High Temperature Superconducting Magnets for Fusion Applications

Gregory Krueper, University of California, Irvine
Dr. Yuhu Zhai, Princeton Plasma Physics Laboratory

Goals

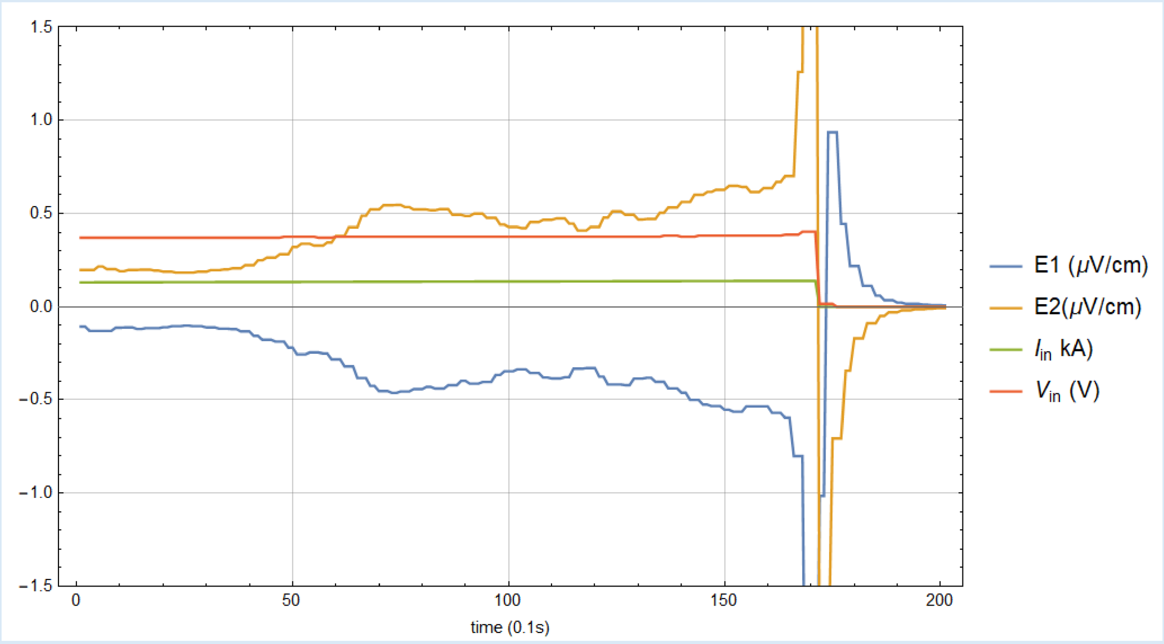
- Design, build, and test a model high temperature superconducting (HTS) magnet
- Improve laboratory data acquisition capabilities
- Investigate other ways to detect HTS quench

