BNL Quarterly Report on Superconducting Magnetic Energy Storage Prepared for ARPA-E Through CRADA No. BNL-C-11-01 with ABB Inc.

Q11 Progress Report and Status of Milestones

Superconducting Magnet Division
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July 15, 2013

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Summary

Fabrication and Testing of Pancake Coils for 1.7 MJ SMES

This quarter marks the completion of a significant internal milestone – construction and QA testing of all single pancake coils in double pancake assembly as required for the final SMES system. The 1.7 MJ SMES consists of 28 single pancakes (14 double pancakes) the in inner layer and 18 single pancakes (9 double pancakes) in the outer layer.

The 77 K QA testing of double pancake assemblies is important in eliminating any weak section in the coil either due to construction or the conductors. The test results can be categorized into three types. An example of the first type is shown in figure 1 where the 77 K performance of both single pancakes is similar. An example of the second type is shown in figure 2 where the 77 K performance of the two single pancakes is significantly different from each other. An example of the third type is shown in figure 3 where one of the coils shows a significantly inferior performance 77 K performance, and is to a level that the coil can't become part of SMES device. It may be noted that the risk of damage to the conductor will be much higher at 4 K (where SMES will operate) than that at 77 K (where these QA tests are carried out) because of higher current, higher fields and higher stresses due to Lorentz forces. Two such cases were found where one of the two single pancakes in each deemed unacceptable (there was no case where both deemed unacceptable).

Repairing this assembly required taking apart the two double-pancake coil assemblies. In both cases, one single pancake was good. Taking apart the double pancake assembly turned out to be a difficult and time consuming task, since the epoxy glue between the two single pancakes had set well. However, we were able to take them apart and in both cases, we were able to use the good pancake from that assembly and were successfully able to pair it with the newly wound pancake into a double pancake structure.

The 77 K QA tests of the two repaired assemblies showed that they pass the essential QA test and can be used in the final 1.7 MJ SMES system.

The above procedure resulted in retesting the two pancakes after a significant period of time. We noticed a slight change in the performance in a few turns of one of those two coils. A careful review of the construction records revealed that the two groups of turns that showed reduced performance were those that were flagged by technicians during the winding. This was discussed and explained in details during the presentation made in a weekly meeting. Since many other coils with similar performances had been previously accepted, this coil was also accepted, however, with the change in performance duly noted.

With all pancakes successfully built, performance measured at 77 K and the QA test passed, we can now make an overall summary. A Histogram of the performance of all the coils in double-pancake assembly is shown in figure 4 and in the single pancake assembly in figure 5. The pancakes can carry more current in a single pancake assembly as the field is lower. The measured resistance of the special diagonal splice which electrically connects two single pancakes into a double pancake is shown in figure 6.

The outer coil winding has been slow and has consumed significantly more labor than that was used in winding inner coil windings. Technicians had to stop the production run often and get approval from the cognizant scientist every time there was a concern (there were many such instances). In many cases, a microscope was brought in to examine the conductor carefully, and in several instances the coil had to be unwound with several turns removed and a new splice made. Many of these discrepancies have been noted in the travelers. Even though, SuperPower has replaced the conductor, the time required to identify these coils has increased the time to fabricate the coils. At the end of this reporting period, the remaining funds available to spend in the magnet division are $73K. With these funds, we should still be able to assemble the SMES system leaving insufficient funds for integrated testing. We are exploring options to address this.

