NCSX Plans for Coil Testing October 12, 2006

At the May 2006 SC Review, the Committee recommended conducting a cost/risk analysis to determine the need for cold testing on a Type A and Type B coil (in addition to a Type C coil) and to consider structural analysis modeling verification during the cold test. The goals of cold testing, i.e. power testing a coil at cryogenic temperature, would be 1) to verify that the coil behaved as predicted, thus validating our analytical models of the coil; and 2) to qualify a system for monitoring the structural behavior of the modular coils during experimental operations. Note that all modular coils will be tested at room temperature as part of the manufacturing procedure. Room temperature tests include resistance measurements, ground insulation and insulating break voltage tests, and flow and leak tests of the coolant tubes. In addition, the Project is implementing tests to measure the inductance and polarization index of each coil.

The C1 coil was cold tested in June 2006. Prior to cooling down to cryogenic temperature, a megger test was performed. The insulation resistance to ground dropped markedly at 7kV. The coil was re-tested with a 9V Digital Voltmeter (DVM) and showed a resistance to ground of only 2Mohms. The coil had previously been tested following vacuum pressure impregnation (VPI) at 7.5kV and registered a resistance to ground of 75Gohms. The weak link in the insulation was traced to the lead block area. It was decided the resistance to ground was adequate to proceed with cold testing. The coil was cooled down to cryogenic temperature. The resistance to ground was re-measured using the DVM and improved modestly to above 4Mohms. The coil was then tested at full current without incident.

Following the test, the lead block area was opened. In the process of opening the lead block area, the upper chill plate was partially separated from the winding pack. The resistance to ground was checked and measured 15Gohms at 7.5kV, a dramatic improvement. It was determined that the upper chill plate was the likely culprit and represented a weak link in the design. The decision was made to remove the upper chill plate on C1 and all coils in process (C3 and beyond). No significant impact on coil performance was identified. With the chill plate removed, the resistance to ground was checked at 5kV and measured 110Gohms, which exceeds our requirements. Additional insulation was applied in this area and the repair procedure was completed.

The C2 coil was manufactured the same way as the C1 coil and showed a resistance to ground of 22Gohms at 7.5kV following VPI. The suspect chill plate on the C3 coil was removed prior to VPI. Testing of the C3 coil following VPI showed a much healthier resistance to ground of 150Gohms at 7.5kV, which is comparable to C1 after repair and much higher than C2. This trend continued for C4 which had a 150Gohm resistance at 7.5kV. The project now plans to make the same repair to C2 that was made to C1 because of the improved resistance to ground demonstrated on the C1, C3 and C4 coils.

The coil resistance, the observed temperature rise, and the cooldown rate between shots were all in agreement with predicted values during the testing of the C1 coil. The coil resistance was measured to be 1.7 milli-ohms at 89K. The observed temperature rise was 28K. The characteristic temperature decay time between shots was measured to be 13 minutes. These results validated our electrical and thermal models of the coil, providing high confidence that the coil will behave thermally and electrically during operation as predicted.

Displacements across the width of the coil (approximately 2m) during a pulse were measured with a displacement gauge and were in excellent agreement (within 2%) with predicted values. The displacement measurements are very significant because they are a measure of the response of the whole coil assembly, not just a local area, and provide high confidence that the structural modeling of the coil assembly is reasonable.

In addition to the displacement measurements, conventional (resistive) strain gauges were applied to the winding form and winding pack prior to cold testing. These gauges were used because of previous favorable experience on ATF. Bench tests were conducted prior to testing C1 that confirmed that these gauges could be used in a cryogenic environment. However, the test data from these gauges during testing of the C1 coil was not usable. Examination of the test data revealed that the substantial voltage ripple in the power supply and magneto-resistive effects in the strain gauges precluded getting useful data. Failure to get good strain gauge data from the C1 test limited validation of the structural model of a single coil to the displacement measurement results and left us without a qualified system for monitoring the structural behavior of the modular coils during experimental operations.

The Project plans to substitute fiber optic strain gauges for the non-functional resistive gauges on the production coils. The fiber optic gauges are immune to voltage ripple and magneto-resistive effects. Such gauges have been used very successfully on the NSTX TF coils, albeit at room temperature. They are being qualified for use at cryogenic temperatures at ORNL. The gauges will begin being installed on the production coils once the qualification testing at ORNL is successfully concluded.

The Project has reviewed future test plans and determined based on cost/benefit considerations that the best path forward is 1) to focus in FY07 on assuring that we have a qualified system for monitoring the structural behavior of the complete modular coil assembly and 2) completing coil testing during integrated systems testing and initial operations on the complete modular coil assembly. It is imperative that we qualify a system for monitoring the structural behavior now because the sensors must be installed in FY07 prior to field period assembly operations. Furthermore, there does not appear to be anything that the Project would learn performing additional cold testing on individual coils that would not also be learned later by testing the complete modular coil assembly. Given 1) the success in testing the C1 coil; 2) the design similarities between all coil types; 3) the fact that even at full current, a single coil only experiences half of its peak stress compared to operation in the complete modular coil assembly; and 4) we would still want to measure the structural behavior of the complete modular coil assembly, the expected benefits of additional cold testing on individual coils appear to be limited.

The cost of testing another Type C coil was estimated to be $145K. The cost of testing a Type A or B coil was estimated to be $180K. The additional costs associated with testing a Type A or B coil are related to the interfaces with the power systems and cryostat and analysis of coil performance. These costs have already been incurred for the Type C coils during C1 testing. Rather than doing additional cold testing of individual coils, the project is planning to add more thermocouples and fiber optic strain gauges and to investigate improved diagnostics such as displacement gauges which can operate in a cryogenic environment and Fiber Bragg Gratings which offer the potential for monitoring of strain and temperature within a winding pack. This will result in a better understanding of the structural behavior of the modular coils during experimental operations and improved confidence in setting machine operating limits.