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

Q13 Progress Report and Status of Milestones

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Preparation of Pancake Coils for 1.7 MJ SMES Assembly

During this period, we assembled all (28) inner pancakes and all (18) outer pancakes on their respective steel support tubes. Assembly included machining of: the structure to coil insulation, coil-to-coil insulation, and copper disks to increase the uniformity of coil cool-down and voltage taps. This operation (e.g., arranging voltage tap wires so that they are not dislodged by the coils) required great care. The outer diameter of all inner pancake coils and similarly of outer pancake coils should be the same and both must have a conductor on the last turn lined up so that the superconductor coating side faces outward to make the splice. This task has been completed for both inner and outer layers. In addition all leads and voltage taps have been brought out for all inner pancakes (see Fig. 1 for inner layer and Fig. 2 for outer layer). Preparation is being made to put fiberglass-epoxy on the inner layer. The last step before that is being carried out – namely bringing and applying nomex and kapton buffer layers before the fiberglass epoxy is applied. In addition, a few test runs were made to evaluate details of putting fiberglass epoxy.

We had to perform machining on the copper discs and end plates as local pressure points were discovered that were damaging the insulation. Insulating sheets between double pancakes and copper discs also had to be machined or remade. It is important to take care of these details in a reasonable manner as a small local weak point may limit the performance of this very demanding device. We also manufactured a few thick G-10 discs for the end structure of inner coil. G-10 discs will help maintain proper electrical isolation. The last G-10 disc is also to be used to terminate various instrumentation lines from the coil. This will be the transfer point of instrumentation from the magnet coil to the outside panel. Since the length of the outer coil is smaller than the inner coil, a different kind of structure was developed which consists of two G-10 discs and a bridge between the two to extend the length.

The external support tube was found to be out-of-round (as much as 0.7 mm). This complicates the situation since we are relying on a tight fit between machined outer diameter of the coil (machined after putting fiberglass epoxy) and inner diameter of the coil. Mechanical pressure was applied to reduce this ovality but some has to be tolerated for practical reasons. Special cryogenic grease will be used to fill those small gaps.

We also carried out the high-pot test of both inner and outer coils during which a high voltage is applied across the whole set of outer coils. The purpose of this test is to ensure that the integrity of the insulation and other components of the coils is not compromised by the high voltage generated during the energy extraction process after a quench. All components passed the test above 1 KV. At least one more such test will be performed before we move to the next process of finalizing the assembly of the coil.