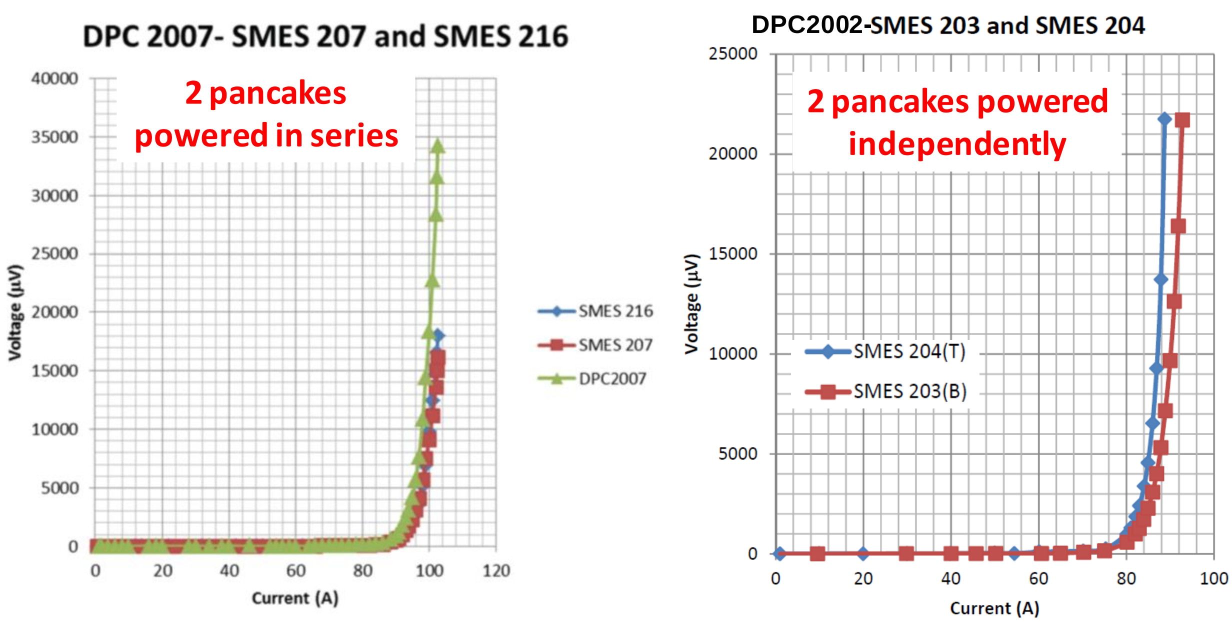


Figure 1. Doublepancake assembly with two single pancakes having similar critical currents, as measured at 77 K.

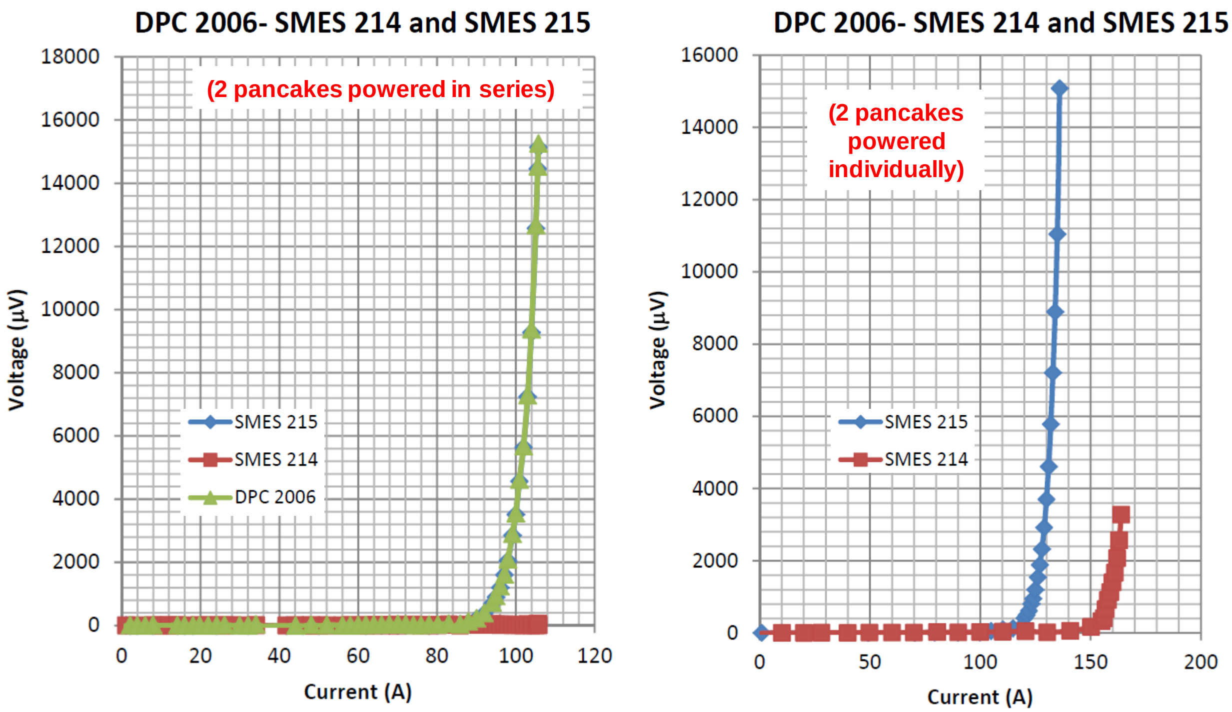
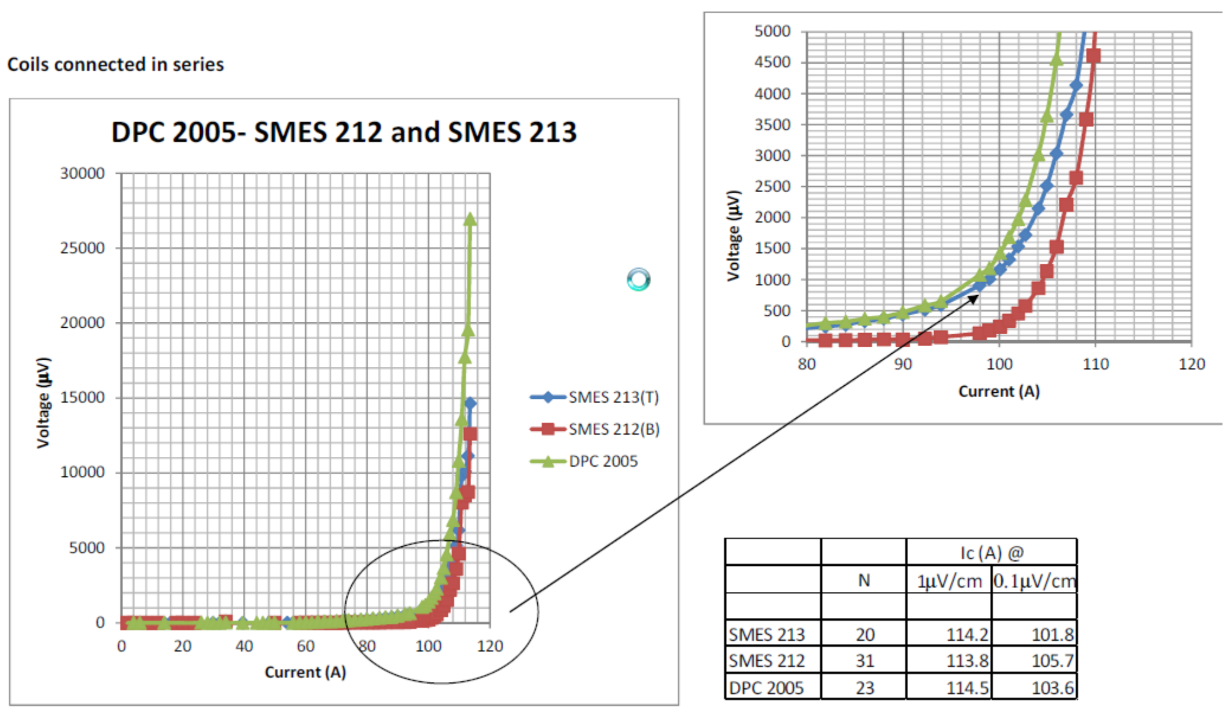


