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

Q15 Progress Report and Status of Milestones

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Summary of Completed Tests

Many tests have been completed throughout the design and assembly phases. The key ones to note here are:

- Double pancake coils tested to 1140 Amps
- 12 pancake inner coil assembly tested to 760 Amps
- Full completed magnet, with both inner and outer coils, tested at 27 K to 350 Amps, 12.5T and ~ 0.4 MJ, record high values for HTS magnet at this temperature
- A manual trip or trigger of the QDP was initiated at 37A and tripped both inner and outer coils without any damage.

Damage Incurred in Inner Coil

In the process of recent ongoing testing, while operating at 167 Amp and 35 K, the quench detection system initiated a controlled energy extraction process due to an error in manual data entry. This energy extraction takes about 6-7 seconds. The transient resulted in some damage to the system while the coil itself was well below the quench or mechanical limits. BNL performed initial trouble shooting, and we believe that the only damage is to the instrumentation (voltage taps) of the inner coil. However, we cannot confirm this without more detailed examination to confirm that the superconducting portions are fully intact. The outer coil does appear fully intact (based on low current testing), including instrumentation. Confirmation of "no damage" to outer coil will come only when it is tested to its previous values at the same temperature (for example, 37 Amp at ~77 K). Determining the exact nature of the damage (and doing repairs) will require significant disassembly of the inner magnet coil. At this stage of the project we have neither the funds nor time to do that.

Given the undetermined state of the inner coil that includes both open circuits and some short circuits, BNL has determined that it is neither prudent nor safe to continue with further energization or testing of the inner coil. In fact the Enhanced Safety Review to be conducted by Magnet Division will not permit such testing of the inner coil at this time. Thus the inner coil has been electrically disconnected.

Use of Outer Coil for Final Testing

The below plans for further testing include only the outer coil, due to damage to inner coil instrumentation. Earlier testing has established that a trigger of the QDP at 37A does not damage the coils; hence this is considered a safe level. Testing the outer coil at higher amperages are not recommended since it puts the outer coil at risk of damage similar to what occurred to the inner coil. Until we have examined the inner coil, determined the root cause of the damage, and fixed any identified problems in both the inner and coil, we don't recommend any testing of either coil above 37 Amps.

Remaining Tests Per CRADA Milestones (a) through (f) (dated January 16, 2014)

Items (a) (b) and (c) are complete.
Item (d), magnet test, is complete at 77 K (in fact was tested down to 27 K).
Item (f) contains 8 bullets. The first 4 bullets were completes. The last 4 bullets all relate to integrated testing at 77 K and 4 K. These were partially completed, as described below, but not completely due to the inability to use the inner coil and the fact that the converter has not been available to BNL for testing.

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Coil Assembly Completion and Test

Individual coil assembly for both inner and outer layers (28 pancakes for inner and 18 for outer) was completed. Inner and outer coils were assembled together in single support structure to complete the SMES coil assembly. SMES coil was installed on the top hat. Because of the R&D nature of the device, and because this is the first time the coil will be tested to high fields, the SMES coil itself was heavily instrumented. A significant amount of that instrumentation was brought out and much of that was used in monitoring the performance of pancakes and splices during the cold test.

Figures 1 through 4 show the SMES magnet coil during various stages of final assembly.

The SMES coil was installed in the Dewar and all signals were verified using small DC currents at room temperature. A critical milestone of ~77 K system test (quench protection and coil) with BNL power supplies was completed on May 22. This test checks the completed magnet as a whole, following the numerous QA tests performed throughout the construction. For instance, for the first time, all 46 pancake coils, including the many sophisticated joints and leads, were tested together. This test also included a very large amount of superconductor in a compact and challenging magnet structure.

The Cool-down process went very well both times. We saw no degradation in performance. The advanced quench protection system, consisting of many channels, was able to protect a large number of pancake coils individually and together. We were able to isolate small resistive voltage (at mV level), despite the large noise and inductive voltages and were able to shut down the power supply and extract the energy out to avoid a runaway situation.

Figure 5 shows that the coil reached a little over 36 Amp at ~77 K. The quench protection system turned off the power supply and extracted the energy when the voltage threshold for detecting quench was exceeded. Thorough checks after the event showed no change in the status of coil and all components of the diagnostic system (electronics, voltage-tap, etc.). This demonstrated the safe operation of a critical sub-system of the energy storage device.

The ultimate design goal at ~4 K is 700 Amp (~25 T) is about 20 times more in current (over ~36 A) and about 400 times more in stored energy and forces. Therefore, we set an intermediate goal of reaching at least 350 Amp (50% of the design current) at an intermediate temperature. We successfully reached that and created the above mentioned record magnetic field (12.5 T at ~27 K). We saw an early indication of coil reaching its limit at that temperature but it was below the threshold of tripping the quench detection system.

We let the temperature in coil rise drift (rise) slowly and began testing the system again at about 35 K. During this test, system issued a false quench signal at ~167 Amp and started the fast energy extraction. This was due to an operator error and not due to coil reaching its limit or showing any resistive signal.