Background

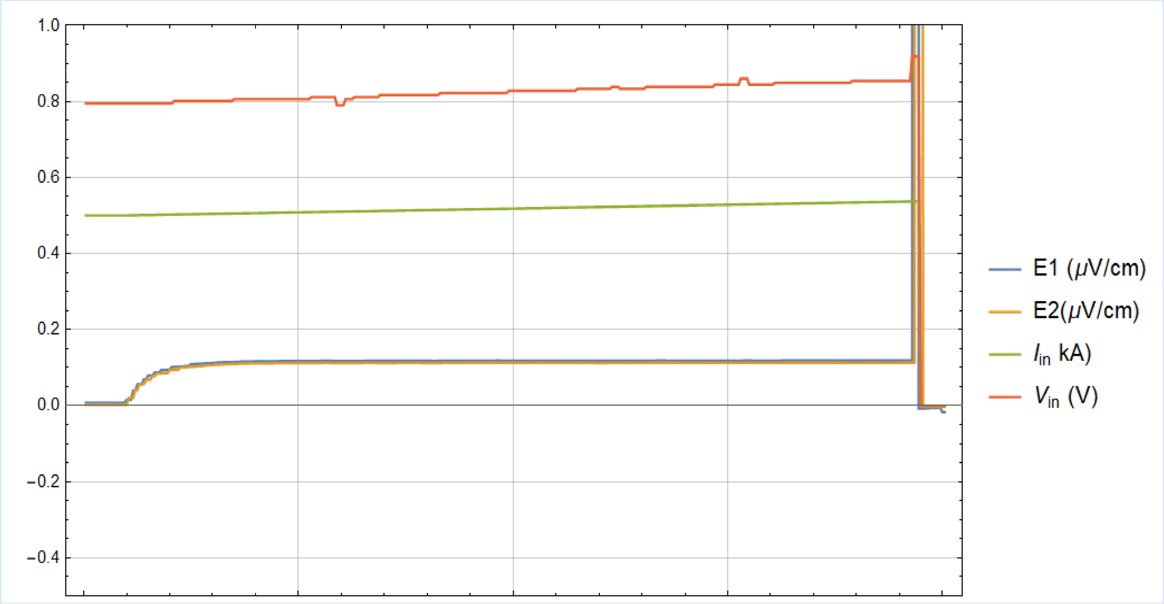
Testing the performance of superconducting magnets is difficult due to the combination of cryogenic cooling with liquid helium, kiloamperes of current through Nb_3Sn coils, magnetic fields as high as 30 Tesla, and water-cooled electrical elements. Extra care needed to be taken to protect the magnet wires from excessive heat if part of the wires revert to a non-superconducting state, or "quench." If this happens, all the magnetic energy stored in the solenoid needs to be discharged safely into a dump resistor, normally triggered if a voltage reading across the coil exceeds a certain value.

Analysis on Previous Tests

I analyzed test data collected In collaboration with the University of Geneva on two superconducting coils tested at varying current levels and background magnetic field. Two voltage difference measurements across the coils, input current and voltage, and background magnetic field were all recorded at 10Hz. While fluctuations in electric field in the coil prior to quench showed signs of instability, the quench and discharge of the coil was poorly resolved due to limited instrumentation. This was reported back to the University of Geneva and helped guide our design of a new experimental setup.