Figure 2. Doublepancake assembly with two single pancakes having significantly different critical currents, as measured at 77 K.



		Ic (A) @	
	N	1µV/cm	0.1µV/cm
SMES 213	20	114.2	101.8
SMES 212	31	113.8	105.7
DPC 2005	23	114.5	103.6

Figure 3: Doublepancake assembly with two single pancakes in which one single pancake (SMES213) did not pass 77 K QA test.That single pancake (SMES213) was replaced.

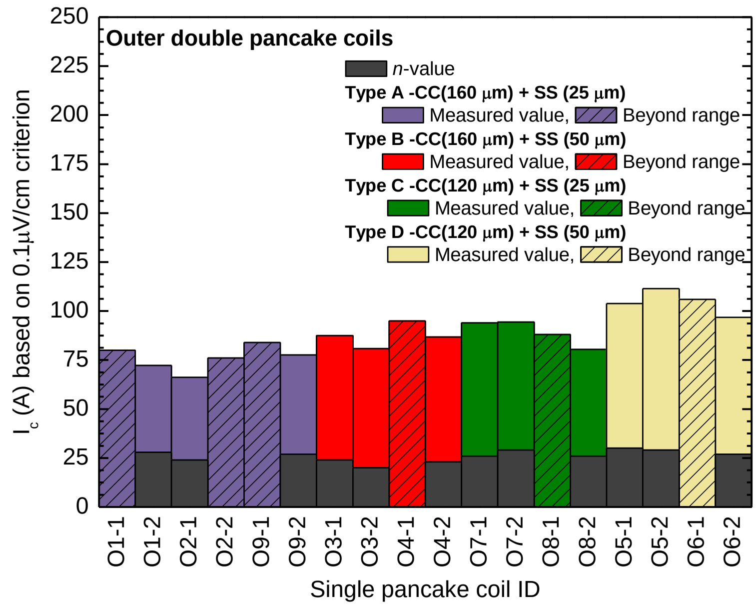


Figure 4. Histogram of critical current of outer single pancake measured in a doublepancake assembly at 77 K. Crossed section are the single pancake with expected critical current significantly higher than that shown in the graph but could not be measured as the test was limited by the lower performing comanion single pancake.

