kRad/s (Si)). A secondary emission monitor calibrated with a Faraday cup is used to measure the beam fluence to an accuracy of better than 5%. The beam profile has been established by a variety of means, showing the dose to have fallen by only 2% at a radius of 2 cm. We have used the CNL facility for a wide variety of tests on electronic devices and detector components. The laboratory can also produce neutron beams of up to 60 MeV kinetic energy.

Description of first year project activities

In the first year, we plan to study radiation damage due to neutrons in samples of NdFeB permanent magnet materials using the MNRC facilities.

Permanent magnet beam optical elements have been in use in the SLC damping rings at SLAC since 1985. They are also candidates for use in final focus quads, damping rings, wigglers, and possibly elsewhere in the LC. It would be advantageous to use NdFeB for such magnets due to its lower cost and its higher energy product, $(BH)_{max}$, relative to SmCo. Its Curie temperature, T_C, is lower than that of SmCo, however, so one must evaluate the degradation of its magnetic properties due to radiation damage.

Neutrons from photonuclear reactions are an important source of radiation damage to permanent magnets at LC in beam tunnels and damping ring enclosures. The radiation doses have been estimated in the NLC beam tunnel using a simulation based on electron losses [1]. These losses create showers of secondary particles dominated by electrons, positrons, photons and neutrons. The neutron energy spectrum is broad but peaked near 1 MeV. In a region under a magnet, approximately 25 cm below the beam line, the equivalent fluence of 1 MeV neutrons (normalized to radiation damage in silicon) was estimated to be 1.9×10^{14} cm^{-2} for 10 years of operation. The magnets themselves are likely to see much higher neutron fluences, especially in other locations, such as the damping rings.

Brown and Cost [2] have shown that the remanence of NdFeB permanent magnets may be reduced significantly for neutron fluences of this order of magnitude and higher when irradiated at an elevated temperature (350 K). The rate of reduction with fluence depended on the magnet operating point during irradiation, the intrinsic coercivity of the material and the manufacturer of the material. It is necessary to characterize candidate materials for LC NdFeB permanent magnets using neutron fluences comparable to those expected during the useful life of the magnet. The proposed measurements appear to be unique in their ranges of coercivity, loading and neutron energies and to complement the measurements of Ito, *et al.* using 200 MeV protons [3]. This work must be started now for NdFeB magnets to be considered in the baseline LC design.

High doses of gammas and electrons are also present in these locations, of course, but the associated radiation damage is expected to be much less than from the neutrons. (SLAC is in a good position to verify this with candidate materials if desired. Samples of NdFeB have already been tested to a gamma dose of 277 kGy (Si).)

Measurements of the radiation environment are in progress in the SLAC damping rings that will allow us to estimate the neutron fluences in the LC damping ring magnets. These are being done on a time scale that is consistent with our proposed neutron damage measurements. Fermilab is also estimating beam loss distributions and particle fluxes for LC collimation systems which will help specify the requirements elsewhere.

For the NdFeB tests, simple assemblies of magnet blocks will be made at Fermilab or SLAC that fit into the reactor test chambers and provide as broad a variation in operating points over the different constituent blocks as possible. We plan to study materials with two different values of coercivity and from two different manufacturers. The damage due to 1 MeV-equivalent neutrons will be the focus of the study. The presence of ^{10}B in the material with its large thermal neutron capture cross section greatly increases the radiation dose delivered for a given thermal neutron fluence relative to fast neutrons, so this of interest as well. Thus, magnet assemblies will be irradiated and measured at increasing doses using 1 MeV-equivalent neutrons, supplemented with separate thermal neutron irradiations as necessary. After each dose, the induced radioactivity will be monitored by MNRC personnel. SLAC personnel will then transport the magnet assemblies back to SLAC to evaluate changes in magnetic properties. A Hall probe will be needed to monitor the magnetic fields at MNRC.

As an example, the times required at MNRC to reach a fluence of 10^{15} n/cm^2 are 7 hr for 1 MeV-equivalent neutrons and 30 min for thermal neutrons. An initial estimate shows that the radiation fields would be well below 1 mR/hr at a distance of 1 ft after such a thermal neutron irradiation for pure $Nd_2Fe_{14}B$. Some materials contain substantial percentages of Dy or Tb, however, which have large activation cross sections for thermal neutrons. This may limit our ability to irradiate samples with thermal neutrons in these cases.

We do not propose to test SmCo samples in this program. There is already a proof of principle for the use of SmCo in the SLC and evidence from Ito *et al.* [3] that the material is considerably more radiation-hard than NdFeB. Further, SmCo presents a severe handling and disposal problem due to the copious production of the long-lived radioactive isotopes ^{153}Sm and ^{60}Co by thermal neutrons. We also note that SmCo damage studies are continuing in the SLAC damping rings by the SLAC people in this proposal.

Future Plans

In addition to possible continuation of magnet material tests, future plans include testing of CCDs and other electronic and electro-optical devices and materials for LC accelerator and detector applications using neutrons at MNRC or in the 63 MeV proton radiation test beam at CNL.