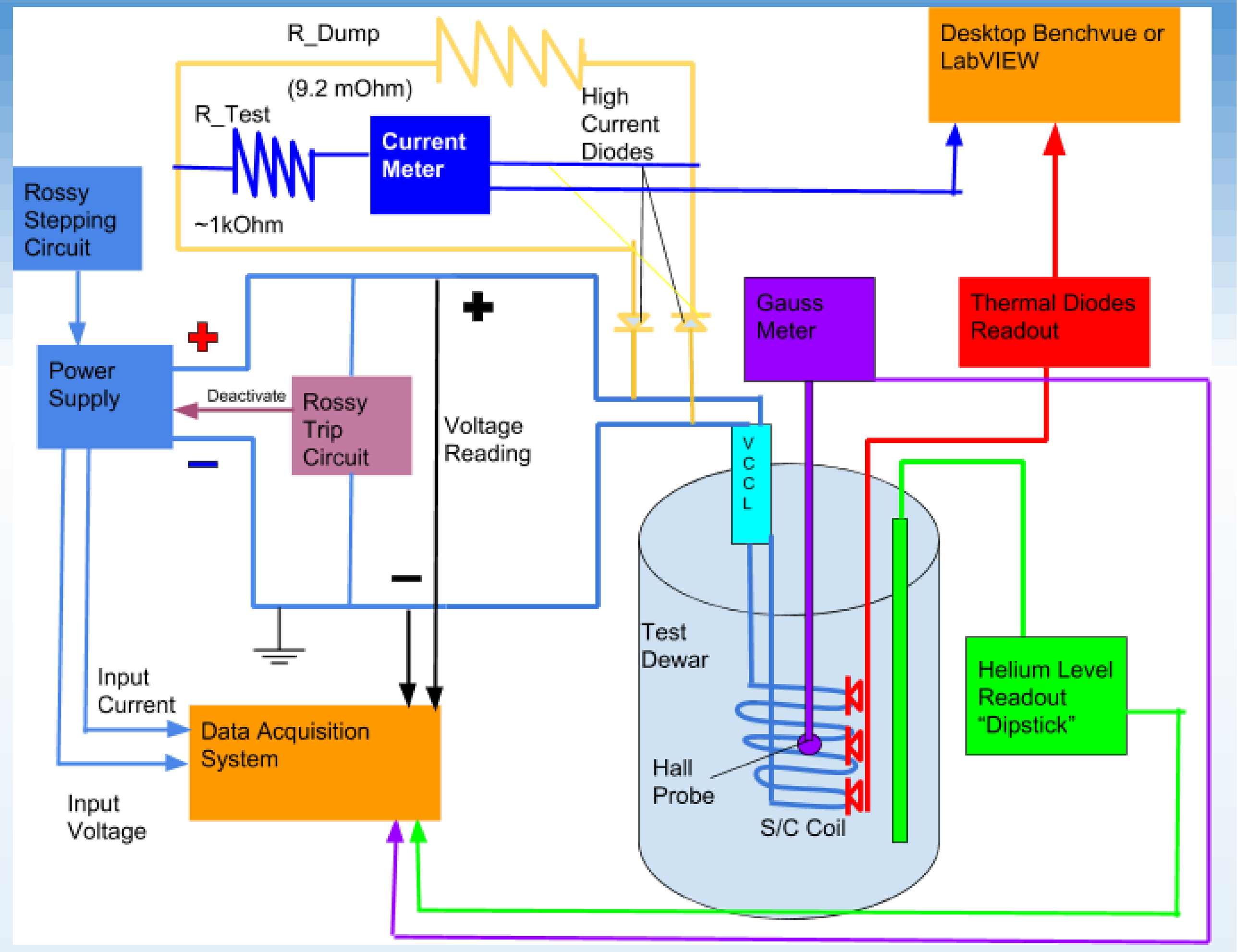
Coil 1



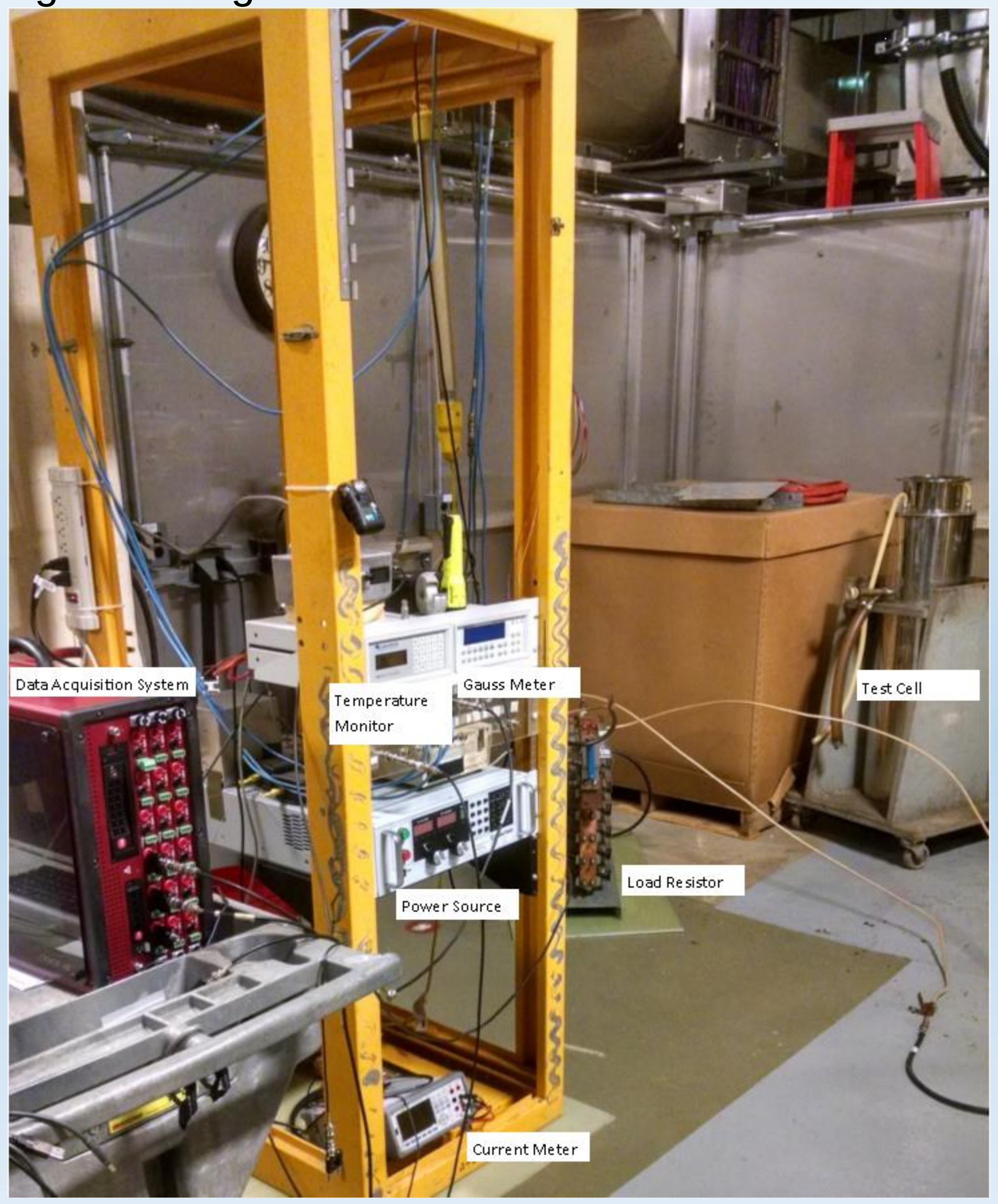
Coil 2

Magnet Lab Upgrades

My main task was to assist in the assembly of a new configuration of instruments to obtain better data during coil tests. This required significant reading and learning to operate each instrument independently, and then synchronously with the help of LabVIEW or BenchVue automation. I also determined which communication cables to purchase in order to receive digital information from each of the instruments. In addition, I characterized each instrument's noise-equivalent resolution, time constants, and recording speed, which for voltage and current measurements can be as good as 5 significant figures at 50kHz.