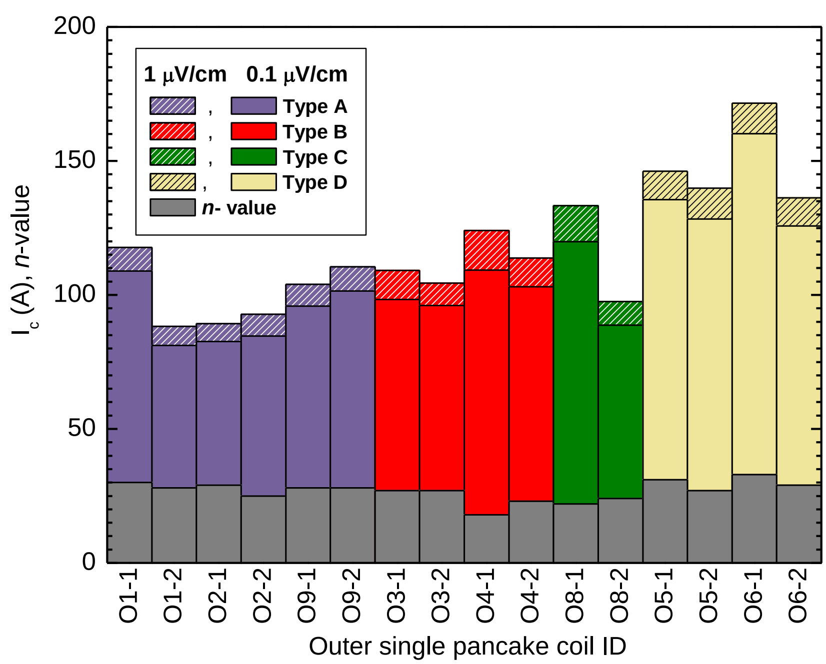


Figure 5. Histogram of critical current of outer single pancake measured as a singlepancake unit at 77 K.

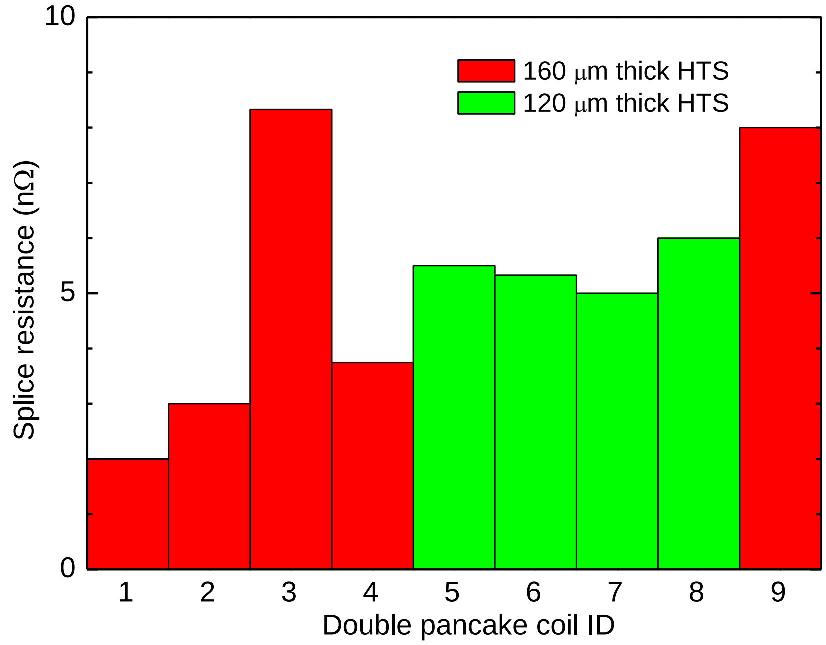


Figure 6. Hostogram of resistance of diagonal splice between two outer single pancakes measured as a at 77 K. Since the measurement covers two splices the average splice resistance per splice is half of this, which is significantly less than 5 nΩ.

Engineer Design of the 1.7 MJ Support Structure

Another major area of focus during this quarter was on completing the detailed engineering analysis (thermal, magnetic, mechanical). . This work was earlier postponed awaiting a decision of choice between 1.7 MJ and 2.5 MJ systems.

After receiving the final recommendation that the device will be a 1.7 MJ SMES coil, we immediately started working on the detailed engineering design of the final system. The design work was prioritized so that all parts needed for the magnet were ordered as soon as possible.

Figure 7 shows the engineering design of the mechanical structure and magnet assembly. Figure 8 shows the magnet cooling that minimizes thermal gradients across the coil. This work allowed us to order all magnets parts and plan in detail how the magnet will be assembled with the inner and outer pancake coils.

We have received all parts for inner coil assembly and for its support structure. This includes inner and outer stainless steel tube on which the coils will be assembled and additional inner and outer stainless steel tubes which are major part of the support structure.