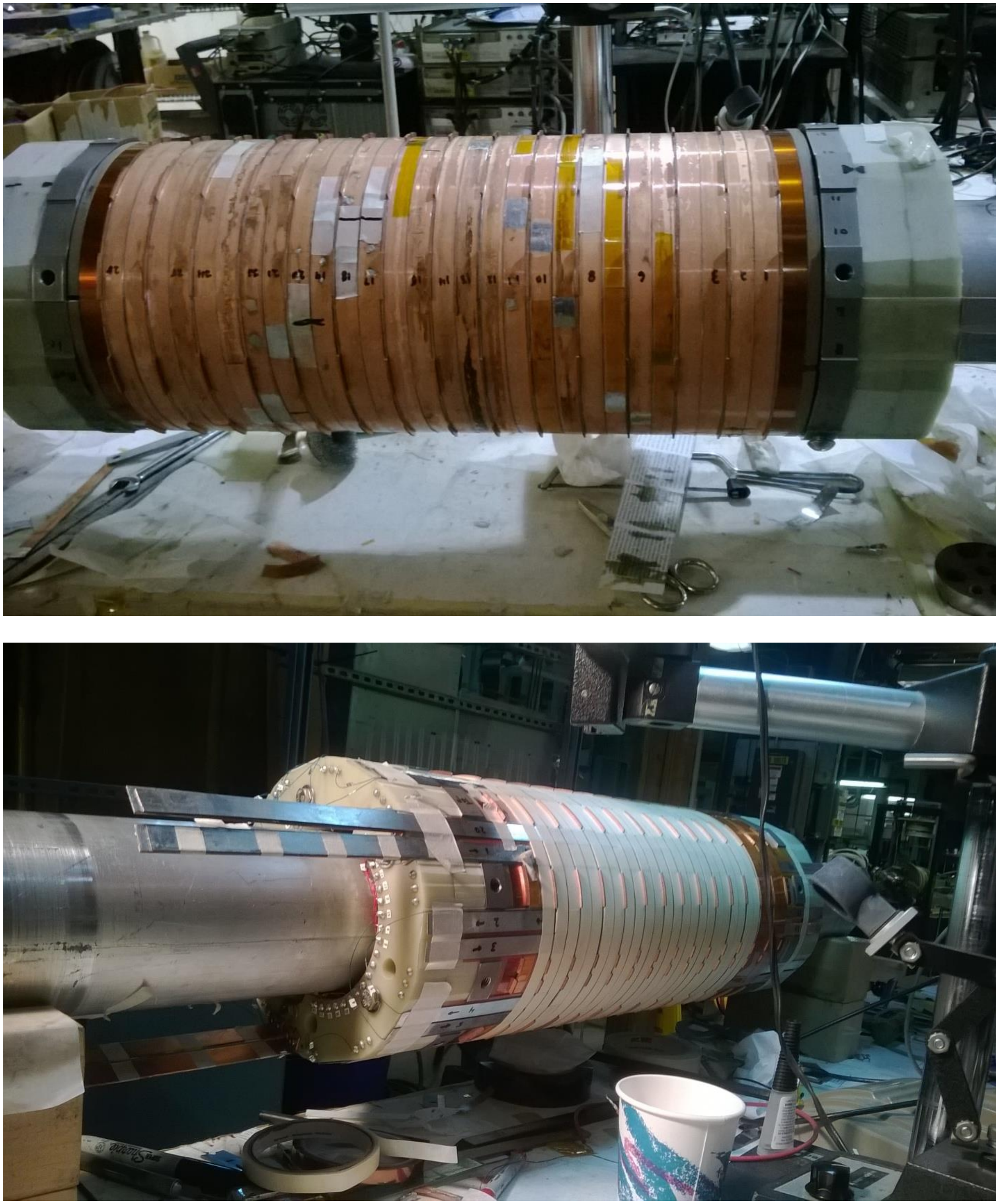


Fig. 1: Inner pancake coils during assembly. Upper picture shows before the leads are put and lower after.