Schematic of experimental setup with new instruments

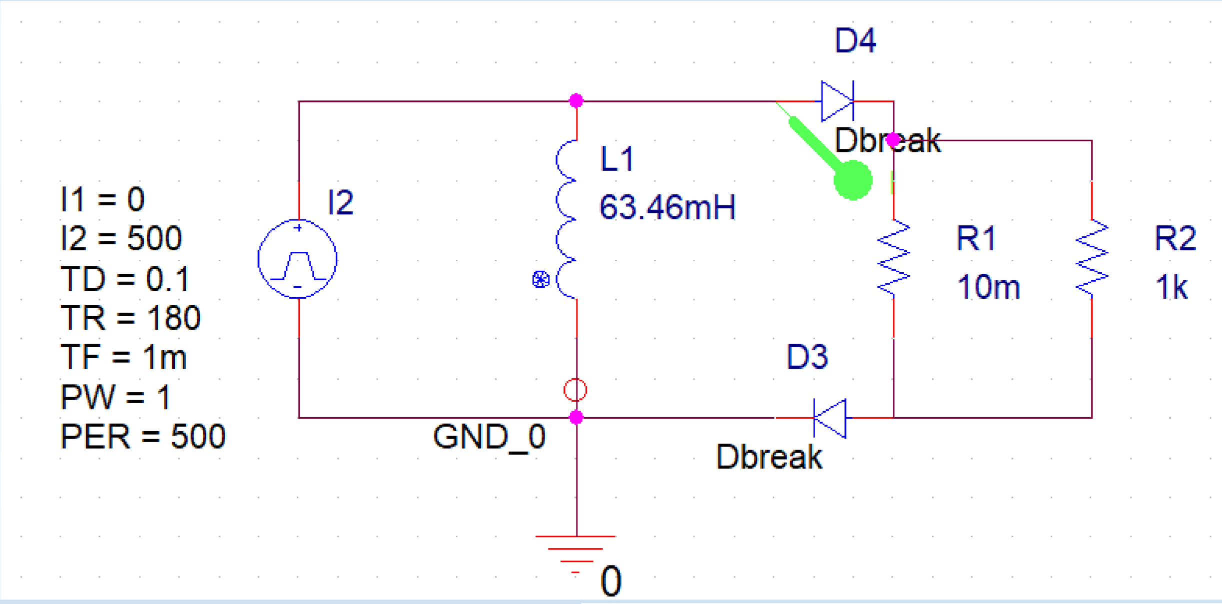


All instrumentation as situated in the lab

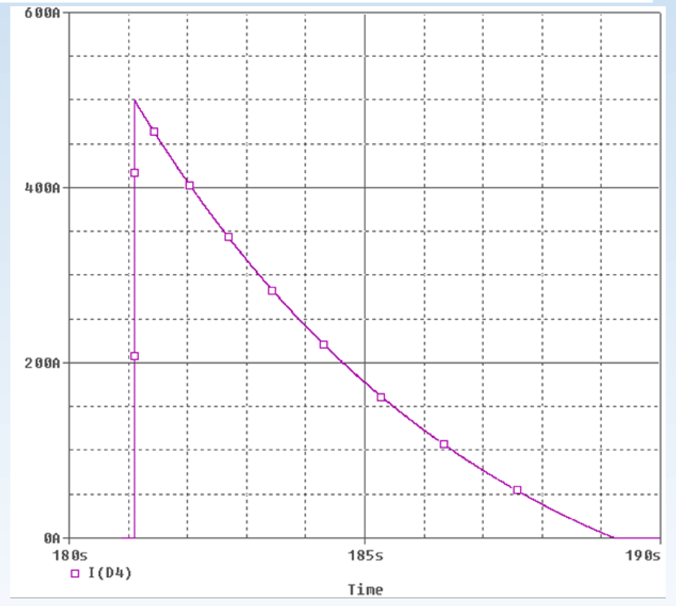
Due to the limits of RS232 communication, I opted instead to use our Data Acquisition System to synchronously record the analog outputs of fast signals – voltage on the coil and magnetic field - while the temperature monitor readings were recorded over RS232, and current meter over USB. A final "test run" of all instruments demonstrated success in acquiring synchronized, precise data.

Circuit Simulations

To understand what will happen during discharge of the coil current, I ran PSPICE simulations to determine power distributions and discharge time. This allowed me to optimize the value of our dump resistor to protect the coil from high voltage and ohmic heating.



R_dump = 10mΩ
Peak current: 500A
Total stored energy: 7.9kJ
Discharge time: 3 s
Peak coil voltage: 7.06V
Peak power dump: 2.5kW
Diode voltage: 1.04V