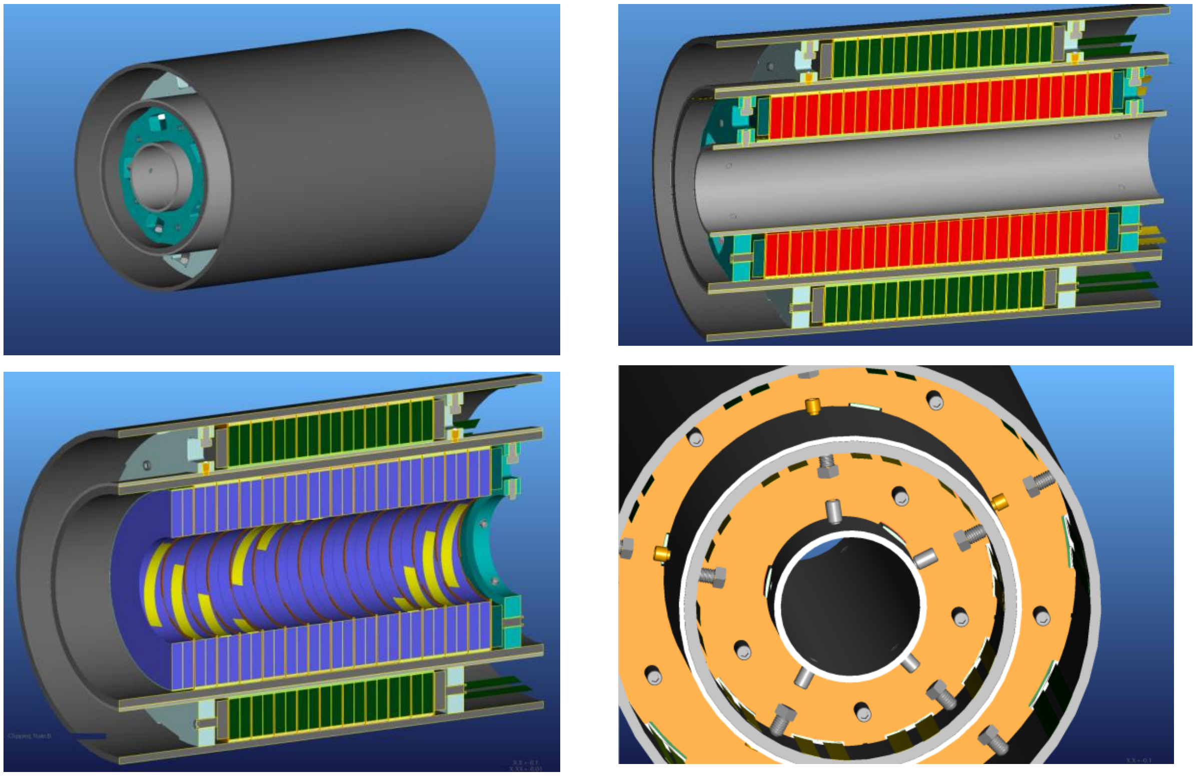


Figure 7. Engineering design of the mechanical structure and magnet assembly.

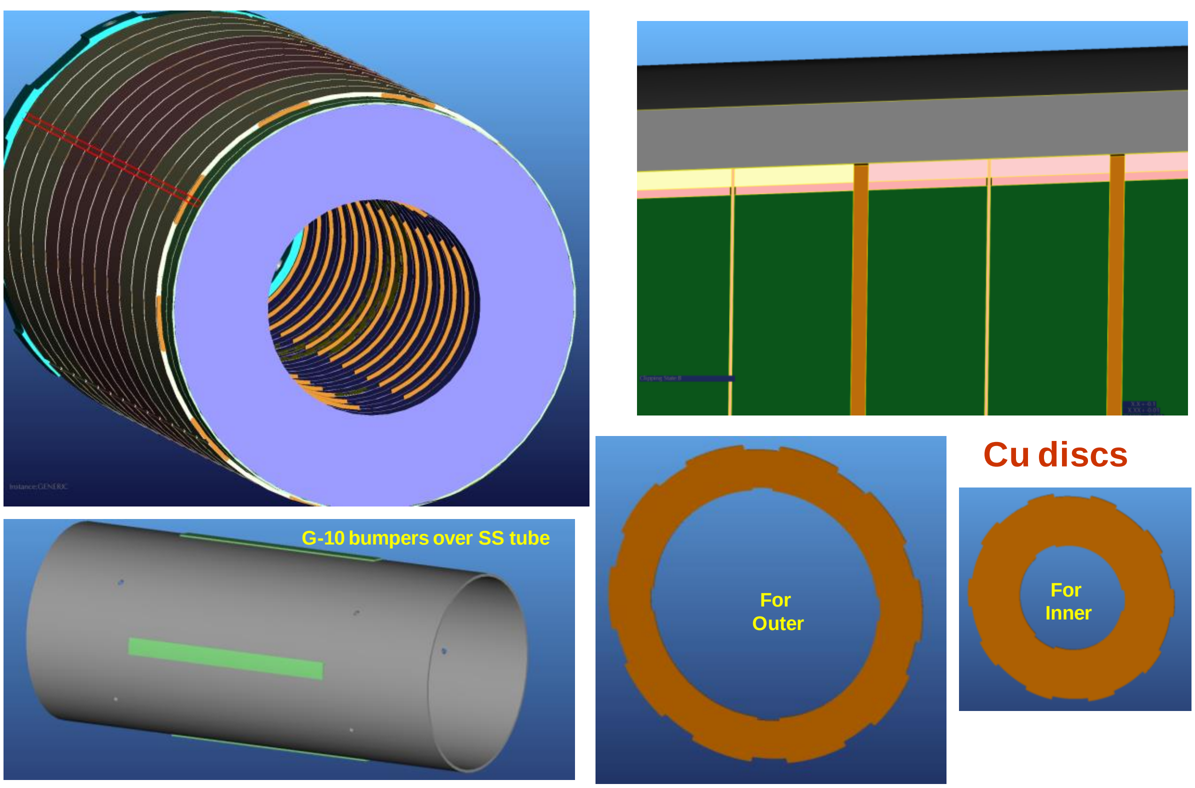


Figure 8. Engineering design of the magnet cooling that minimizes the thermal gradient across the coil.