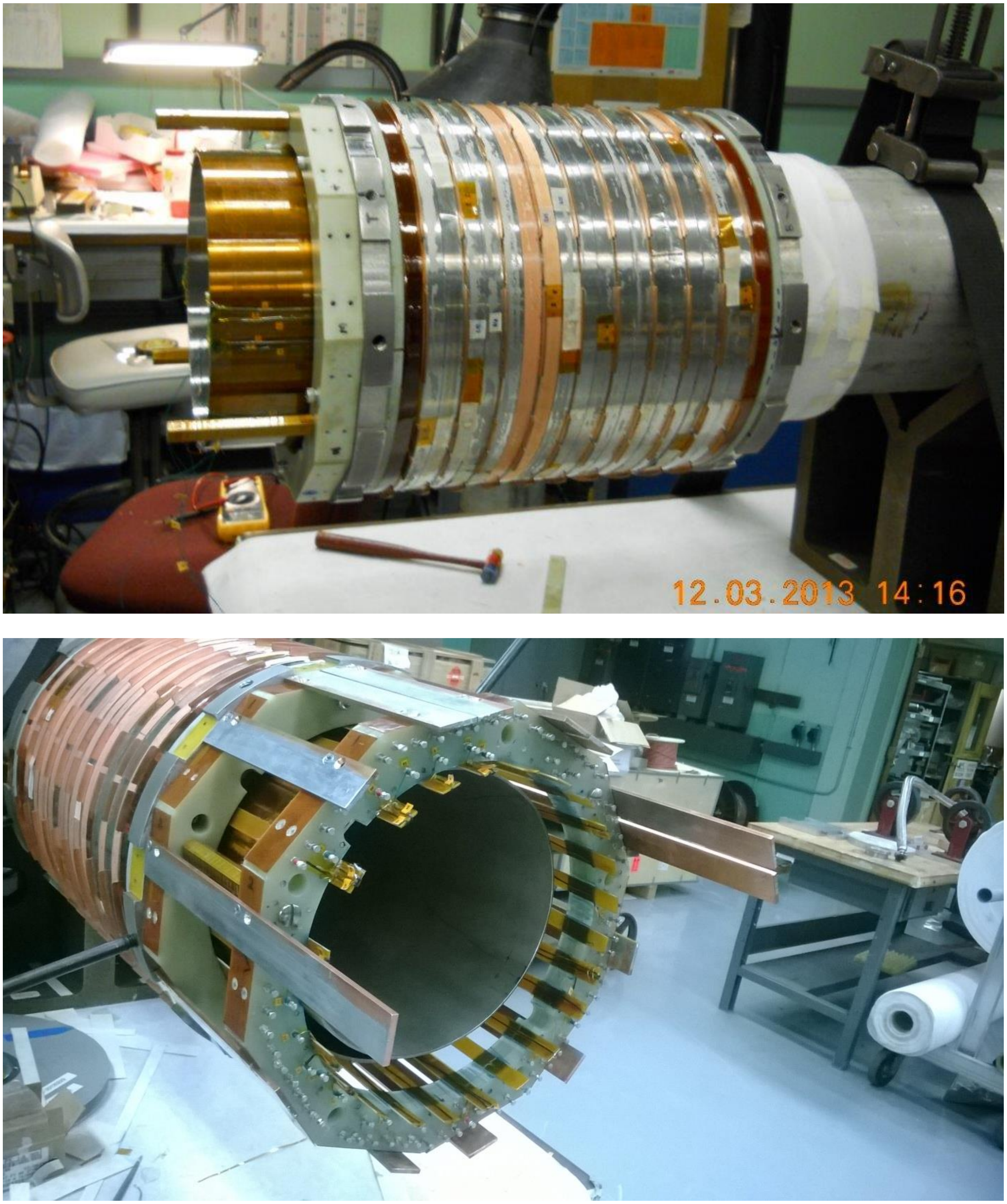


Fig. 2: Outer pancake coils during assembly. Upper picture shows before the leads are put and lower at the time when preparation is being made for installing current leads.

Splice Joints between Double Pancakes and Leads

Leads from each pancake (28 inner and 18 outer) travel out of the structure and are connected externally before returning back to the next pancake. There have been many occasions where the magnet performance was found to be limited by the leads. Therefore, they should be proven to be robust, have sufficient margin and have low resistance. For this purpose, we use at least two conductors.

Several additional splices have to be put in many pancakes to bring the HTS side to the outside so that a HTS-to-HTS joint can be made between the pancake and the lead. The requirement for an additional splice depends on the number of splices within each pancake. Since HTS is always on the inside at the beginning of winding, an extra splice is needed in all cases except when there is an odd number of splices. This was the case for 16 out of the 28 inner coils.

We developed and tested several configurations for current leads. Fig. 3 shows one chosen for the outer coil. This is consisted of two single strand HTS tapes from SuperPower and one copper stabilizer. The results of measurements performed at 77 K are shown in Fig. 4. Computed joint resistances are given in Table 1. Because of the small cross-section area available for the perpendicular joint (12 mm X 12 mm), the splice resistance is higher than the nominal value which is typically less than 5 nano-ohms within each pancake. The arrangement for the inner coil is shown in Fig. 5.

Fig. 3: Development and test of lead joint for outer coil.

