Strain Sensors for High Field Pulsed Magnets

Mentors: Kevin Farinholt and Chuck Swenson

Introduction

High magnetic field pulsed magnets provide large magnetic fields (60-100 Tesla) through the use of nested resistive coils (shown in Figure 1) that are cooled in a bath of liquid nitrogen. Systems generate large hoop stresses in the coils can containment shells, and can produce strains on the order of 1% within structural components. One difficulty in monitoring these systems is that the high magnetic fields interfere with traditional resistive devices (strain gauges), and the cryogenic environment makes bonding and temperature compensation major issues that must be addressed.

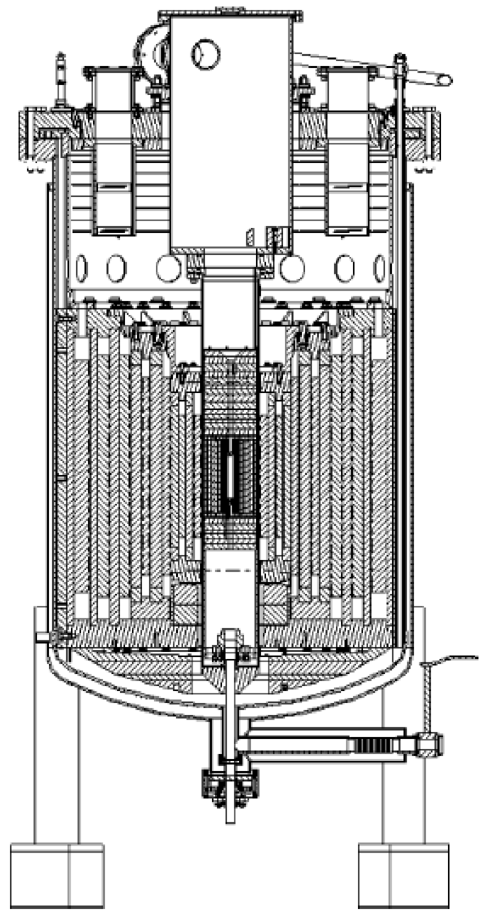

Figure 1: Cross-section view of the 100 Tesla multi-pulse magnet

On July 28, 2000, the National High Magnetic Field Laboratory (NHMFL) at Los Alamos National Lab experienced a catastrophic failure in their 60 Tesla long pulse magnet. This failure occurred after 914 pulses had been made (401 at > 57.5T), and was the result of improper heat treatment in a series of the containment shells that house the electromagnetic coils. Once the structural failure was initiated, the full system failed within 5ms, destroying each of the nine coils as well as several pieces of auxiliary equipment near the magnet. Figure 2 illustrates some of the coil damage and shell fragmentation that resulted from this catastrophic failure. Presently the NHMFL monitors coil inductance and resistance to identify anomalies that could indicate problems with the system's structural integrity. One capability that the NHMFL would like to incorporate in new pulsed magnet designs is the ability to monitor strain directly, in real-time as the magnet is pulsed.

Project Outline

The objective of this project will be to investigate strain sensing techniques that could be used to monitor deformation within the steel shells of a magnet at cryogenic temperatures. Two potential approaches that will be considered are fiber-optic and foil strain gauge sensors. Students will consider several issues with the use of each sensor type, i) bond integrity at cryogenic temperatures,

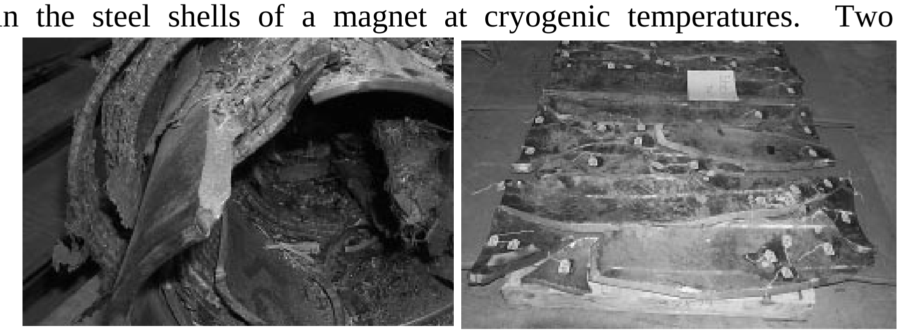

Figure 2: Damage in coil 4 (left) due to shell failure (right) of the 60T pulse magnet.

ii) electromagnetic interference, and iii) temperature dependent response characteristics. The first four weeks will be focused on sensor modeling, characterization and design. We will work with the NHMFL to instrument a small prototype that will be tested at their facility. Initial tests will consider strain under static conditions, as well as while the magnet is being energized. Time permitting, we will take lessons learned in the first experiment to modify the setup and conduct a second experiment at the NHMFL.

Project Schedule

This project will be conducted over a nine week period. The expected work is outlined in the following timeline:
Week 1: Safety training and project introduction
Week 2: Literature survey of sensing techniques and operating environments
Week 3: Analytical study to estimate strain in magnet shell / conduct laboratory tests of sensors
Week 4: Begin design of strain sensor for NHMFL experiment
Week 5: Finalize sensor design and send drawings to NHMFL for fabrication
Week 6: Conduct experiments at NHMFL
Week 7: Conduct experiments at NHMFL
Week 8: Analyze results
Week 9: Present project findings

Suggested Reading

1. Sims, J.R., Schillig, J.B., Boebinger. G.S., et al., 2002, "The U.S. NHMFL 60T Long Pulse Magnet Failure", *IEEE Transactions on Applied Superconductivity*, Vol. 12, No. 1, pp. 480-483.
2. James, S.W., Tatam, R.P., Twin, A., Morgan, M., Noonan, P., 2002, "Strain response of fibre Bragg grating sensors at cryogenic temperatures," Measurement Science and Technology, 13, pp. 1535-1539.
3. Swenson, C.A., Gavrilin, A.V., Han, K., et. Al., 2006, "Performance of 75T Prototype Pulsed Magnet," *IEEE Transactions on Applied Superconductivity*, Vol. 16, No. 2, pp. 1650-1655.