Engineering design and electrical connection of leads is shown in figure 9. Both inner and outer coils are divided in two segments and connection is made in such a way that asymmetric Lorentz forces are not created when energy is partially extracted from one section of the coil.

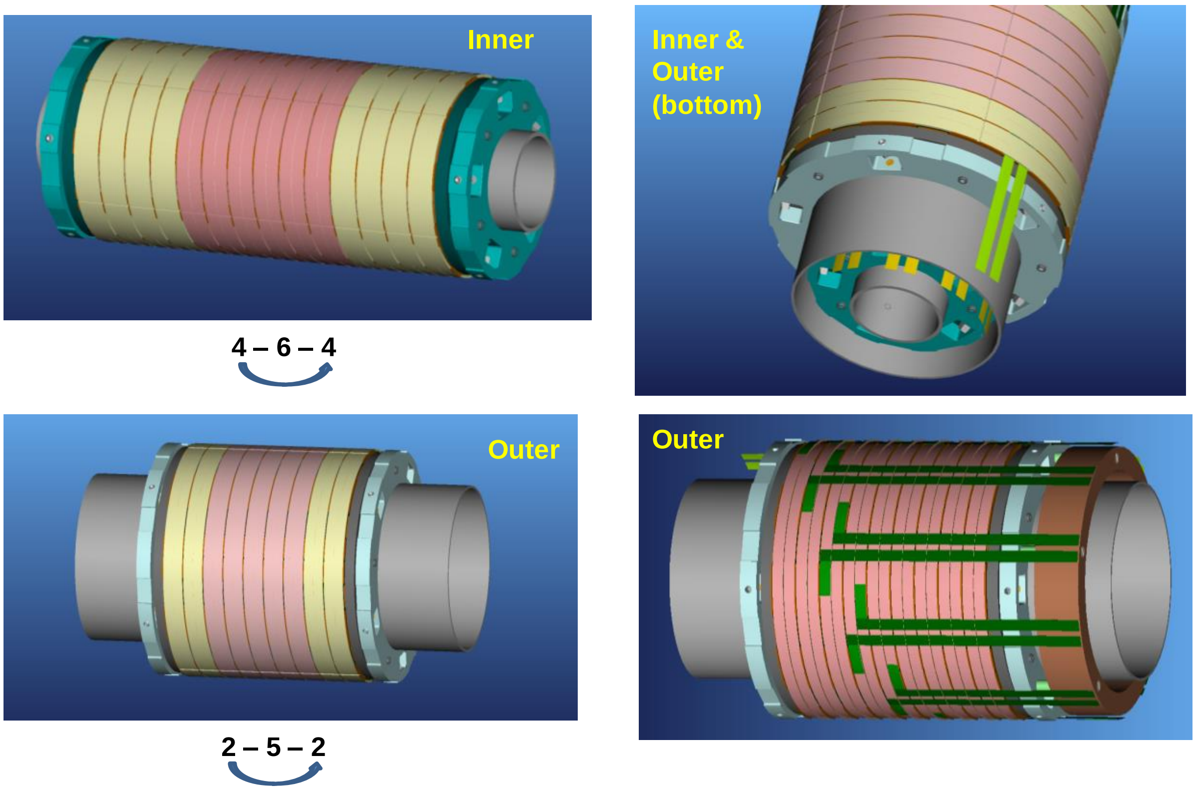


Figure 9. Engineering design of the electrical connection and leads.

Figure 10 shows the 2-d and 3-d magnetic analysis. Figure 11 shows the mechanical analysis with ANSYS. The analysis shows the stress and strain on the conductors stays within the desired range.