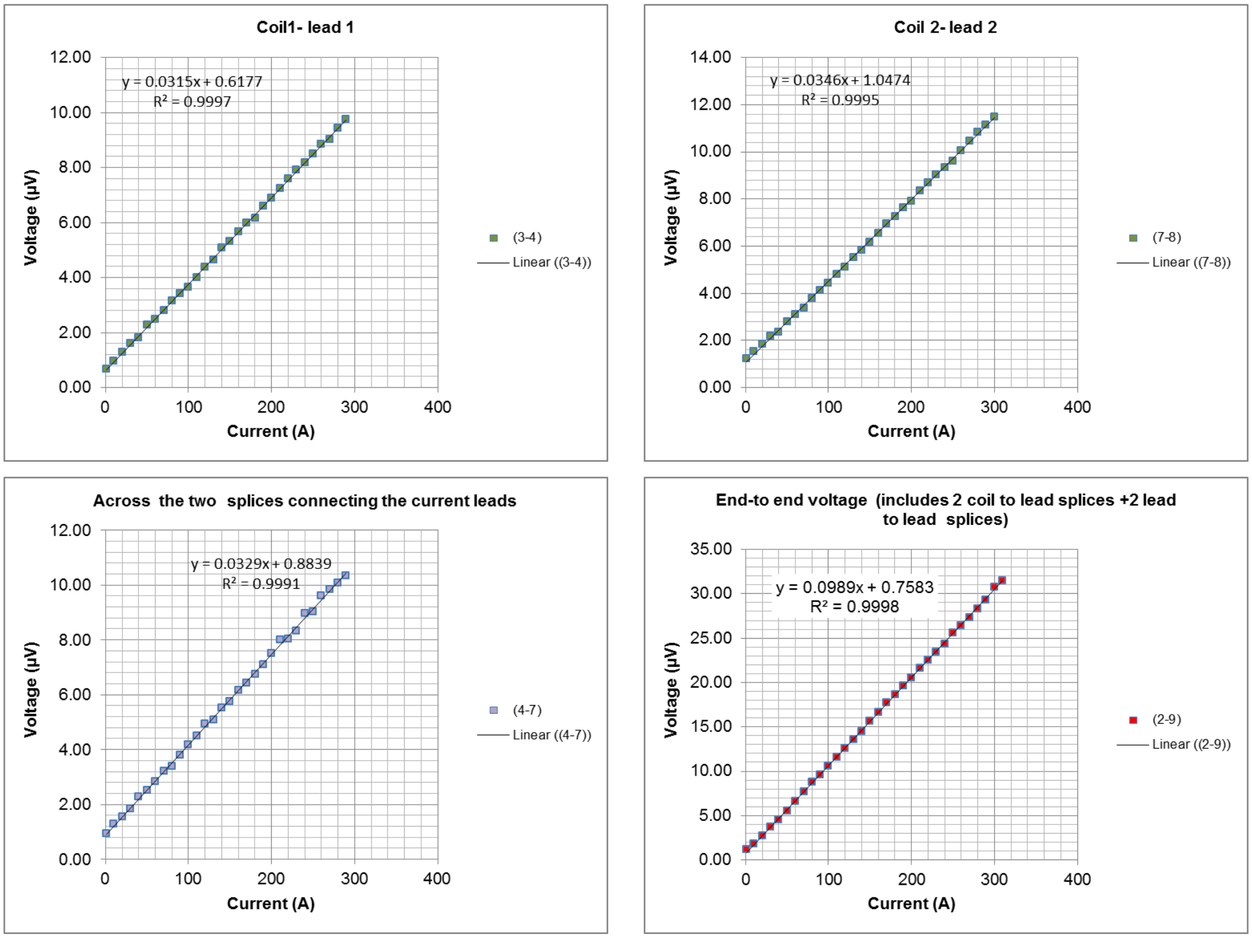
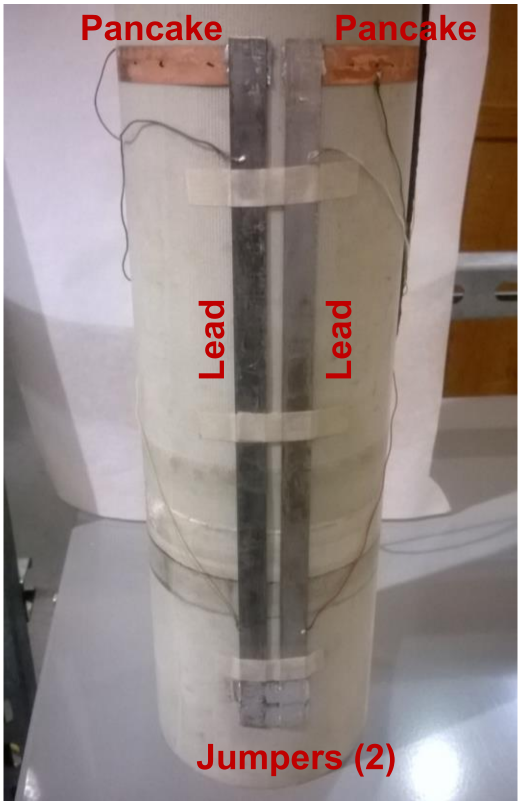
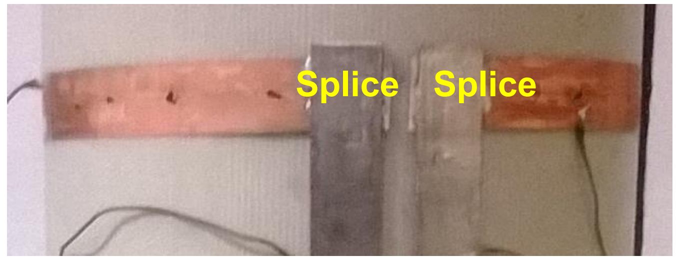