However, unlike after the previous energy extraction at 36 Amp, after the above trip we could not reproduce the original signals in the inner coil even at low current level (few Amps). As a precaution the outer coil was tested to only small current and at that level it didn't show a similarly bad behavior. Thorough tests after the event indicated that the diagnostics internal to the inner coil (voltage taps, etc.) have been compromised. This prevented BNL from determining if there was damage to individual pancakes or just to the diagnostics system.

Since the SMES coil had been powered successfully to 350 Amp (12.5 T) and powering of the coil didn't show any sign of degradation, it appears that the damage was caused during the shut-off and energy extraction period during the event.

Since it had previously been established that shut-off at 37 Amp doesn't cause any damage and since the outer coil didn't show any major sign of damage, the subsequent system integration test was limited to 37 Amp in the outer coil. Also, the operating temperature was lowered to provide additional margin.

More details and data analysis will be presented in the final SMES report.

Figure 1: Outer coil with stainless steel support tube being installed.

Figure 2: Outer coil with support structure being inserted over the inner coil with support structure.

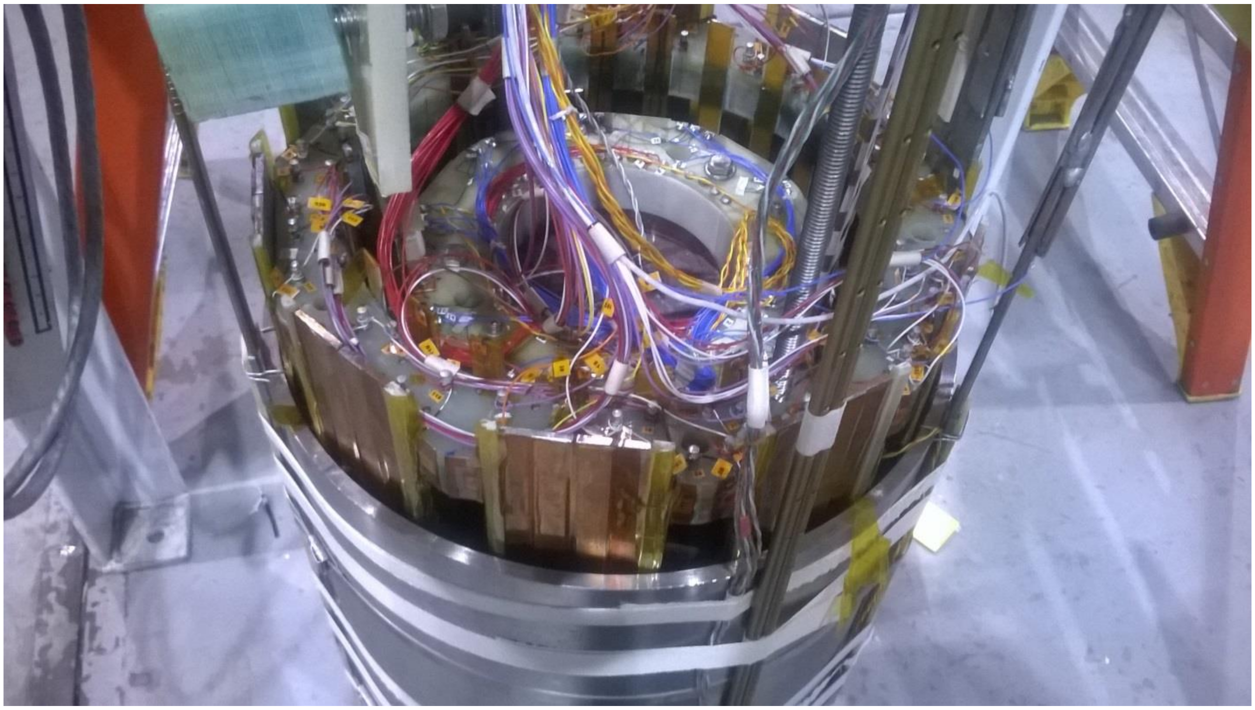

Figure 3: Instrumentation coming out of the SMES coil.

Figure 4: SMES coil installed on the top hat for testing.