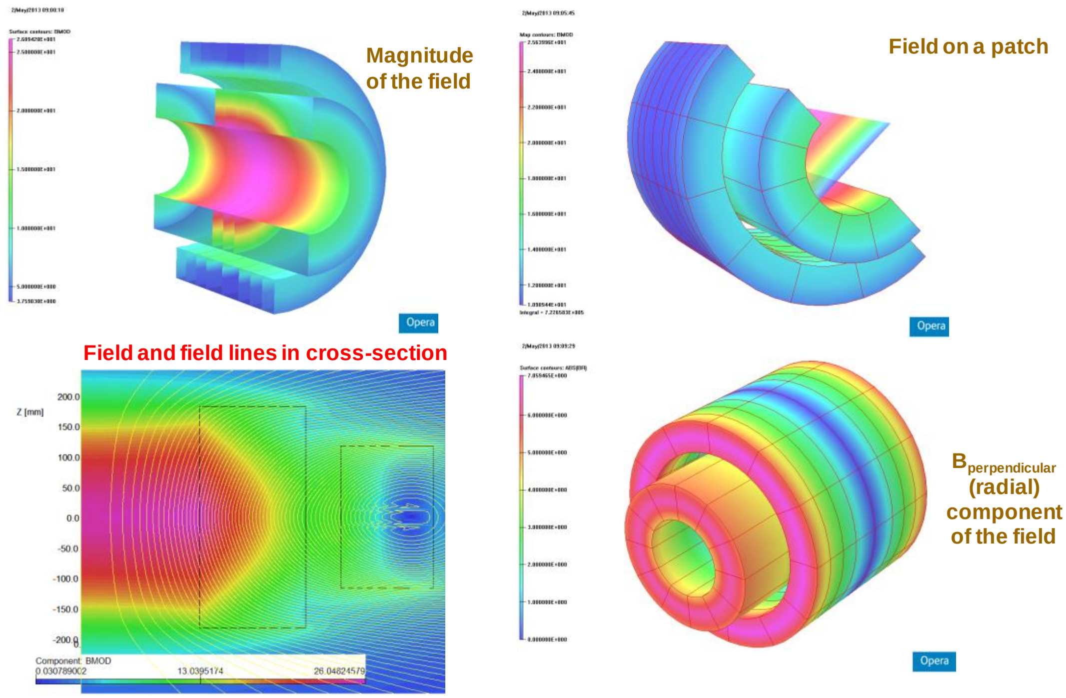


Figure 10. Magnetic design and analysis of the final design with OPERA3d.

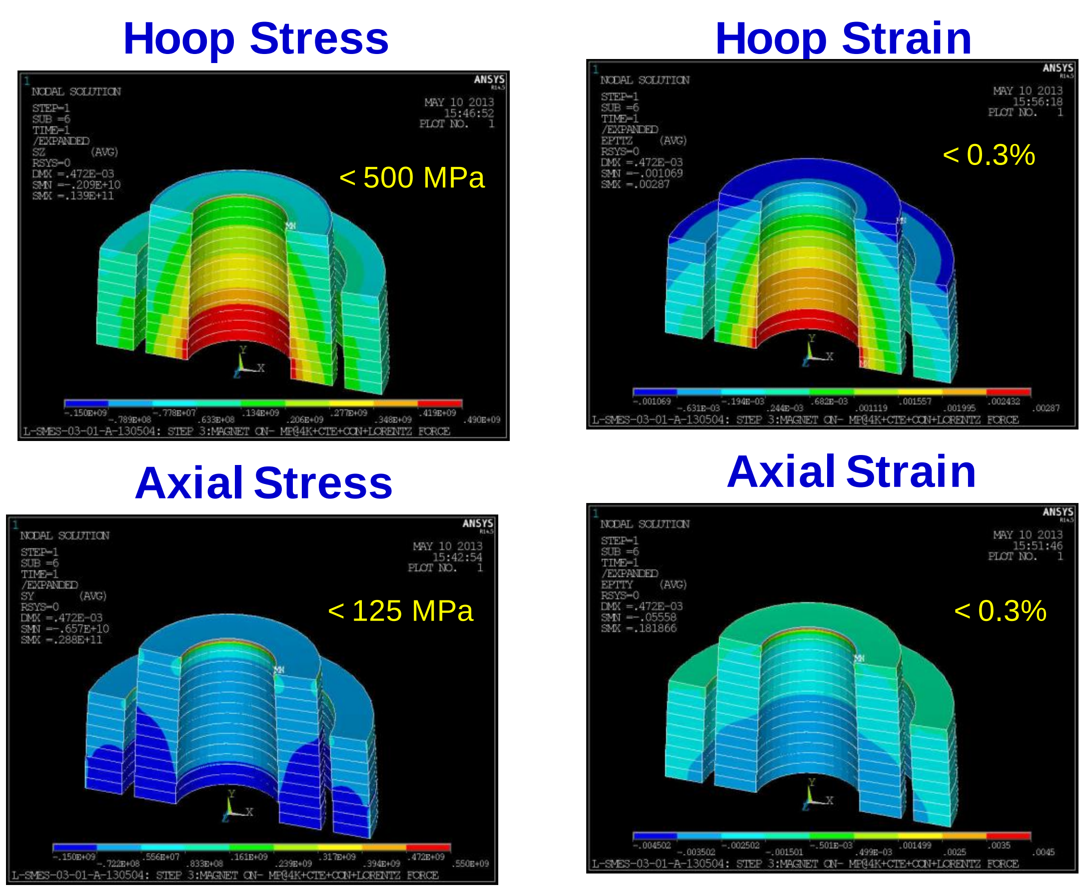


Figure 11. Mechanical design and analysis of the final design with ANSYS. Stress and strain within the coil remain within the acceptable limit and deformation due to Lorentz forces remian ~200 μm.

Advanced Quench Protection and Energy Extraction Systems

We continue to develop and test the quench detection and quench protection system. Prior to using this system with the full SMES coil, we are debugging it with magnet coils built for other projects. It was recently tested with a superconducting solenoid for RHIC e-lens system that has similar inductance as the SMES coil.