Fig. 4: Measured V-I curve for test performed at 77 K to evaluate the performance of lead splices for outer coil.

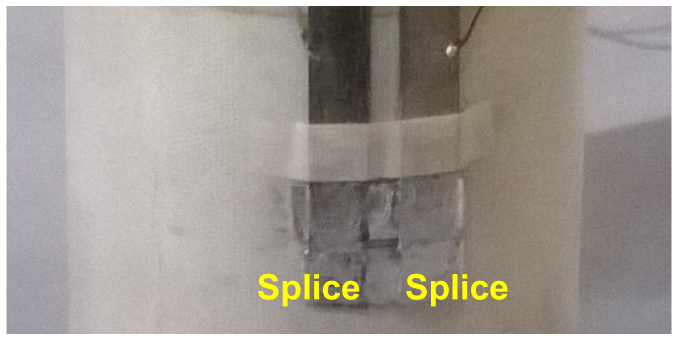
Table 1: Measured splice joint resistance in a test set-up for outer coil.

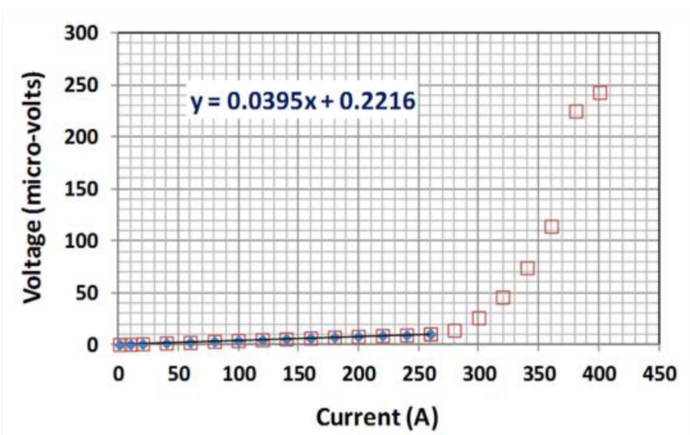
Splices	Splice resistance at 77 K
Coil1 (SP)- Current lead 1 (SP)	31.5 nΩ
Current lead 1- Current lead 2 (two interconnecting splices)	32.9 nΩ
Coil 2- Current lead 2 (SP)	32.9 nΩ
Total (coil1- Current lead 1+ Current lead 1- Current lead 2 + Coil2- Current lead 2)	98.9 nΩ