Budget

This proposal includes an estimated UC Davis budget for the first year, as follows:

- a Hall probe is needed for monitoring the sample magnetic fields at MNRC;
- additional supplies will be required for the iradiations, such as materials for supplemental dosimetry;
- a part-time assistant is needed to help in performing the irradiations and measurements at MNRC;
- travel funds are needed for trips by UC Davis personnel to MNRC and occasional trips to SLAC; and

- funds are required to cover incidental MNRC costs associated with the tests. Note that the MNRC cost estimate is preliminary and could change as the requirements become better known. MNRC does not charge UC Davis for beam time.

The cost of the part time assistant is based on an undergraduate student working half time during the academic year. The assistant must drive to and from the off-campus facility and be qualified to deal with the potentially radioactive samples.

Item	Cost
GMW Assoc. Model 133 Digital Teslameter + MPT 132-2s Hall Probe	$ 3443
Assistant (part time) (including benefits)	$ 8899
Travel	$ 1590
Supplies	$ 1000
MNRC incidental expenses (preliminary)	$ 1000
Indirect costs	$ 3218
Total	**$ 19180**

Relevant Experience of Personnel

Maxwell Chertok is Assistant Professor of Physics UC Davis working mainly on the CDF experiment at Fermilab. During the CDF Run II upgrade, Chertok helped develop a radiation-hard fiber optic readout (Dense Optical Interface Module) for the new silicon vertex detector for CDF. As part of this project, Chertok performed several radiation damage tests on various prototypes of these devices and on fiber ribbon at the Fermilab Booster.

David E. Pellett is Professor of Physics at UC Davis working mainly on the CDF experiment at Fermilab. He has performed a number of radiation damage studies on silicon detectors and electronics for SSC, LHC and Tevatron applications at the UC Davis cyclotron. A brief bibliography follows:

D.E. Pellett and J. Bacigalupi, "Study Of Radiation Damage To PIN Photodiodes Using 63-Mev Protons," *Symposium on Detector Research & Development for the Super Collider, Fort Worth, TX* (1990).

D.E. Pellett and S.T. Liu, "Performance of Honeywell RICMOS-IV SOI Transistors After Irradiation to 27 Mrad(Si) by 63.3 MeV Protons," *Nucl. Phys. Proc. Suppl. 78* (1999).

G.P. Grim, D.E. Pellett *et al.,* "Measurement of SEU Cross Sections in the CDF SVX3 ASIC Using 63 MeV Protons," *Nucl.Instrum.Meth.A447* (2000).

James E. Spencer is a Staff Scientist at SLAC. He has had long experience with permanent magnet optical elements, having made the first proposal for a permanent magnet (PM) final focus system in 1984. He proposed, designed and built the first SLAC PM multipoles for injection, extraction lines and damping rings for the SLC. He made the first comparison of SmCo and NdFeB in PM multipoles. He measured the induced radioactivity and showed methods to mitigate radiation effects in such magnets. A brief bibliography follows:

James E. Spencer, "Some Optics Alternatives for the SLC FFS," *SLAC-CN-264* (1984).
James E. Spencer, "PM Protocol and Tolerances for the SLC Damping Rings," *SLAC-CN-300* (1985).
James E. Spencer, " Comparison of SmCo and NdFeB in PM Multipoles, "*SLAC-PUB-4090* (1986) and 1987 PAC.
James E. Spencer, "Experience with the SLC PM Multipoles," *SLAC-PUB-6558*

James T. Volk is a Staff Scientist at Fermilab. He has had long experience with design and construction of PM beam optical elements. He built the Fermilab recycler, which uses 500 strontium ferrite magnets for storage of antiprotons. He developed prototype magnets and set up the factory to build the Recycler magnets and perform all production measurement of these magnets. The main field in all the recycler magnets were adjusted to be within 5 parts in 10,000 of the ideal field. He has presented papers on this work at PAC 2002, MT16 and MT17. Since 1999, he been working on prototype adjustable quadrupoles for the LC. He has designed and build three different styles of PM quadrupoles using both NdFeB and SmCo. He has presented papers at MT-17 on adjustable PM quadrupoles. He has also designed and built many smaller special purpose permanent magnets for the recycler and other experiments at Fermilab.

Zachary R. Wolf is a Staff Scientist at SLAC and is in charge of the SLAC magnetic measurements group. He built the current measuring apparatus for accurate single block magnetization measurements and made all of the current-generation measurements of individual blocks and PM multipoles at SLAC. His measurements of the SLC damping ring PM sextupoles are reported in SLAC-PUB-6558. Also, see, for example,
J.T. Volk, Z.R. Wolf, et al. "Adjustable Permanent Quadrupoles for the Next Linear Collider," *SLAC-PUB-8859* (2001).

References

[1] S. Roesler *et al.*, "Dose to Electronics in NLC Beam Tunnel," SLAC RP 99-15, Dec. 1999.

[2] R.D. Brown and J.R. Cost, "Radiation-Induced Changes in Magnetic Properties of Nd-Fe-B Permanent Magnets," *IEEE Trans. Magnetics Vol. 25,* 1989.

[3] Yoshifumi Ito *et al.,* "Magnetic flux loss in rare-earth magnets irradiated with 200 MeV protons," *Nucl. Instr. and Meth. B 183*, 2001.