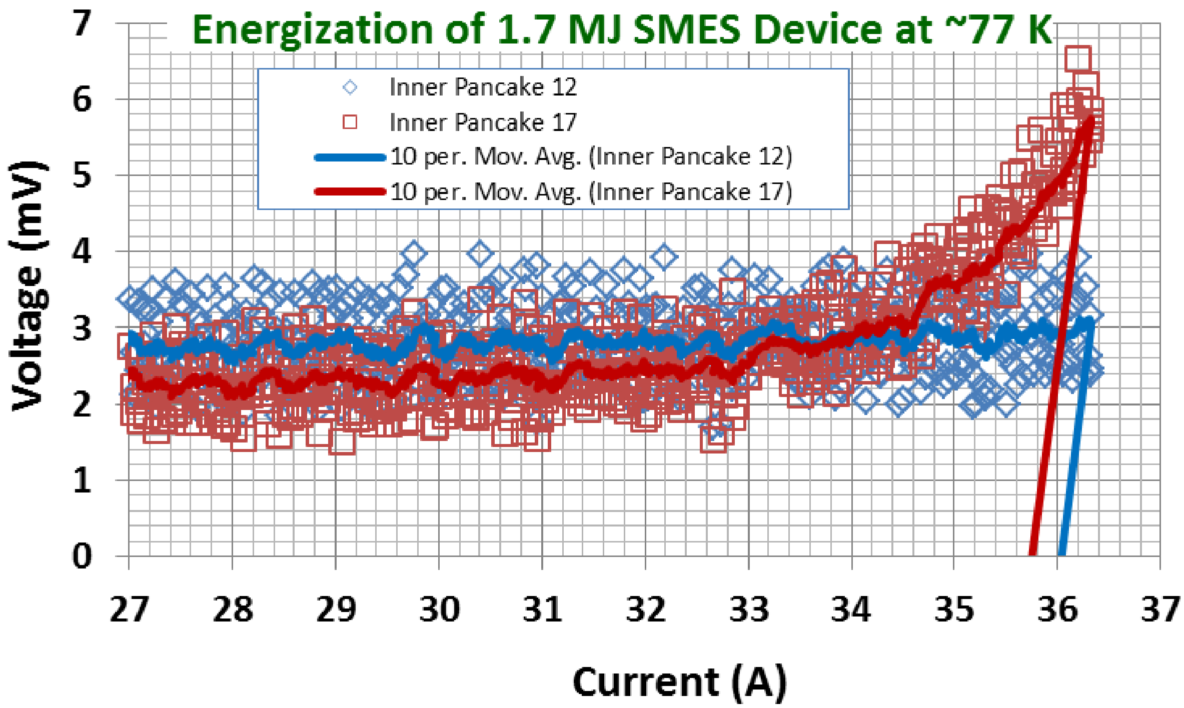

Figure 5: Coil reached a little over 36 A at ~77 K. The quench protection system turned off the power supply and extracted the energy when the voltage threshold for detecting quench was exceeded.

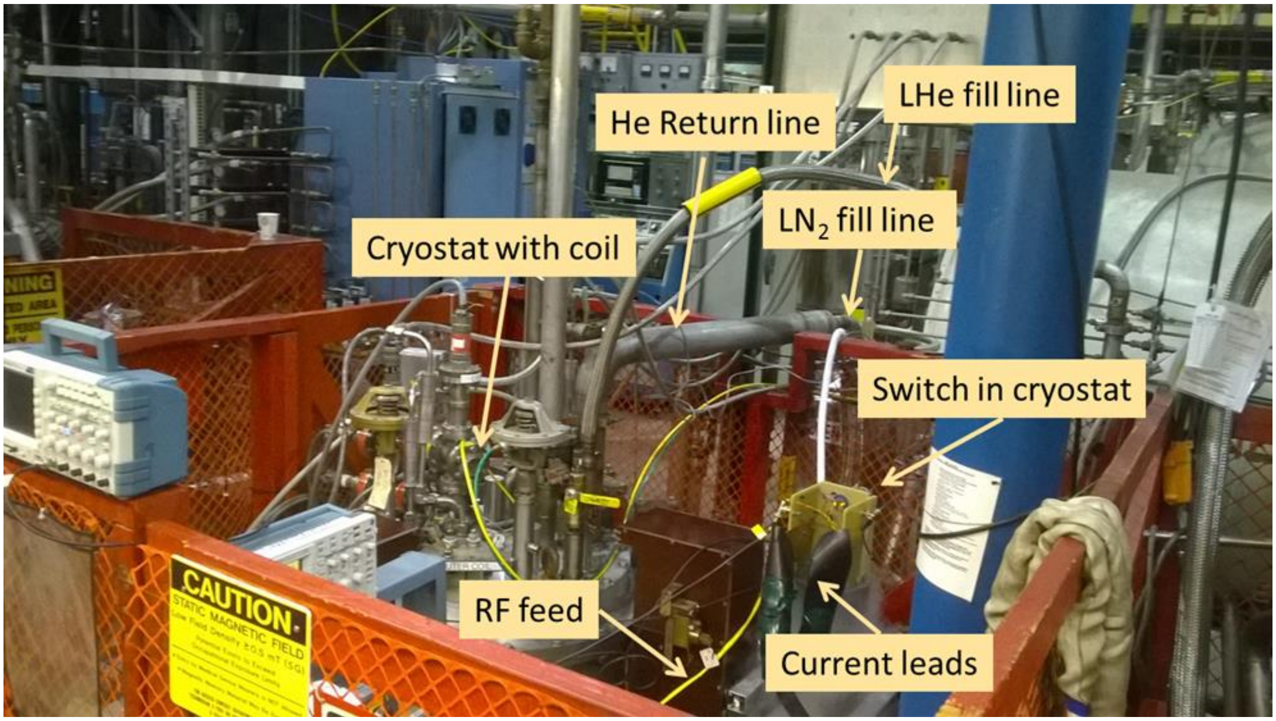

Figure 6: Integrated Test Layout