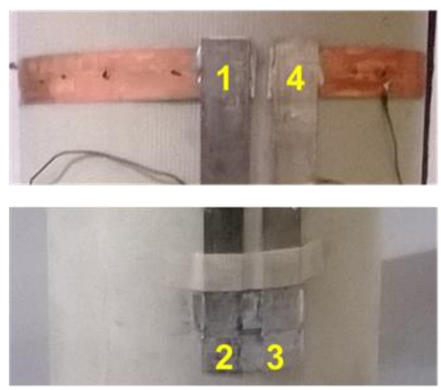




Double HTS tape in addition to single HTS tape used in the coil (total three)







Resistance in nano-ohms (overlap area of a single splice 1.2cmX1.2cm=1.5cm^2)

	SP-ASC	2xASC-ASC	SP-ASC
	1	2,3	4
one outer	275	93	307
two outer	295	52	296
one inner	51	99	40
two inner	49	61	40
three inner	49	81	38

	SP-SP	2xSP-SP	SP-SP
	1	2&3	4
one inner	55	88	69
two inner	55	42	61

Chosen as final configuration (inner)

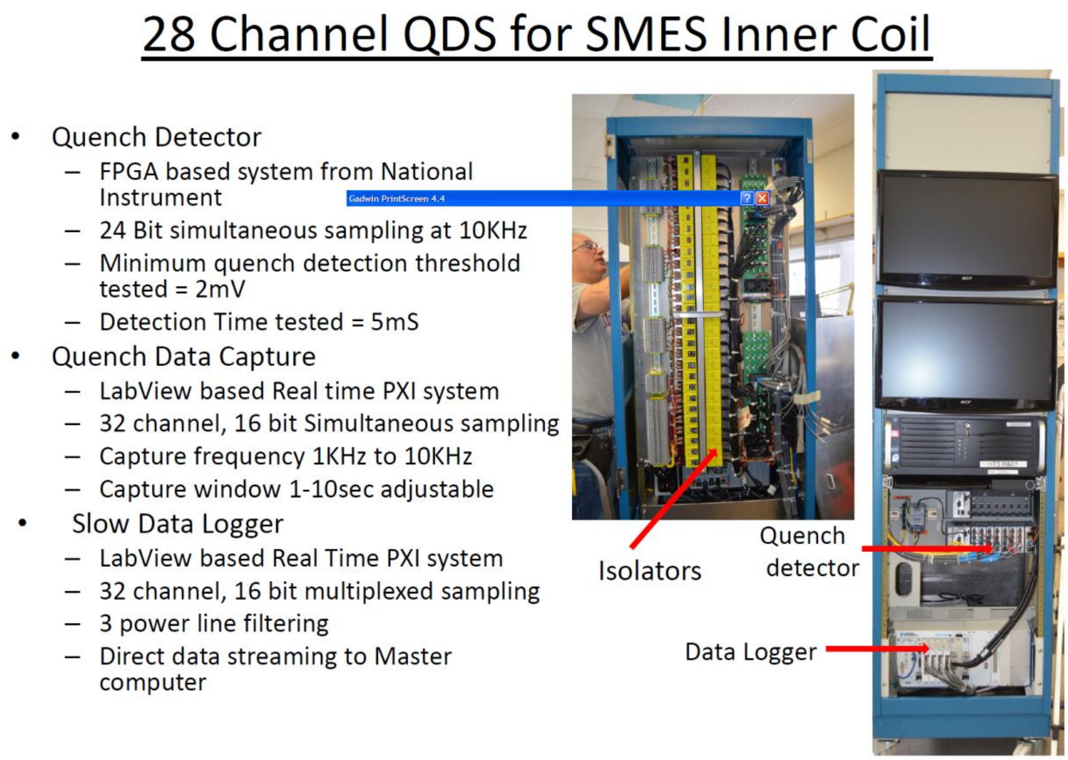
Fig. 5: Development and test of lead joints for inner coil.