One of the major activities during this period was the evaluation of individual components to ensure they can withstand the anticipated high voltages in the quench detection and protection circuitry. We have identified and tested the type of hardware needed. We have tested and evaluated high voltage isolators with +/-500mv input and +/- 10V output with isolation in range of 2KV to 3KV. Apart from precision, we are looking at long term zero input offset stability. We evaluated isolators from Knick USA (Morgan Hill, CA), and are awaiting the delivery of two other isolators from another manufacturer, Verivolt of Berkeley, CA as shown in figure 12. The order for a 48 channel system that can withstand over 1 kV has been placed from the special funds made available by the laboratory management.

Energy extraction and other components of the power supply have also been installed. Figure 13 shows adjustable dump resistor for energy extraction and DCCT.

We continue to develop the LabView based software that will operate the quench protection and overall SMES system operation.

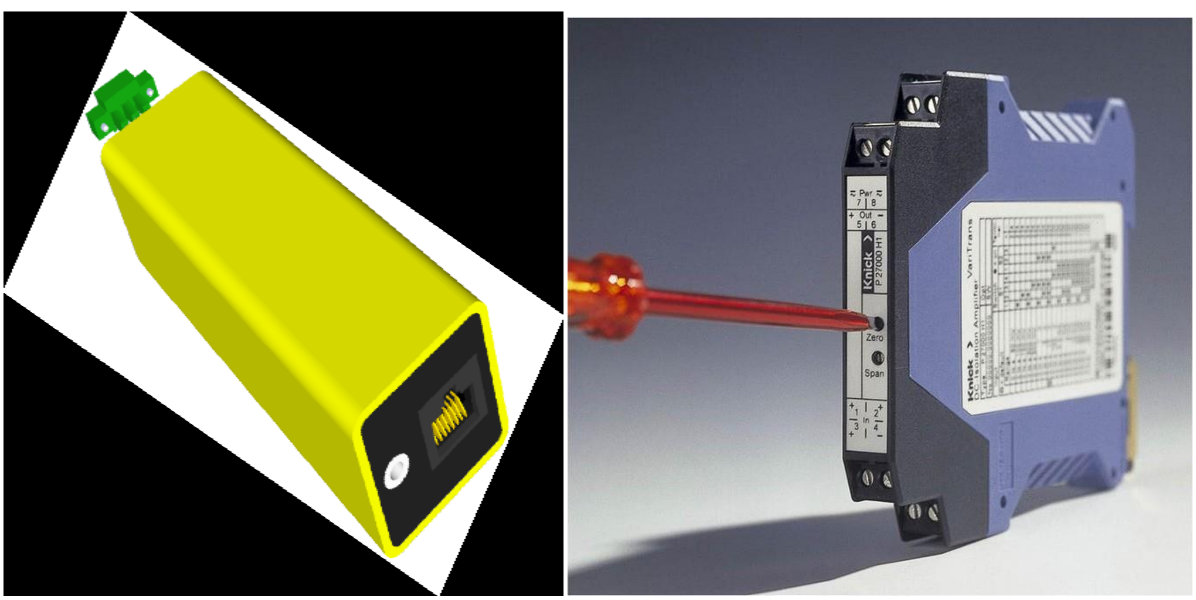


Figure 12. High voltage isolators – from Verivolt on left and Knick USA on right.

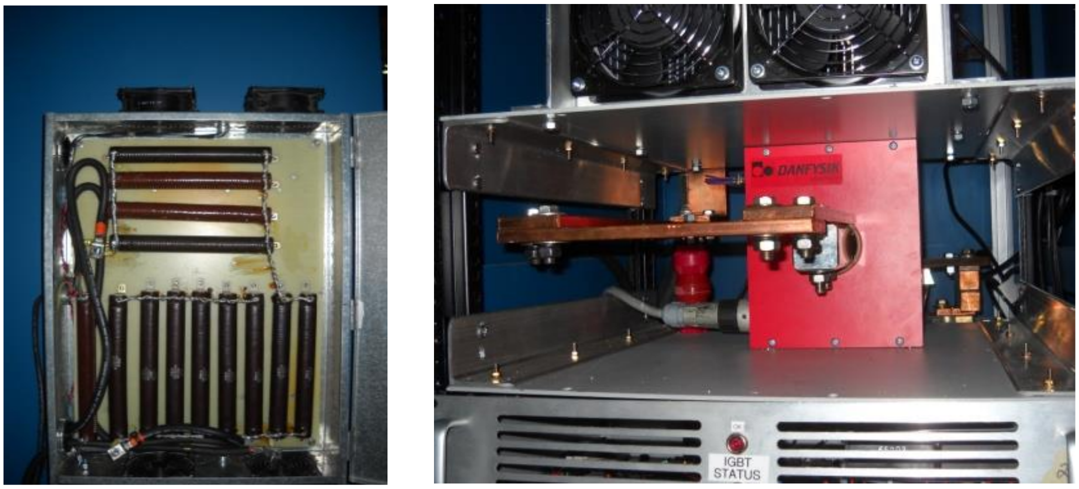


Figure 13. Adjustable Dump Resistor(left) and DCCT (right).