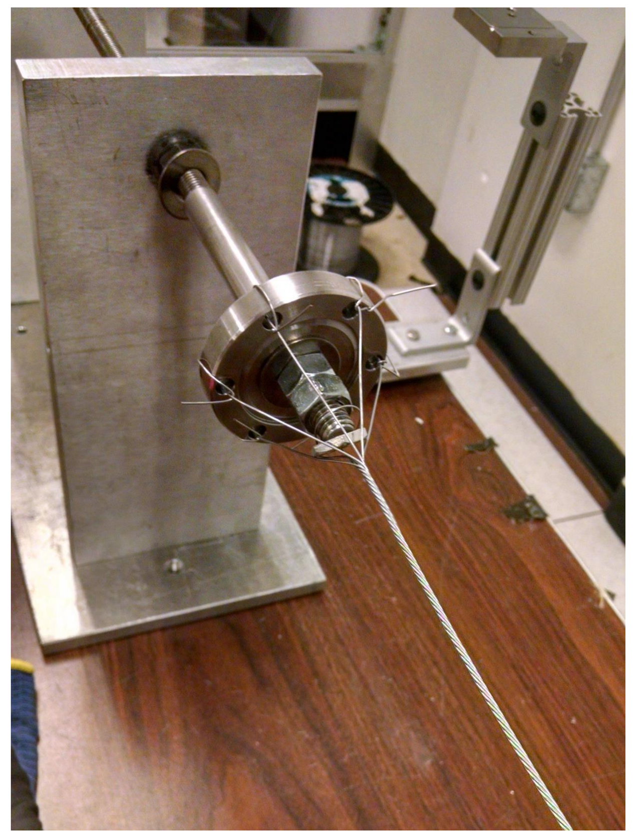


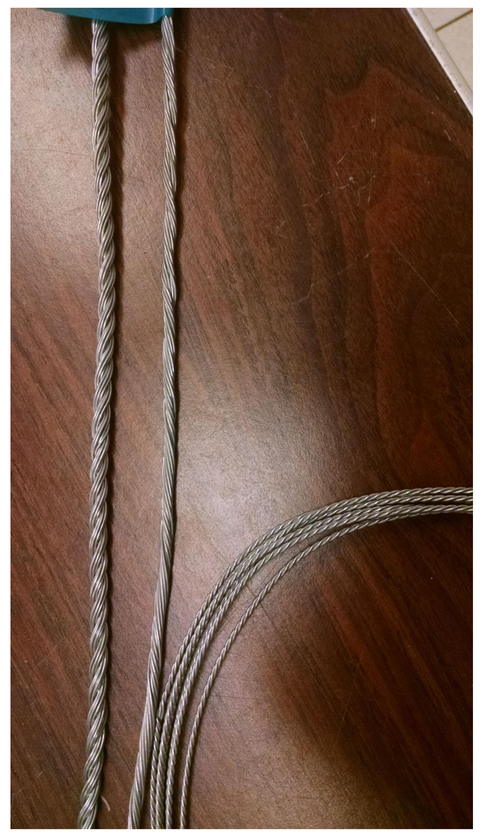
Acknowledgements

Daniel Klasing, Stuart W. Cramer High School
Bruce Berlinger, PPPL
Department of Energy Science Undergraduate Laboratory Internship Program
PPPL Science Education Department

Coil Winding

To help guide future work in developing reliable processes to wind cables of superconducting wire as part of the Flit Superconductor Project, I aided fellow intern Daniel Klasing in manually winding prototype Nb_3Sn coil configurations. These included triplet and hexagonal configurations, and each sample was tested for mechanical robustness. Overall, the hexagonal configuration proved to have greater mechanical strength and a higher packing factor.





Optical Quench Detection

Working on this project allowed me to develop a proposal for an optical diagnostic to outperform the normal voltage measurements for quench detection. With the help of Dr. Luis Delgado-Aparicio and Dr. Ahmed Diallo, I can now propose to use absorption spectroscopy and monitoring blackbody radiation to monitor the temperature profile of a superconducting surface, thus detecting quenches before they occur.

Future Work

- Make an algorithm for processing & filtering data
- Full test on a 60mH inductance coil with only metal insulation
- Analysis of collected data
- Correlation to any damage to the coil
- Apply for graduate fellowships with proposal for optical detection of HTS quenching