Advanced Quench Protection and Energy Extraction Systems

The basic quench detection (QD) hardware and software have been successfully developed. We tested this system with the coils made for another HTS magnet project, namely HTS quadrupole for Facility for Rare Isotope Beams (FRIB). The QD system was able to protect the HTS coils against the quench when there was an increase in temperature caused by a vacuum leak. Events during this test had the typical signatures of the quench in NbTi (Low Temperature Superconductor) coils associated with the conductor motion and the flux motion. Those HTS coils were retested and no observable degradation was found. This is a reassuring development which increases our confidence on the quench protection system before testing the HTS SMES.

The system is being expanded to allow more channels as needed for SMES and also for the complete test of FRIB quadrupole. Please see Fig. 6 where the 28 channel setup is shown for the inner coil and the 18 channel setup is shown for the outer coil. Fig. 6 also lists the key components used in building the system. Current schedule is such that the expanded quench system should get tested first in FRIB qudrupole before it is used in SMES. The FRIB quadrupole will also use the same two power supplies (Fig. 7) as those used in the initial testing of SMES.

The quench detection and protection system is integrated with the high voltage isolators, as required for 1.7 MJ SMES for fast energy extraction. The system has been assembled in a new larger cabinet to accommodate all high voltage isolators and many other components as there was not sufficient space in the previous setup. Software is being further developed for system integration of the quench detection and protection system with the switch and the power convertor. A schematic (electrical block diagram) of the fully integrated system is shown in Fig. 8.



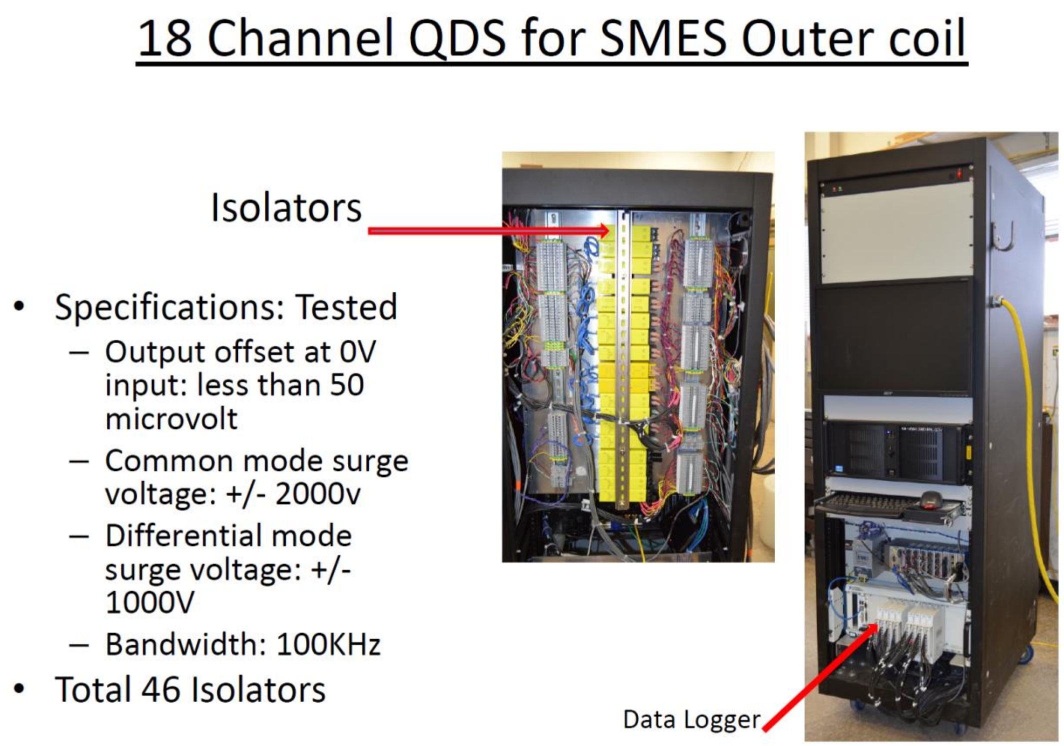


Fig.6: Quench Detection System (QDS) and Quench Protection System (QPS) hardware for inner and outer coil with a list of components including high voltage isolators.

2 Power Supplies and energy Dump Systems

- 1500A, 8V, 1500A DCCT
- IGBT Switch
  - Turn Off Time = 10uS
  - Air cooled
- SS Dump resistor: 1.0Ω, 50KW

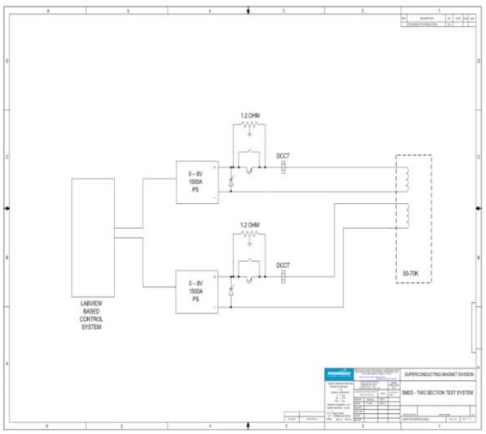


Fig.7: Two power supplies (one for inner and one for outer) – each power supply has its own set of dump resistors for fast energy extraction.

Fully Integrated System

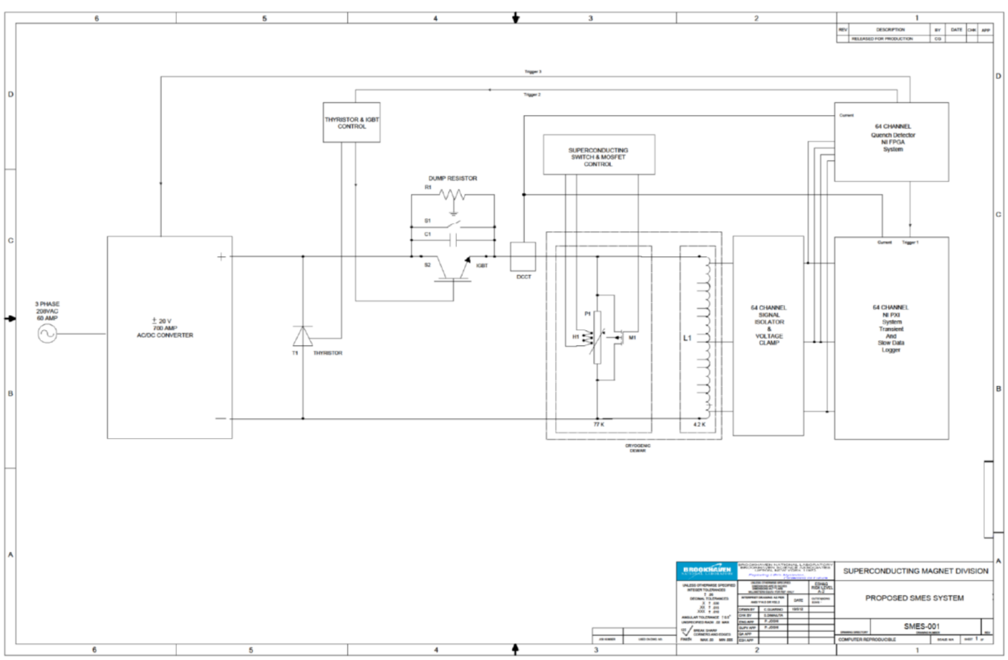


Fig.8: Schematic of the integrated system.